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THE PROBABILITY OF HIGHLY PATHOGENIC AVIAN INFLUENZA INTRODUCTION AND TRANSMISSION IN WESTERN JAVA POULTRY CHAINS: LINKING VALUE CHAINS AND EXPERT ESTIMATES

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Abstract: In Indonesia, several poultry value chains exist in conjunction. The introduction and transmission routes of highly pathogenic avian influenza (HPAI) may differ between these different poultry chains. Consequently, critical areas for control may differ between the poultry value chains and the actors within these chains. However, there is no estimation of the relative importance of the different actors in the Indonesian poultry value chains regarding the probability of HPAI introduction and transmission. To fill this gap, qualitative risk assessments of HPAI introduction and transmission were employed and linked with a previously established value chain map of poultry production in Western Java. Introduction and transmission probability estimates were determined through expert knowledge elicitation. Expert elicitation is acquiring expert opinions on unclear subjects due to insufficient evidence, physical constraints, or resource limitations. Results indicated variable HPAI introduction and transmission risks in the different value chains in West Java, ranging from low to very high. Critical actors were all farming sectors, private collecting farms, traditional outlets, and semi-automated slaughterhouses. Linking the value chain with an expertise-based estimation for introduction and transmission is an efficient and systematic way to identify opportunities for control measures for developing countries.

Keywords: qualitative assessment, HPAI introduction and transmission, value chain map, HPAI, critical control

Abstrak: *Di Indonesia, terdapat beberapa rantai nilai unggas yang saling berhubungan satu sama lain. Rute masuk dan penularan flu burung yang sangat patogenik (HPAI) dapat berbeda di antara rantai unggas yang berbeda ini. Akibatnya, area kritis untuk pengendalian mungkin berbeda antara rantai nilai unggas dan aktor dalam rantai ini. Namun, tidak ada estimasi mengenai tingkat kepentingan relatif dari berbagai pelaku dalam rantai nilai unggas di Indonesia terkait dengan probabilitas introduksi dan penularan HPAI. Untuk mengisi kesenjangan ini, dilakukan penilaian risiko kualitatif terhadap introduksi dan penularan HPAI dan dihubungkan dengan peta rantai nilai produksi unggas di Jawa Barat yang telah dibuat sebelumnya. Perkiraan probabilitas introduksi dan penularan ditentukan melalui elisitasi pengetahuan para ahli. Hasilnya menunjukkan risiko introduksi dan penularan HPAI yang bervariasi pada rantai nilai yang berbeda di Jawa Barat, mulai dari yang rendah hingga yang sangat tinggi. Aktor-aktor penting adalah semua sektor peternakan, peternakan pengumpul swasta, outlet tradisional, dan rumah potong semi-otomatis. Menghubungkan rantai nilai dengan estimasi berbasis keahlian untuk introduksi dan penularan merupakan cara yang efisien dan sistematis untuk mengidentifikasi peluang tindakan pengendalian bagi negara-negara berkembang dalam rantai unggas di Jawa Barat. Menghubungkan rantai nilai dan perkiraan para ahli.*

Kata kunci: *qualitative assessment, HPAI introduction and transmission, value chain map, HPAI, critical control*

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INTRODUCTION

In 2003, Indonesia experienced a highly pathogenic avian influenza (HPAI) H5N1 epidemic that posed a major challenge to animal and human health (Dolberg et al. 2009). Regardless of the many control measures that were put in place, HPAI is still endemic, with continued reports of outbreaks. The Food and Agriculture Organization (FAO) of the United Nations reported that the failure of HPAI control programs in Indonesia was caused by the country's complex poultry production structures (Food and Agriculture Organization, 2011). The poultry production structure consists of two channels and four sectors. The modern channel for commercial poultry production is served by sectors 1 and 2, while sectors 3 and 4 cater to low biosecurity and village poultry farms. The complexity of the poultry production structure generates many routes for HPAI introduction and transmission. A recent study identified that the HPAI introduction and transmission routes and risks differ between marketing channels, each characterized by different governance structures (Indrawan et al. 2018).

An in-depth overview of probabilities of HPAI introduction and transmission across poultry chains is essential to designing effective control measures. Proper knowledge of the importance of the various actors in the value chain can be applied to define strategies and incentives for reducing HPAI introduction and transmission risk. However, limited data is available on the influence of various value chain actors on HPAI introduction and transmission, and it is unclear what the critical control points are in the value chain. Previous studies attempted to examine HPAI transmission and possible critical points for interventions using value chain mapping (McLeod et al. 2009). However, the overall actors' HPAI introduction and transmission probabilities remain unclear. It is due to insufficient data or when such data is unattainable. Consequently, we do not know which actors are the most important and at what stages of the value chain authorities should control. Therefore, this study is intended to provide an approach to resolve this challenge by expert elicitation. Many studies have evaluated HPAI transmission for specific Indonesian poultry value chain parts. The main objective of these studies was to analyze poultry farms and the movement of live birds in the market as the source of HPAI transmission.

We found several studies that focused on HPAI transmission between poultry farms (de Glanville et al. 2010; Idris et al. 2015; Durr et al. 2016; Wibawa et al. 2018), studies that examined HPAI transmission in live bird markets (Indriani et al. 2010; Kurscheid et al. 2015), studies that looked specifically at the role of poultry movements in HPAI transmission, and a study that reviewed beyond the farms and live birds which described the role of different agro-ecological systems in HPAI transmission (Gilbert and Pfeiffer, 2012). A more comprehensive study in the poultry supply chain used a value chain approach to examine HPAI transmission (McLeod et al. 2009; Sudarman et al. 2010). A recent study evaluated the role of governance in the value chain with regard to biosecurity and HPAI control measures (Indrawan et al. 2018). However, this study only looked at the interaction between different chains and their governance structures. An overview of the value chain and its critical actors regarding HPAI introduction and transmission is unavailable. The objective of this study is to assess the probabilities of HPAI introduction and transmission for all actors in the poultry value chain. Therefore, we elicited expert knowledge on the probability of HPAI introduction and transmission and linked this information to the value chain map to generate a holistic overview of HPAI in the poultry value chain. This effort bridges the knowledge gap between the poultry value chain and its specific components. The framework will allow a systematic assessment of (i) the probability of HPAI introduction and transmission for individual actors in the poultry value chain and (ii) the identification of the critical actors in the poultry value chain for HPAI introduction and transmission. The study provides an in-depth discussion of the critical value chain actors affecting HPAI introduction and transmission routes.

METHODS

Poultry value chain of HPAI introduction and transmission probabilities

Risk assessment entails systematically identifying and assessing the probability of an unwanted event and its follow-up consequences (Costard et al. 2014). A poultry value chain map developed by Indrawan et al. (2018) was used to outline the assessment for the probabilities of HPAI introduction and transmission

(Figure 1). The poultry map consists of two types of marketing channels: modern channels, which include slaughterhouses and cold chains, and traditional channels, which include live bird markets. Within each channel, two chains can be distinguished based on their governance, resulting in four poultry chains with different governance schedules that manage the interaction among actors. The modern channels consist of the integrator chain and the semi-automated slaughterhouse chain. The traditional channel comprises the controlled slaughter-point chain and the private slaughter-point chain. The integrator chain is the most coordinated one, with medium-to-high biosecurity practices directed by the slaughterhouse. The semi-automated slaughterhouse chain is also relatively coordinated with medium-to-low biosecurity control and is governed by the semi-automated slaughterhouse. The controlled slaughter-point chain is a daily-based transaction chain directed by traders. The government controls the location of live-bird markets and imposes some biosecurity measures on the slaughter points. The private slaughter-point chain is the least coordinated chain, with daily-based transactions governed by traders in the absence of any control. Using this map of four chains, we outlined the three different pathways of possible HPAI introduction and transmission in the value chain: HPAI introduction sources from an external chain, HPAI transmission sources from other actors within the chain, and HPAI transmission sources from the same type of actor within the value chain (Fig 1). These three pathways were asked for all possible pairs of actors that were linked in the value chain (in the same chain or from different chains).

Expertise-based estimation of HPAI introduction and transmission probabilities

In the absence of sufficiently detailed quantitative information on HPAI introduction and transmissions in the poultry value chain, we used a qualitative risk assessment to create an overall overview of the probabilities for the different poultry chains. A qualitative assessment is commonly used to measure risk in the context of animal diseases and HPAI (de Glanville et al. 2010; Onkundi et al. 2010; Wieland et al. 2011; Idris et al. 2015; Desvaux et al. 2016; Kelly et al. 2018). In a similar qualitative approach, we designed a questionnaire for the expertise-based assessment of two indicators: (i) the probability of HPAI introduction or transmission for the defined pathways and (ii) the uncertainty of the probabilities.

The probability question was designed to elicit estimates on HPAI introduction and transmission for the defined pathways in the value chain. An example of probability assessment questions for the farm were: (i) “What is the probability of HPAI introduction from outside the chain into the chain?” and (ii) “If HPAI is introduced in a farm, what is the probability of transmission to another specific actor (e.g.: farms or collecting farms)?”. Both questions were based on a one-year time period. These questions were asked for each identified actor in the value chain. The respondents provided the estimated probability within the classes. Table 1 presents the quantitative interpretation of probability classes used in this study, similar to previous studies by the European Food Safety European and Authority (2006) and Kasemsuwan et al. (2009). The interpretation was used to explain qualitative statements into quantitative ranges for computational purposes.

Since the experts’s estimate of the probability may be uncertain, we also asked the experts for an estimation of the uncertainty in order to map the quality of the probability estimates for each pathway. Definitions of these uncertainty categories were based on Kasemsuwan et al. (2009) and are presented in Table 2. The uncertainty question was combined with the probability question and took the following form: “What is the uncertainty of your answer on the probability estimate?”.

The assessment form was completed by experts selected or recommended during two workshops on HPAI in Western Java, held in October 2017. The first workshop was held with the veterinary faculty at Bogor Agricultural University, and the second workshop with poultry chain stakeholders at the Center for Veterinary Subang. Experts were identified during these workshops based on their knowledge about 1) veterinary epidemiology, 2) the poultry value chain in Western Java, and 3) HPAI. Of the total group of identified experts, 18 were present at one of the workshops, while 75 were not. The former filled out the questionnaire during the workshop. The latter group was sent the questionnaire by email or regular mail. From the second group, 34 experts filled in and returned the questionnaire, of which 29 completed. In total, 47 experts filled in the questionnaire and provided data to estimate HPAI 175 introduction and transmission. Table 3 lists background information on participating experts.

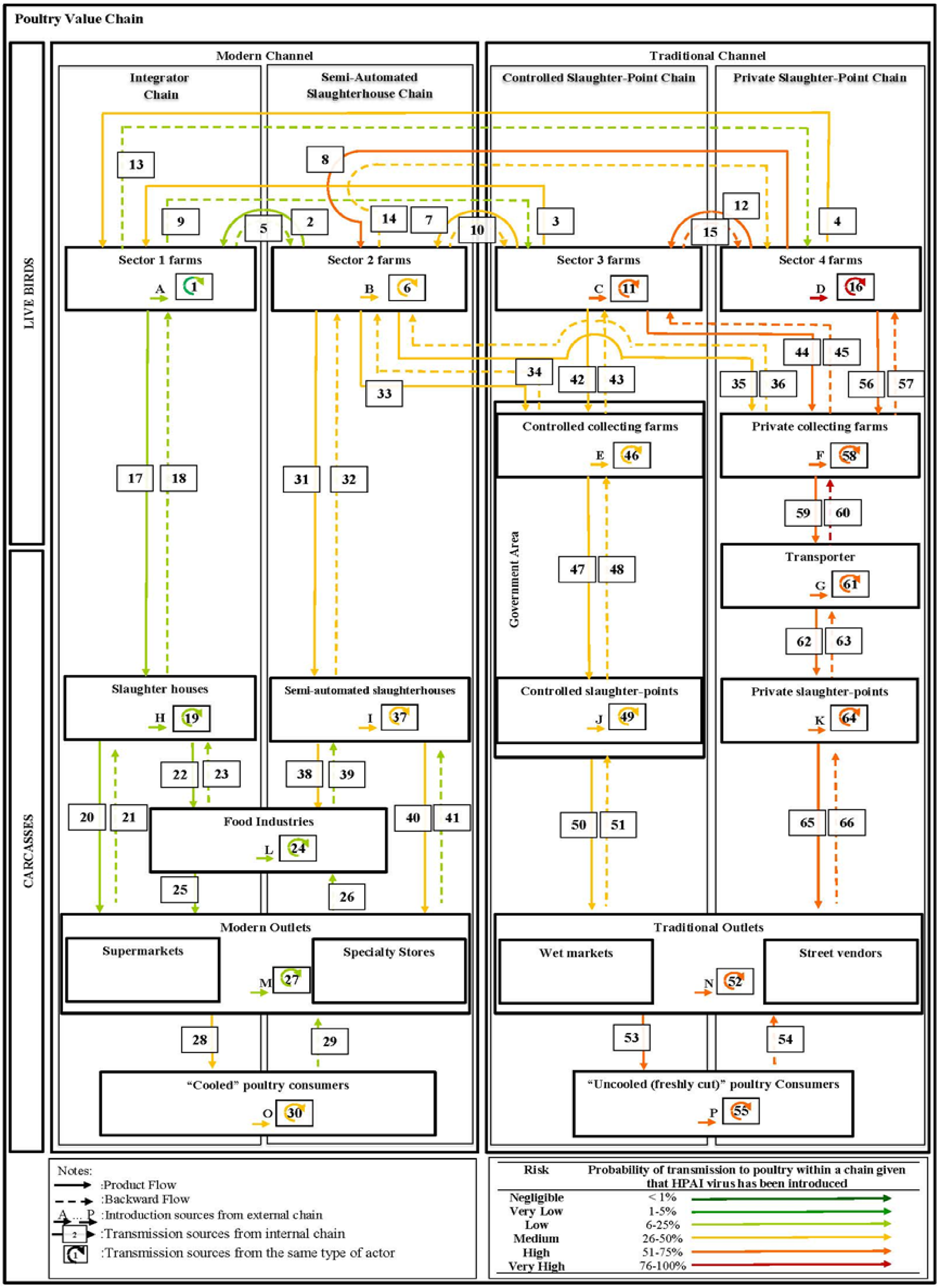

Figure 1. Mapping the expertise-based probabilities of HPAI introduction and transmission in the poultry value chains. Capital letters refer to introduction from an outside source, numbers refer to transmission from inside the chain. Colors represent the probability level.

Table 1. Quantitative interpretation of defined probability categories in the qualitative assessment

Risk	The probability of HPAI transmission to poultry within a chain given that the virus has been introduced
Negligible	< 1%
Very Low	1–5%
Low	6–25%
Medium	26–50%
High	51–75%
Very High	76–100%

Table 2. Definition of the uncertainty categories associated with the probability estimates

Uncertainty Category	Interpretation
Low	There are solid and complete data available; strong evidence is provided in multiple references; authors report similar conclusions.
Medium	There are some but not complete data available; evidence is provided in a small number of references; authors report conclusions that vary from one another.
High	There is scarce or no data available; evidence is not provided in references but rather in unpublished reports or based on observations, or personal communication. Authors report conclusions that vary considerably;
Unknown	There is no data available, no reference, no personal communication, no experience

Note: unknown was considered in the analysis as the highest uncertainty level

Table 3. Background of the experts participating in the qualitative assessment

Background	n
Animal Health Company	10
Government officer	10
Lecturer	14
Sector 1 Farm	5
Sector 2 Farm	2
Sector 3 Farm	6
Total	47

Data Analysis

As a first step in analyzing the questionnaire results, we compared the median of the estimated probabilities of HPAI introduction and transmission routes through the chain and the associated uncertainties. We summarized the estimated probabilities in a table and represented the level of uncertainty with a color code. Via the Mann-Whitney U test, we determined whether the probabilities of HPAI introduction and transmission were significantly different between types of farms, categorized as sector 1 (industrial and integrated farms), sector 2 (commercial poultry production with high bio-security farms), sector 3 (commercial poultry production with low bio-security farms) or sector 4 (village or backyard poultry farms).

Secondly, each pathway probability in the value chain was mapped and colored according to the probability of introducing or transmitting HPAI. The association between the mean probability estimate and the mean uncertainty for each chain actor was summarized in a Cartesian diagram.

Finally, we determined which actors are critical in controlling HPAI by examining the probability of HPAI introduction and transmission for different actors in different chains. The selection criteria of critical actors for each chain was limited to the probability for each HPAI introduction from an external chain, the probability of HPAI transmission within the chain, and the probability of HPAI transmission across actors of the same type in the chain. A high probability of introduction and transmission will show the actor's critical vulnerability to HPAI.

RESULTS

Probabilities of HPAI introduction and transmission in the poultry value chain

There was a wide range of expertise-based probability estimates for the three different pathways for each chain actor: HPAI introduction sources from an external chain, HPAI transmission sources from an internal chain, and HPAI transmission sources from the same type of actor in the value chain (Table 4). For all chain actors, except for consumers that consumed "cooled" poultry, the probability of HPAI transmission within the chain was higher than the probability of transmission across actors of the same type or the probability of introduction.

Table 4. The comparison between Q25, median and Q75 of the expertise-based estimates of the probabilities of HPAI introduction and transmission and its associated uncertainty. The colors represent the uncertainty level.

	Chain actors	Probability of perceived risks of HPAI								
		Introduction from external chain			Transmission from internal chain			Transmission from the same type of actor		
		Q25	Q50	Q75	Q25	Q50	Q75	Q25	Q50	Q75
			Median			Median			Median	
A	Sector 1 farms	0.01	0.05[abc1]	0.05	0.19	0.66[abc13]	0.91	0.01	0.05[abc3]	0.05
B	Sector 2 farms	0.05	0.25[ade12]	0.25	0.87	0.95[a13]	0.99	0.25	0.25[ade23]	0.50
C	Sector 3 farms	0.50	0.75[bdf1]	0.75	0.93	0.98[b13]	1.00	0.50	0.75[bdf3]	0.75
D	Sector 4 farms	0.75	1.00[cef]	1.00	0.91	0.95[c]	1.00	0.75	0.75[cef]	1.00
E	Controlled collecting farms	0.05	0.25	0.50	0.63	0.72	0.94	0.25	0.25	0.50
F	Private collecting farms	0.50	0.75	0.75	0.97	0.99	1.00	0.50	0.75	0.75
G	Transporter	0.50	0.75	1.00	0.86	0.94	1.00	0.50	0.75	1.00
H	Slaughter houses	0.01	0.05	0.05	0.07	0.14	0.58	0.05	0.25	0.50
I	semi-automated slaughter houses	0.05	0.25	0.50	0.32	0.58	0.81	0.05	0.25	0.50
J	Controlled slaughter points	0.05	0.25	0.50	0.44	0.75	0.88	0.25	0.25	0.50
K	Private slaughter points	0.50	0.75	1.00	0.75	0.94	1.00	0.50	0.75	0.75
L	Food industries	0.05	0.05	0.25	0.32	0.63	0.81	0.01	0.25	0.25
M	Modern outlets	0.05	0.05	0.25	0.06	0.44	0.63	0.01	0.25	0.25
N	Traditional Outlets	0.50	0.75	0.75	0.81	0.94	1.00	0.25	0.75	0.75
O	"Cooled" poultry consumers	0.05	0.25	0.25	0.05	0.25	0.50	0.05	0.25	0.50

- Mann-Whitney U test. There is a significant difference at the 5% level between Sector 1 and Sector 2 farms (a), between Sector 1 and Sector 3 farms (b), between Sector 1 and Sector 4 farms (c), between Sector 2 and Sector 3 farms (d), between Sector 2 and Sector 4 farms (e), and between Sector 3 and Sector 4 farms (f).
- Mann-Whitney U-test . There is a significant difference at the 5% level between the probabilities of HPAI introduction from an external chain and HPAI transmission from an internal chain (1), between the probabilities of HPAI introduction from an external chain and HPAI transmission from the same actor type (2), and between the probabilities of HPAI transmission from an internal chain and transmission across the same actor type (3).
- Color scheme represents uncertainty level:

low uncertainty;
medium uncertainty;
high uncertainty;
unknown uncertainty;

The expertise-based probabilities of HPAI introduction and transmission are categorized into low, medium, high or unknown uncertainty, represented by different colors in Table 4. The probability estimates for introduction from an external chain for sector 1 farms had a low level of uncertainty. The majority of probability estimates were associated with a medium level of uncertainty, especially in the transmission from an internal chain. The probability of introduction and/or transmission for the actors in the private slaughter-point chain were mostly associated with a high level of uncertainty.

Differences in the probabilities for HPAI introduction and transmission for each pathway can be described as follows. The probability of HPAI introduction from an external chain significantly differed across different farm types (P<0.05). Similarly, the probability of HPAI transmission from the same kind of actor in the value chain was significantly different across different farm types (P<0.05). However, in terms of HPAI transmission within the chain, only sector 1 stood out (P<0.05) from the other farm sectors. Furthermore, only for sector 2 farms, all introduction and transmission probabilities significantly differed across the three pathways (P<0.05).

Mapping HPAI introduction and transmission in the value chain

As illustrated in Figure 1, the expertise-based probability estimates (median) for HPAI introduction and transmission in Western Java poultry chains were low, medium, high, or very high. Negligible and very low probabilities did not occur. The pathways related to the actors in the integrator chain had a low probability of introduction or transmission (represented by a light green arrow). The pathways related to the actors in the semi-automated slaughterhouse chain and the controlled slaughter-point chain had a medium probability (represented by a yellow arrow). All other probabilities were estimated as high or very high by the experts (represented by orange and red arrows).

Figure 1 reveals three important findings. First, three very high-risk transmissions could be distinguished: HPAI introduction from an external chain into sector 4 farms, HPAI transmission between actors in sector 4 farms, and HPAI transmission from transporters to private collecting farms in the private slaughter-point chain. Second, a high probability of transmission in sector 4 farms is linked with a high probability of HPAI introduction and transmission to a private slaughter-point chain. Third, there is a substantial probability of transmission between the modern channel and the traditional channel caused by sector 2 farms and trading activities. The highest probability of transmission was from sector 4 farms 250 to sector 2 farms.

Figure 2 represents a plot of the mean probability of introduction or transmission and its associated mean uncertainty. In three different transmission pathways, we found, in general, that a higher probability estimate is associated with a higher level of uncertainty. The estimated probabilities for transmission within the chain were relatively uncertain. The estimate for transmission sources from an internal chain had a higher uncertainty for all actors. The estimated probabilities for introduction sources from an external chain and transmission sources from the same type of actor in the value chain had a low uncertainty for modern channel actors such as sector 1 farms, sector 2 farms, slaughterhouses, food industries, and modern channel outlets.

Identification of critical chain actors in the introduction and transmission of HPAI

Farms were the most critical actors for introducing and transmitting HPAI within the chain (Table 5). Sector 4 farms were also the most critical factor in introducing HPAI in the private slaughter-point chain. In other chains, various other actors were critical. Sectors 1, 2, and 3 farms were identified as the critical actors for transmission within their chain. In the private slaughter-point chain, the private collecting farms were the critical actors for transmission within the chain. Sectors 2, 3, and 4 farms were the critical actors for transmissions across the same type of actor. The traders were not mentioned since they were not involved physically in producing, transporting, or processing the live bird.

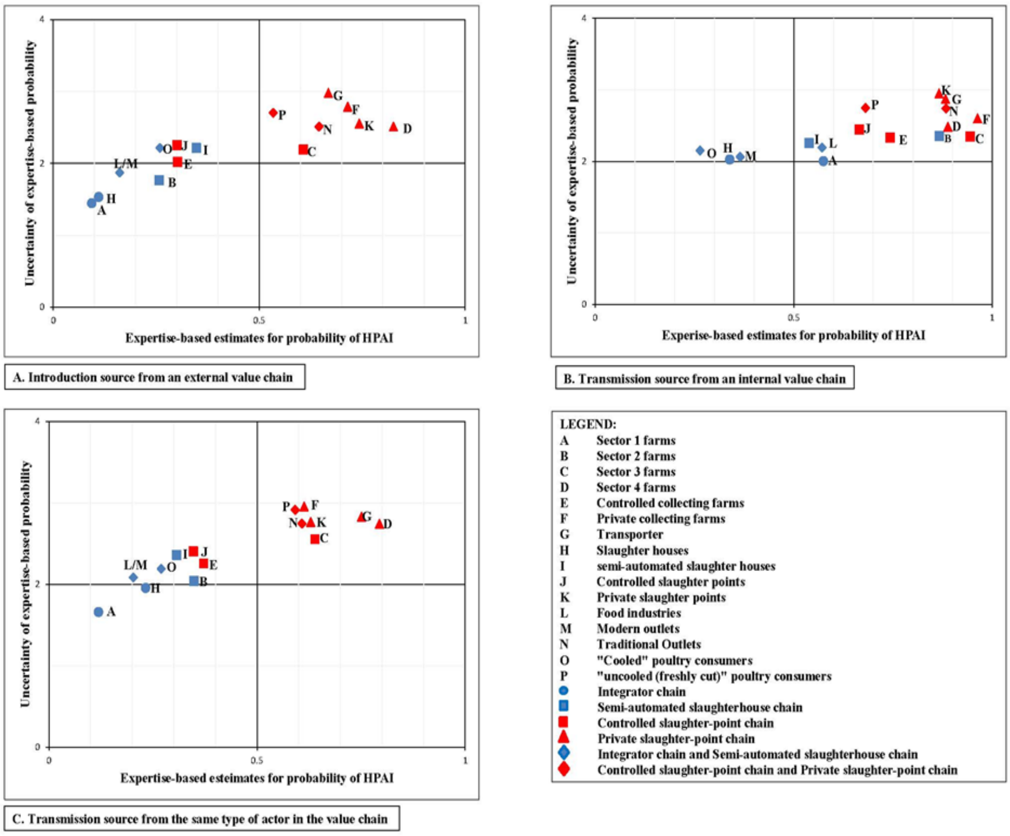

Figure 2. Matrix of the mean expertise-based estimates for probabilities of introduction and transmission of HPAI in the poultry value chain in relation to the associated mean uncertainty

Table 5. Critical actors in the expertise-based probability of HPAI introduction and transmission in the poultry value chains of West Java

Possible Pathways	Modern Channel		Traditional Channel	
	Integrator Chain	Semi-automated Slaughterhouse Chain	Controlled Slaughter-point Chain	Private Slaughter-point Chain
Introduction sources from an external chain	All actors that are involved with live-bird	semi-automated slaughterhouses	Traditional Outlets	Sector 4 farms
Transmission sources from an internal chain	Sector 1 farms	Sector 2 farms	Sector 3 farms	Private collecting farms
Transmission sources from the same type of actor in the value chain	All actors that are involved with live-bird	Sector 2 farms	Sector 3 farms	Sector 4 farms

By combining a value chain analysis with a qualitative risk assessment, a systematic overview of the relation between disease risk and the actors in and organization of the chain can be obtained 280. Rich and Perry (2011) emphasized the use of value chain thinking in integrating disease epidemiology and its relationships with economic behavior. In this line of thinking, Irvine (2015) showed that value chain analysis is a robust systematic framework to evaluate a health surveillance system for poultry. Later on, Antoine-Moussiaux et al. (2017) developed an analysis tool for HPAI surveillance constraints by integrating the value chain with participatory approaches. Indrawan et al. (2018) were able to link chain governance with HPAI biosecurity and this study adds to this line of work. We provided a systematic approach to assess the probability of HPAI introduction and transmission in the poultry value chain. Our study implemented a qualitative risk estimate based on available expert knowledge. Although there are a number of quantitative studies on transmission of HPAI in the Western Java poultry chain (de Glanville et al. 2010; Indriani et al. 2010; Idris et al. 2015; Durr et al. 2016; Wibawa et al. 2018), there is not enough data to provide a complete overview of the probabilities of introduction and transmission across the different actors and sectors. However, a qualitative approach can be used to organize available transparent information in a setting with unknown risks when complete data are unavailable (Wieland et al. 2011). Qualitative estimate studies do have limitations, for instance, due to an over or under-estimation in the context of a judgment or rough calculation (Wieland et al. 2011). Although it is possible for experts to make probability estimates, they are always associated with a certain level of uncertainty. Therefore, we asked the experts to also estimate their uncertainty about their judgment. In this way, we could identify the critical actors regarding the introduction and transmission of HPAI in the Western Java poultry sector. The obtained knowledge about uncertainty is important in the interpretation of the results, and critical actors, especially those where the level of uncertainty is high, should be the main target of further quantitative research that can confirm the findings or reduce the level of uncertainty. Such results can, in turn, be the basis for policies that reduce the risk of HPAI introduction and transmission.

Our results indicate that the critical actors differed between the various poultry chains. This might be because of differences in chain governance structures. Various actors involved in live bird production and processing were critical actors in the less coordinated chains, such as the semi-automated slaughterhouse chain or the controlled and private slaughter-point chains. In the two latter, collecting farms and slaughterhouses were also critical actors. Since the less coordinated poultry chains are characterized by a medium-to-low level of biosecurity, the probability of HPAI introduction and transmission was higher (Indrawan et al. 2018). In contrast, most actors in the more coordinated chains, such as the integrator chain, were estimated to have a low HPAI introduction and transmission probability. Because of the clear governance in the integrator chain and the obvious economic advantage of biosecurity, the probability of HPAI introduction and transmission was the lowest for sector 1 farms and other actors that handled live-bird. While consumers had the highest estimated probability and thus may be considered the main actors, it is unclear how critical they are in HPAI introduction and transmission. We excluded them from the critical actors since they were at the end of the chain and had no direct impact.

With regard to the critical actors for HPAI introduction and transmission in the poultry value chain, a number of issues can be identified. First, the expertise-based probability estimates in the value chain are linked to the level of governance: HPAI introduction or transmission may be more likely as a consequence of a lower level of governance. The most critical actors in the controlled and private slaughter-point chains have the most contact with different batches of live birds. Most of them are practicing a low level of biosecurity (McLeod et al. 2009; de Glanville et al. 2010; Indriani et al. 2010). There is limited coordination and governance by traders in these two specific chains. Traders do have a lot of influence but are not physically in contact with live birds. Moreover, they have no incentive to reduce the risk of introduction and transmission since their income is hardly affected by HPAI occurrence.

Therefore, any effort to control HPAI that does not consider their influence in the chain will be ineffective (Indrawan et al. 2018). Second, private collecting farms were seen as critical actors in transmitting HPAI. This may be because they play a role as a market for sick poultry. Since the consumers in the private slaughter-point chain may be less aware of the safety of their food, this sick-poultry market has remained viable over the past years. Third, sector 2 farms were considered important contributors to the transmission probability within the less coordinated chains. Their trading

activities with private collecting farms might involve sick poultry to reduce farms' financial risks during an outbreak of HPAI (Indrawan et al. 2018). Moreover, there is also the risk of introducing HPAI on sector 2 farms by trading with less coordinated chains.
Since increased HPAI biosecurity measures apply to those who handle live birds, the effectiveness of HPAI control measures depends on the involvement of those actors (McLeod et al. 2009). An important measure would be to remove the sick poultry market. However, this will not be an easy task, since the traders—as the most influential actors within some of the chains—are not incentivized to quit trading HPAI-affected birds (Indrawan et al. 2018). Tighter government regulation and law enforcement, including penalties for chain actors, may need to be established to engage the private sector in prevention and control (McLeod et al. 2009; Kurscheid et al. 2015).

The current study provides a complete overview of HPAI introduction and transmission probabilities in the Western Java poultry system. The results demonstrate that the risk across various poultry chains is interrelated and that, even for the more integrated poultry chains, it is important to control HPAI in the less coordinated poultry chains. Not only because HPAI can be transmitted without direct poultry contact (e.g., by wildlife) but especially since there is direct contact between the actors in the various poultry chains.

Using a value chain analysis as a foundation of food system analysis and linking it with a qualitative assessment of HPAI introduction and transmission enabled us to suggest critical actors for future mitigation plans and research. This is helpful for a country with limited resources to control HPAI, such as Indonesia. Priority in HPAI mitigation and control should be given to the most critical actors in the value chain, actors that have a relatively high probability of introduction and transmission. For control measures to be successful, it is important that actors are intrinsically motivated. Without intrinsic motivation, such as incentives, health authorities should think about a change in the chain.
However, there is not much knowledge on the motivation of actors in controlled and private slaughter-point chains. However, before even considering measures for mitigation and control, further research should first confirm the critical actors' estimated probabilities that are flagged as highly uncertain. In general, attention should be given to the higher probability of the introduction of HPAI in the semi-automated slaughterhouse chain caused by trade connections with the controlled and private slaughter-point chains. Further quantitative epidemiological work should give more insight into the magnitude of those risks, adding to previous epidemiological studies in Indonesia related to HPAI transmission in live bird markets from sector 3 and 4 farm sectors (Indriani et al. 2010; Kurscheid et al. 2015; Wibawa et al. 2018).

This study has a few limitations. The study was designed to estimate HPAI introduction and transmission based on the model of the poultry value chain in Western Java, adapted from an earlier study (Indrawan et al. 2018) that focuses on the transactional relationship between actors and which may not be appropriate for the real epidemiological situation. Therefore, we only looked at the introduction and transmission for a specific chain governance, making this study rather descriptive. We did not consider the pathways that might exist beyond that governance. Furthermore, the questions with regard to HPAI introduction and transmission were general. It may be necessary to look into biosecurity practices for each actor to get a more accurate estimation for each probability. Finally, the high level of uncertainty implies that it is crucial to carry out a quantitative analysis. In future studies, other explanatory variables, specifically related to epidemiology and biosecurity, can be added to each chain governance.

Managerial Implication

Indonesia's current HPAI control and management approach concentrates on farms and live bird marketplaces while ignoring value chain interactions. This strategy is ineffective because of Indonesia's low resource status and budget-optimized reduction. The government's primary goal is to eliminate the sick poultry market, which encourages poor conduct during HPAI outbreaks, increases the likelihood of HPAI transmission during transportation, and has a detrimental influence on biosecurity and response.

Understanding the probability of highly pathogenic avian influenza introduction and transmission in the Western Java poultry chain allows the government to manage better strategy by including chain actors with the highest probability, notably traders, in the removal of the sick poultry market. Intervention in a specific channel and an actor to regulate introduction and transmission could be emphasized in the government program, with a portion of the money set up for this purpose. The plan should be centered on the targeted actors and channel. This will incentivize traders, farmers, collecting farms, and transporters to work together to reduce the likelihood of introduction and transmission.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This research generated an overview of the probability of HPAI introduction and transmission in the Western Java poultry system. The probabilities of HPAI introduction and transmission were estimated for all actors in the four different poultry chains. Expertise-based estimates for HPAI introduction and transmission identified critical actors affecting HPAI risk in Western Java. Essential sources of introduction in an external chain are semi-automated slaughterhouses, traditional outlets, and sector 4 farms. Essential sources of transmission in an internal chain are sector 1 farms, sector 2 farms, sector 3 farms, and private collecting farms. Sources critical transmission sources from the same type of actor in the value chain are sector 2 farms, sector 3 farms, and sector 4 farms. Involving all stakeholders in the development and implementation of control measures is necessary for successful HPAI control. Finally, the high levels of uncertainty associated with expertise-based probability estimates imply that it is necessary to carry out quantitative research in the future. This study provides an important starting point.

Recommendations

The government may significantly improve biosecurity implementation by eliminating the sick poultry market and launching new measures in the specific channel and targeted actors. Thus, incentivizing farmers can help improve biosecurity and minimize the likelihood of HPAI introduction and transmission. The program management should be designed with incentives for biosecurity improvement. Certainly, cost-benefit evaluations should be performed to ensure the benefits of an upgraded program. The cost-effectiveness of interventions can be evaluated using available long-term budgets, taking into account the distribution of costs and benefits across all value chain participants, including the government. Following that, enforcing laws is critical for increasing productivity and progressing beyond voluntary behavioral adjustments.

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REFERENCES

Antoine-Moussiaux N, Peyre M, Bonnet P, Bebay C, Bengoumi M, Tripodi A. 2017. The value chain approach in one health: conceptual framing and focus on present applications and challenges. *Frontiers in Veterinary Science* 4. https://doi.org/10.3389/fvets.2017.00206

Costard S, Fournié G, Pfeiffer DU. 2014. Using Risk Assessment as Part of a Systems Approach to the Control and Prevention of HPAIV H5N1. *EcoHealth* 11: 36-43. https://doi.org/10.1007/s10393-014-0907-1

de Glanville W, Idris S, Costard S, Unger F, Pfeiffer D. 2010. A quantitative risk assessment for the onward transmission of highly pathogenic avian influenza H5N1 from an infected small-scale broiler farm in Bogor, West Java, Indonesia.

Desvaux S, Nguyen CO, Vu DT, Henriquez C, Ky VD, Roger F, Fenwick S, Goutard F. 2016. Risk of introduction in northern vietnam of hpai viruses from china: description, patterns and drivers of illegal poultry trade. *Transboundary and Emerging Diseases* 63: 389-397. https://doi.org/10.1111/tbed.12279

Dolberg F, Bleich EG, McLeod A. 2009. Impact of avian influenza in the poultry sectors of five South-East Asian countries. *Village Chickens, Poverty Alleviation and The Sustainable Control Of Newcastle Disease* 30: 147.

Durr PA, Wibowo MH, Tarigan S, Artanto S, Rosyid MN, Ignjatovic J. 2016. Defining “Sector 3” poultry layer farms in relation to H5N1-HPAI An Example from Java, Indonesia. *Avian diseases*

60: 183-190. https://doi.org/10.1637/11134-050815-Reg

European, Authority FS. 2006. Statement on migratory birds and their possible role in the spread of highly pathogenic avian influenza by the Scientific Panel on Animal Health an Welfare (AHAW). *EFSA Journal* 4: 357a. https://doi.org/10.2903/j.efsa.2006.357a

[FAO] Food and Agriculture Organization. 2011. Approaches to controlling, preventing and eliminating H5N1 highly pathogenic avian influenza in endemic countries. FAO.

Gilbert M, Pfeiffer DU. 2012. Risk factor modelling of the spatio-temporal patterns of highly pathogenic avian influenza (HPAIV) H5N1: A review. *Spatial and Spatio-temporal Epidemiology* 3:173-183. https://doi.org/10.1016/j.sste.2012.01.002

Idris S, Palupi MF, Sudiana E, Unger F, Costard S, Pfeiffer D. 2015. Qualitative risk assessment of HPAI H5N1 transmission between small-scale commercial broiler chicken farms in Bogor, Indonesia.

Indrawan D, Rich KM, van Horne P, Daryanto A, Hogeveen H. 2018. Linking supply chain governance and biosecurity in the context of HPAI control in Western Java: A value chain perspective. *Frontiers in veterinary science* 5. https://doi.org/10.3389/fvets.2018.00094

Indriani R, Samaan G, Gultom A, Loth L, Indryani S, Adjid R, Dharmayanti NLPI, Weaver J, Mumford E, Lokuge K, Kelly PM, Darminto 2010. Environmental Sampling for Avian Influenza Virus A (H5N1) in Live-Bird Markets, Indonesia. *Emerging Infectious Diseases* 16: 1889-1895. https://doi.org/10.3201/eid1612.100402

Irvine RM. 2015. A conceptual study of value chain analysis as a tool for assessing a veterinary surveillance system for poultry in Great Britain. *Agricultural Systems* 135: 143-158. https://doi.org/10.1016/j.agsy.2014.12.007

Kasemsuwan S, Poolkhet C, Patanasatienkul T, Buameetoop N, Watanakul M, Chanachai K, Wongsathapornchai K, Métras R, Marcé C, Prakarnkamanant A. 2009. Qualitative risk assessment of the risk of introduction and transmission of H5N1 HPAI virus for 1-km buffer zones surrounding compartmentalised poultry farms in Thailand. *The Pro-poor HPAI Risk Reduction Project Report* 9.

Kelly L, Kosmider R, Gale P, Snary EL. 2018. Qualitative import risk assessment: A proposed method for estimating the aggregated probability of entry of infection. *Microbial Risk Analysis* 9: 33-37. https://doi.org/10.1016/j.mran.2018.03.001

Kurscheid J, Millar J, Abdurrahman M, Ambarawati IGAA, Suadnya W, Yusuf RP, Fenwick S, Toribio JALML. 2015. Knowledge and Perceptions of Highly Pathogenic Avian Influenza (HPAI) among Poultry Traders in Live Bird Markets in Bali and Lombok, Indonesia. *PLOS ONE* 10: e0139917. https://doi.org/10.1371/journal.pone.0139917

McLeod A, Kobayashi M, Gilman J, Siagian A, Young M. 2009. The use of poultry value chain mapping in developing HPAI control programmes. *World's Poultry Science Journal* 65: 217-224. https://doi.org/10.1017/S0043933909000166

Onkundi D, Bett B, Costard S, Omore A, Zepeda C. 2010. Qualitative release and exposure assessment on the risk of HPAI transmission between sector 4 farms and between sector 3 and sector 4 farms in Kenya.

Rich KM, Perry BD. 2011. The economic and poverty impacts of animal diseases in developing countries: New roles, new demands for economics and epidemiology. *Preventive Veterinary Medicine* 101: 133-147. https://doi.org/10.1016/j.prevetmed.2010.08.002

Sudarman A, Rich K, Randolph T, Unger F. 2010. Poultry value chains and HPAI in Indonesia: The case of Bogor.

Wibawa H, Karo-Karo D, Pribadi ES, Bouma A, Bodewes R, Vernooij H, Sugama A, Muljono DH, Koch G, Rasa FST. 2018. Exploring contacts facilitating transmission of influenza A (H5N1) virus between poultry farms in West Java, Indonesia: A major role for backyard farms? *Preventive Veterinary Medicine* 156: 8-15. https://doi.org/10.1016/j.prevetmed.2018.04.008

Wieland B, Dhollander S, Salman M, Koenen F. 2011. Qualitative risk assessment in a data-scarce environment: A model to assess the impact of control measures on spread of African Swine Fever. *Preventive Veterinary Medicine* 99: 4-14. https://doi.org/10.1016/j.prevetmed.2011.01.001