Risk of poultry compartments for transmission of High Pathogenic Avian Influenza

Boender G.J.[1], Hagenaars T.J.[1], Backer, J.A. [1], Nodelijk, H.A. [1], Asseldonk M.A.P.M. van[2], Bergevoet R.H.M.[2], van Roermund, H.J.W.[1]

[1] Central Veterinary Institute (CVI) of Wageningen UR, Lelystad, The Netherlands
[2] Economic Agricultural Research Institute (LEI) of Wageningen UR, Wageningen, The Netherlands

Project BO-08-010-011
(Maatschappelijk Aanvaardbare Dierziektebestrijding, MAD)

Report number CVI: 14/I00028

March 2014

Contents

Summary

Epidemiological consequences of poultry compartments during an HPAI epidemic
In order to facilitate the continuation of trade in and from unaffected parts of the poultry industry in case of an HPAI epidemic, EU member states can use 'compartmentalisation' (Commission Regulation EC No 616/2009). Compartmentalisation means defining certain subpopulations of farms which on the basis of their management and husbandry practices are considered to realize a high biosecurity. In 2011 in The Netherlands, there has been an application and subsequent approval of a poultry compartment for the production of fertilised chicken eggs for pharmaceutical purposes (Verbeek Poultry International, VPI).

In case of an HPAI epidemic the infected farms need to be depopulated, transport regulated, protection and surveillance zones (PS zones) set up and dangerous contacts traced, all according to the requirements of the EU. Furthermore, the Dutch contingency plan divides the country into geographical regions, thereby enabling the definition of infected and infection-free zones during a crisis and the regulation of transports according to these zones. One of the benefits of the compartment status is the permission to carry out certain transports within the compartment, even from and to compartment farms that are located in an infected zone (VPI follows a stricter policy by excluding compartment farms when located in a 10 km surveillance zone). The application for a poultry compartment by VPI and the prospect of further ones motivates the Dutch Ministry of Economic Affairs and the Netherlands Food and Consumer Product Safety Authority to raise the following three questions:

1. What are the additional transmission risks that the (specific) VPI compartment poses during an HPAI epidemic, compared to a situation without compartment ?
2. What are the additional transmission risks that a compartment in general poses during an HPAI epidemic, depending on its characteristics ?
3. What are relevant evaluation criteria for granting the compartment status ?

In this study we addressed these questions by quantitatively assessing the veterinary risks based on mathematical model calculations, and by qualitatively discussing the (socio) economic aspects. With respect to questions 1 and 2, we considered the following two types of (additional) transmission risks:

(I) the local HPAI transmission risk from farms *within* the compartment, and
(II) the risk of a 'jump' of HPAI *via* the compartment from infected to other (free) areas in the country.

In order to address question 3, we studied the dependence of these extra risks on the following properties of the compartment: the number of farms within the compartment, transport of eggs and/or live chicken within the compartment and the location of the compartment farms in the country (distance to a densely populated poultry farm area, DPPA).

The results for the local HPAI transmission risk from the VPI poultry compartment farms were as follows. Under the assumed worst-case effectiveness of biosecurity measures, the combined risk of egg transport, feed delivery, professional contact and rendering contact among the VPI farms leads to a transmission probability (cumulative over the entire infectious period of the infected farm) to any given other farm in the compartment of approximately 0.6.

So if HPAI were introduced in one of the farms of the VPI compartment, the probability of infecting any given other farm of the compartment would be high. The resulting between-farm reproduction number of the VPI farms increases with a factor 50 from 0.05 (when not part of a poultry compartment) to 2.4 (when part of a poultry compartment). The relatively high transmission risk within the VPI compartment arises as a result of the closed contact structure designed to keep HPAI introduction risks from outside the compartment as low as possible. This relatively high risk implies that if one compartment farm is suspected of being infected with HPAI, then all other farms of the compartment must be considered as dangerous contact farms. This finding supports the rationale of VPI policy to remove a compartment farm from the compartment as soon as it becomes part of a surveillance zone (10 km ring) around a detected non-compartment farm. A strategy deemed sensible when a compartment farm is located more than 10 km from a new HPAI outbreak (so not in the surveillance zone), is to visit this farm as last in the sequence of feed, rendering, and professional contacts.

The results for the risk of jumps of HPAI from one area via a poultry compartment to another area in the country were as follows. This risk was negligible for VPI. The reason for this low risk is the long distance of approximately 60 km between the VPI farms and the closest densely populated poultry livestock area (DPPA), which is the Gelderse Vallei in The Netherlands. For the scenario where animal (live chicken) transport would take place within an otherwise VPI-like compartment, this risk remained negligible, due to the low frequency of chicken transport compared to that of eggs. If one of the compartment farms is located in or close to the Gelderse Vallei, the risk of HPAI transmission jumps via the compartment cannot be neglected anymore. It increases about tenfold when the distance to the Gelderse Vallei is reduced from 40 km to 0 km, reaching a value that is 1.5-1.6 times larger than the jump risk in absence of a compartment in the country.

Focussing the biosecurity measures within VPI on the transport of eggs yields the strongest effect on reduction of the local HPAI transmission risk of the VPI farms. This is caused by the high frequency of these transports in VPI. But even when HPAI transmission by egg transports was fully blocked by biosecurity measures, the local transmission risk of the VPI farms would be reduced by 63% to a value of 0.9 for the between-farm reproduction number, still much higher than the mean risk of the VPI farms when not in a poultry compartment (0.05). Thus, in order to reduce risks further, the biosecurity measures must be aimed at *all* contact possibilities together between farms within VPI, like egg transports, feed delivery, professional contacts and rendering contacts. Even then, in order to reach a local transmission risk for the compartment farms in the same order of magnitude as when not in a compartment, a biosecurity improvement of 98% is needed. Thus, a factor 50 of risk reduction compared to the 2003 crisis biosecurity level would need to be achieved by the biosecurity measures executed by VPI in the compartment.

The closed contact structure of the VPI compartment is an aspect that deserves close scrutiny. As a consequence of this contact structure, each farm within the compartment has frequent (indirect) contact to all of the other farms, yielding ample HPAI transmission possibilities. The importance of strict biosecurity measures applied to vehicles and professionals going from one compartment farm to the next has been confirmed in this study. Also, any options for reducing the number of connections in the contact network deserves to be scrutinized. Another strategy of interest is to set transport routes such that compartment farms located closest to high-risk areas are visited last on the day.

The local transmission risk of the farms in a VPI-like compartment is linearly proportional to the number of farms within the compartment. This means that for a larger compartment the within-compartment transmission risk will be proportionally larger. However, this risk could be reduced by introducing separate networks within the poultry compartment: for example when comparing a compartment size of 10 to that of 5 by using two trucks for egg transport, thus connecting only half of the farms by one truck and the other half of the farms by the other truck. For each of these specific situations, the generic model developed in this study can be adapted and used to evaluate the corresponding risks. The generic model can be adapted for any compartment in the future.

Socio-economic consequences of poultry compartments during an epidemic

A distinguishing feature of a poultry compartment is that during an epidemic their farms, in an infected area (but for VPI outside the 10 km surveillance zones), can continue with business as usual, provided that none of the compartment farms becomes infected. In contrast, other farms in an infected area are confronted with stringent movement restrictions. This study has shown that the additional transmission risk caused by a compartment is mainly borne by the compartment farms themselves, and other farms are not more exposed, provided that the compartment farms are all located sufficiently far away from a DPPA. If one or more compartment farms are located in or close to a DPPA, the compartment will substantially increase the probability of a jump of HPAI from a DPPA to another region. If such a jump causes the newly infected area to be subjected to export restrictions it will thereby severely affect all non-compartment farms in the newly infected region.

Decision criteria for granting compartment status to applicants

From this study a number of strategies emerge for limiting transmission risks associated with compartments, other than the obviously important strategy of applying stringent biosecurity measures to all contact events. These strategies could be considered as or translated into requirements on compartments, i.e. used as criteria that should be met by applicants in order to obtain compartment status. These strategies are as follows:

- Avoiding the inclusion in a compartment of farms located in or close to a densely populated livestock area;
- Aligning all regular transport and visitor routes as much as possible to one fixed route (physically) along the compartments farms;
- Setting the transport/visitor route(s) such that compartment farms located closest to high-risk areas are visited last on the day.

Regarding strategies during an HPAI epidemic, the analysis supports the rationale of VPI policy to remove a compartment farm from the compartment as soon as it becomes part of a surveillance zone (10 km ring) around a detected non-compartment farm. A strategy deemed sensible when a compartment farm is located more than 10 km from a new HPAI outbreak (so not in the surveillance zone), is to visit this farm as last in the sequence of feed, rendering, and professional contacts.

Introduction

Research questions

Epidemics of highly pathogenic Avian Influenza (HPAI) can have a large impact on animal welfare and the poultry industry, and – due to the zoonotic character – also on public health. The total export of poultry meat and eggs amounted in 2012 a value of 3.5 billion € (PVV, 2013). In 2003 the total costs of the HPAI epidemic in The Netherlands, which started in a densely populated poultry livestock area, amounted to 270 million € (Anon., 2004).

Because of multiple possible introduction routes, several reservoirs and mutations from low pathogenic AI (LPAI), poultry flocks in The Netherlands are at a continuous risk of becoming infected by HPAI. In case of an outbreak the infected farms need to be depopulated, transport regulated, protection and surveillance zones (PS zones) set up and dangerous contacts traced, all according to the requirements of the EU (Anon., 2007). Additionally, control measures can be taken to reduce transmission in the affected area by pre-emptive culling or emergency vaccination.

In order to facilitate the continuation of trade in and from unaffected parts of the poultry industry in case of an HPAI epidemic, EU member states can use both ‘zoning’ and ‘compartmentalisation’ (Commission Regulation EC No 616/2009, implementing Council Directive 2005/94/EC). Zoning is part of the Dutch contingency planning, also for other contagious diseases in livestock. It means dividing the country in geographical regions enabling the definition of infected and infection-free zones during crises. Compartmentalisation means defining certain subpopulations of farms which on the basis of their management and husbandry practices are considered to realize a high biosecurity. In 2011 in The Netherlands, there has been an application and subsequent approval for a poultry compartment for the production of eggs for pharmaceutical purposes (Verbeek Poultry International, VPI).

One of the benefits of the compartment status is the permission to carry out certain transports within the compartment even from and to compartment farms that are located in an infected zone (VPI follows a stricter policy by excluding compartment farms when located in a protection and surveillance zone). This application and the prospect of further ones motivated the Dutch Ministry of Economic Affairs and the Netherlands Food and Consumer Product Safety Authority to raise the following three questions:

1. What are the additional transmission risks that the (specific) VPI compartment poses during an HPAI epidemic, compared to a situation without compartment ?
2. What are the additional transmission risks that a compartment in general poses during an HPAI epidemic, depending on its characteristics ?
3. What are relevant evaluation criteria for granting the compartment status ?

In this study we addressed these questions by assessing the veterinary risks, and by qualitatively discussing the (socio-)economic aspects. With respect to questions 1 and 2, we considered the following two types of (additional) transmission risks:

(I) the local HPAI transmission risk from farms *within* the compartment, and
(II) the risk of a ‘jump’ of HPAI *via* the compartment to other (free) areas in the country.

We studied the dependence of these extra risks on the following properties of the compartment: the number of farms within the compartment, transport of eggs and/or live chicken within the compartment and the location of the compartment farms in the country (distance to a densely populated poultry farm area, DPPA). The dependences identified help to define assessment criteria for the approval of a poultry compartment in The Netherlands.

Background

In 2004 the World Organisation for Animal Health (OIE) introduced the concept of compartmentalisation, in the chapter on zoning and regionalisation of its Terrestrial Animal Health Code (The Code:http://www.oie.int/eng/normes/mcode/ en_sommaire.htm). In chapter 4.3 of The Code zoning and compartmentalisation is described as ‘procedures implemented by a country under the provisions of this chapter with a view to defining subpopulations of distinct health status within its territory for the purpose of disease control and/or international trade.’ In addition, chapter 4.4 on the application of compartmentalisation provides a structured framework for the application and recognition of compartments within countries. A compartment may consist of several farms and can be approved for one or more defined animal diseases. Approval should be based on a detailed and documented biosecurity plan drawn up and implemented for the disease(s) concerned.

In the Netherlands, Verbeek Poultry International (VPI), an enterprise producing fertilized chicken eggs for pharmaceutical purposes, applied for the approval of a poultry compartment for Avian Influenza. This VPI poultry compartment application was approved by The Netherlands Food and Consumer Product Safety Authority (NVWA) in 2011. The poultry farms within the VPI compartment are characterized by a closed contact structure and biosecurity measures designed to minimize the risk of introduction of HPAI into the compartment as well as to minimize the risks associated with transport processes within the compartment. One important benefit of a poultry compartment status is that certain transport restrictions during an epidemic in the country do not apply to the farms within that compartment. This facilitates trade, but on the other hand may have consequences for transmission risks of HPAI.

Material and Methods

To analyse the three research questions, first a generic mathematical model was developed. Subsequently, we consider several specific scenarios, corresponding to specific compartment characteristics such as those of VPI. The specific scenarios include a compartment with a farm situated in a densely populated poultry farm area (DPPA), and a compartment with transport of eggs and live chicken instead of only eggs.
First the generic model structure is described and subsequently the VPI compartment characteristics are addressed and how these were translated into a model scenario (model parameter values).

Model structure and approach

We developed a generic model describing HPAI transmission risks between poultry farms in The Netherlands, of which certain specific farms belong to a poultry compartment. As the risk of introduction of HPAI into the country is not part of the research problem, the model focusses on the period after the first farm in the country was detected as HPAI infected, i.e. after the end of the High-Risk Period (HRP). The model consists of compartment farms and all other non-compartment farms in the country, and is spatial, explicitly including all location coordinates of poultry farm in The Netherlands. The model calculates the HPAI transmission risk between non-compartment farms, from non-compartment farms to compartment farms and vice versa, and between compartment farms (see Figure 1). Even during a standstill situation, when no animal transport is allowed, indirect or 'neighbourhood' transmission between farms may still take place, as observed during the 2003 epidemic in the Netherlands. Non-compartment farms under standstill regulations after the HRP, are therefore still 'connected' with each other by neighbourhood transmission of HPAI (indirect contact) although not by transport of live animals (direct contact). Compartment farms are 'connected' with each other by neighbourhood transmission of HPAI and also by transport of live animals or eggs. The probabilities of HPAI transmission by each of these pathways were estimated from the H7N7 HPAI epidemic in The Netherlands in 2003. These probabilities represent the average biosecurity 'level' realized at that time for the processes involved in these pathways. Due to the strict biosecurity measures for the relevant processes taking place within compartments (especially when HPAI is present in the country), the use of these probability estimates from 2003 for processes within the compartment can be viewed as a worst-case assumption.

Figure 1. A generic model of HPAI transmission among poultry farms in the country, of which certain specific farms belong to the compartment.

In order to assess the additional transmission risks that a compartment poses, we use the following two measures of transmission risk: (1) the 'local' between-farm reproduction number, and (2) the risk of a HPAI transmission 'jump' event occurring from one area to another.

(1) Local between-farm reproduction number $R_{0,i}$

The local reproduction number $R_{0,i}$ is associated with farm i and defined as the expected number of newly infected farms caused by farm i if it became infected and all other (poultry) farms in The Netherlands were still susceptible (Boender et al., 2007). $R_{0,i}$ is calculated by summing of all transmission probabilities p_0 (through indirect neighbourhood transmission during the period after the HRP) from source farm i to all possible receiver farms j. For source farms outside the compartment(s) this sum is written as follows:

$$R_{0,i} = \sum_{j \neq i} p_0\left(r_{ij}\right) \qquad (1)$$

Here r_{ij} is the straight-line distance from farm i to farm j. The probability of the between-herd transmission p_0 during standstill is distance dependent and was described by Boender et al. (2007) by

$$p_0\left(r_{ij}\right) = 1 - \exp\left(-\frac{h_0 T}{1+\left(\frac{r_{ij}}{r_0}\right)^{\alpha}}\right) \qquad (2)$$

with parameters h_0=0.002 day^{-1}, α=2.1, r_0=1.9 km, and the infectious period of a farm T=7.5 day, as estimated from the Dutch 2003 HPAI epidemic (Boender et al., 2007). Figure 2 shows this curve, the so called between-herd transmission kernel for HPAI (in short: kernel). This kernel describes the combined result of all (unknown) transmission routes still occurring during standstill (in 2003).

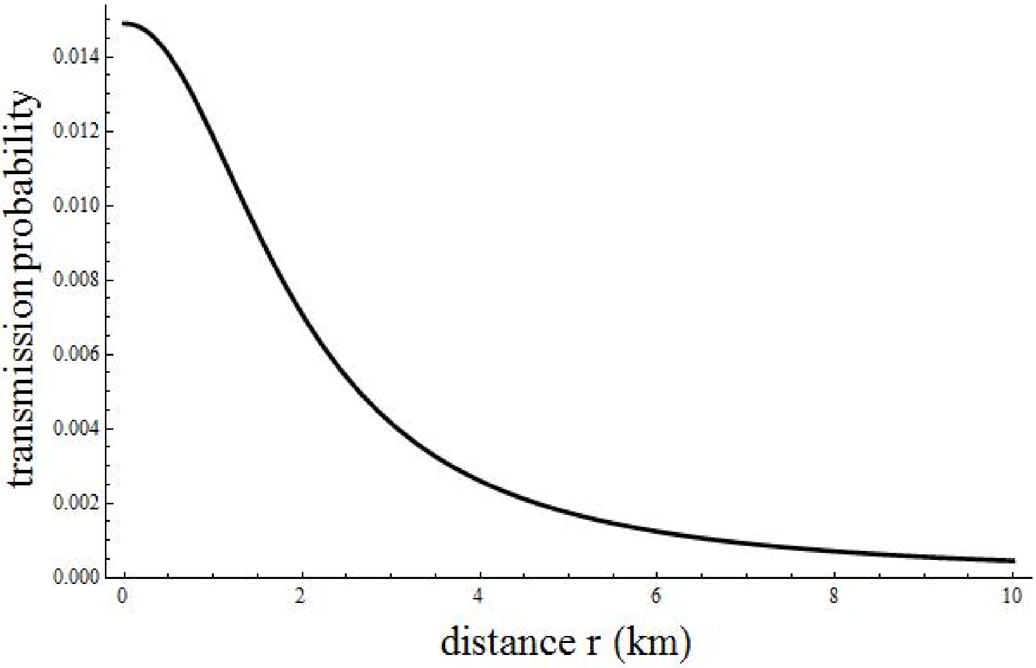

Figure 2. Between-herd transmission probability of HPAI (cumulative over the whole infectious period T) as function of inter-farm distance, estimated from the H7N7 HPAI epidemic in The Netherlands in 2003.

For source farms *m* within the compartment *C* we write:

$$R_{0,m} = \sum_{j \notin C} p_0(r_{mj}) + \sum_{n \in C} p_c(m \to n) \qquad (3)$$

This is the sum of all transmission probabilities p_0 (so caused by indirect neighbourhood transmission only) from source farm *m* to all receiving farms *j* outside the compartment, plus the sum of all transmission probabilities p_c to all receiving farms *n* within the compartment. These latter probabilities p_c are caused by both neighbourhood transmission as well as by the between-farm contact events resulting from the compartment status. We assume that at the spatial scale of the Netherlands, the transmission risks of the latter contact events are independent from the distance between the two compartment farms involved. Mathematically this implies that the probability of transmission p_c within the compartment is an extension of the indirect neighbourhood transmission probability by:

$$p_c(r_{mn}) = 1 - \exp\left(-\left(\frac{h_0}{1 + \left(\frac{r_{mn}}{r_0} \right)^{\alpha}} + \sum_l h_l \right) T \right) \qquad (4)$$

where *m* is the source farm and *n* is the receiving farm both within the compartment, r_{mn} is the distance between these farms, and h_l is the transmission rate (per day) for a given between-farm contact event of type *l* within the compartment.

For areas in which farms with $R_{0,i} > 1$ are clustered, the model predicts that there is a risk of a propagating epidemic to occur in that area; for areas where all farms have $R_{0,i} < 1$ only small series of between-farm transmission events are expected. When considering farms within a compartment, we note that due to the relatively small number of farms forming the compartment, there is no sharp threshold at $R_{0,i} = 1$. This means that then each reduction of $R_{0,i}$, whether or not bringing $R_{0,i} < 1$, is important to limit the total number of infected farms in the compartment.

Of particular interest is the difference $\Delta R_{0,i}$ in the local reproduction number between the situation with and without compartment. For source farms *i* outside the compartment(s), the probabilities $p_0(r_{ij})$ are the same in both situations, and thus the difference is zero in that case:

$$\Delta R_{0,i} = 0. \qquad (5)$$

However, for source farms *m* within the compartment *C* the difference is non-zero:

$$\Delta R_{0,m} = \sum_{n \in C} p_{\mathrm{c}}(m \to n). \qquad (6)$$

We note that when in Equation 4 the 'kernel' part is much smaller than the contact event transmission rate, i.e. $\frac{h_0}{1+\left(\frac{r_{mn}}{r_0}\right)^{\alpha}} << \sum_l h_l$, p_{c} is in good approximation *independent* of the distance between the farms (in the compartment). Therefore Equation [6] can be rewritten as:

$$\Delta R_{0,m} = (N_c - 1)p_c \qquad (7)$$

in which N_{c} is the number of farms within the compartment. Only farms with live chicken are considered in N_{c}, because these farms can suffer from an HPAI outbreak.

(2) The additional risk of a jump of HPAI from one area, via the compartment, to another
The compartment farms may link different areas in the country by means of the allowed transports between compartment farms. This implies that such a compartment constitutes an additional risk of a 'jump' of HPAI to another area. To quantify this additional risk, the probability of neighbourhood ('single-event') transmission from source farm *i* to receiving farm *j*, both located outside the compartment, is compared to the probability of 'triple-event' transmission from source farm *i* to receiving farm *j* via farms *m* and *n* located inside the compartment. This sequence of three transmission events leading to a 'jump' is visualized in Figure 3.

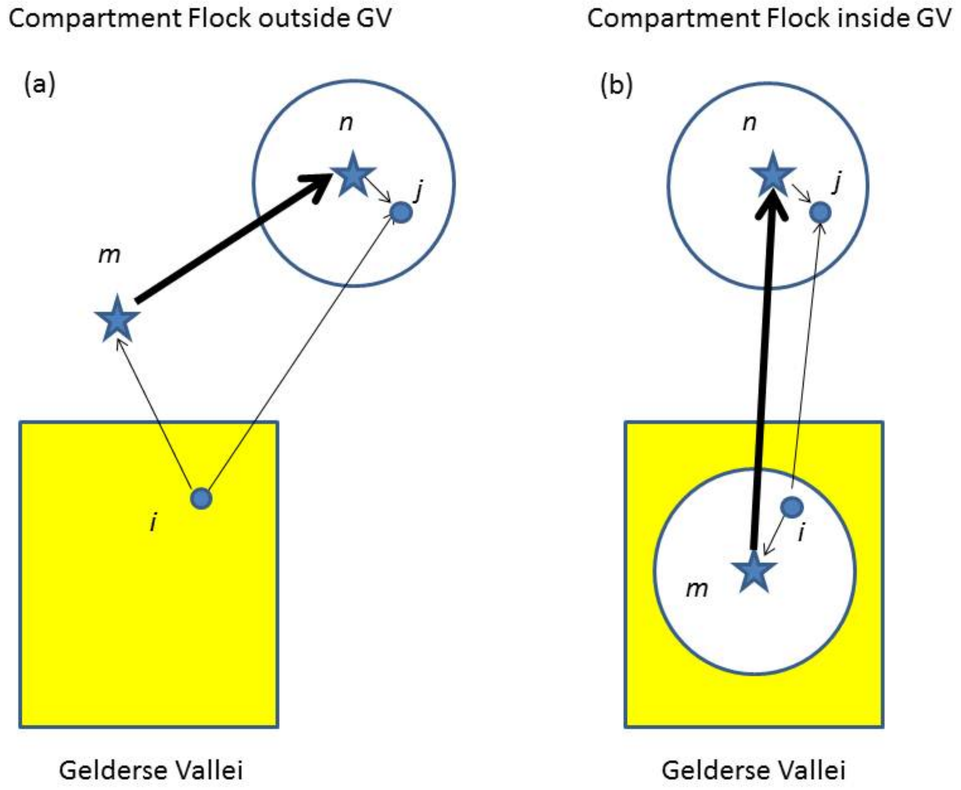

Figure 3. ‘Single-event’ transmission from source farm *i* to receiver farm *j*, both located outside the compartment (i.e. represented by a dot), compared to ‘triple-event ’ transmission from source farm *i* to receiver farm *j* via farms *m* and *n*, both located inside the compartment (i.e. represented by a star). Thick lines represent HPAI transmission by the combination of neighbourhood transmission and by between-herd contact events. Thin lines represent HPAI transmission by neighbourhood transmission only. Circles represent the 10 km surveillance zone around the compartment farms *m* and *n*. The Gelderse Vallei (GV) is the most densely populated poultry farm area in the Netherlands. Shown are the possibilities that the compartment farms (*m* and *n*) are situated outside the GV (Figure 3a) and that one compartment farm (farm *m*) is located within the GV (Figure 3b).

The ‘single-event’ transmission is described by the probability p_0 and can be considered as the ‘background’ transmission which is always there at standstill, whereas the ‘triple-event’ transmission via farms in the compartment is the extra risk caused by the presence of the compartment itself. The ‘triple-event’ transmission p_t is written as the product of three probabilities: transmission from farm *i* outside the compartment to farm *m* inside the compartment, subsequent transmission of farm *m* to farm *n* both inside the compartment, and subsequent transmission of farm *n* to farm *j* outside the compartment:

$$p_\mathrm{t}(i \rightarrow m \rightarrow n \rightarrow j) = p_0(r_{im})p_\mathrm{c}(m \rightarrow n)p_0(r_{nj}). \qquad (8)$$

The additional transmission jump risk from area A (Gelderse Vallei in Figure 3) to area B caused by the compartment is evaluated based on p_0 and p_t as follows. We used 1000 randomly selected sets of farms *i, j, m, n*. Individually these sets are constructed as follows: a random farm *i* in area A was selected. Then, two random compartment farms were selected (*m* and *n*), with farm *n* being located in area B. Subsequently, a random farm (*j*) in area B within a radius of 10 km (the surveillance zone) around farm *n* was selected. The latter 10 km area was chosen because farms in the neighbourhood of a compartment farm are at the highest risk. For each random farm set the 'single-event' transmission probability p_0 from farm *i* to farm *j* was compared with the 'triple-event' transmission probability p_t via compartment farms *m* and *n* by calculating the ratio of the two.

Effect of distance of the compartment to Gelderse Vallei (GV)

To evaluate the effect of an increasing distance of a poultry compartment to the densely populated poultry farm area Gelderse Vallei (GV), we used a similar approach to the one above (see Figure 3a). For this calculation a random non-compartment farm *i* was selected in the GV, a random compartment farm *m* outside the GV, a second random compartment farm *n* outside the GV and a random non-compartment farm *j* in the 10 km surveillance zone of farm *n*. The 'single-event' neighbourhood transmission probability from farm *i* to farm *j* was compared with the 'triple-event' transmission probability via compartment farms *m* and *n*. The ratio between the 'triple-event' transmission risk to the 'single-event' transmission risk was calculated for each selection of farms. Furthermore, the nearest distance of the compartment farm *m* to a farm in the GV was determined. This selection process was repeated 10.000 times, leading to a set of pairs {distance, ratio}. Based on this set a rolling average plot was calculated with a window of {-2.5 km, 2.5 km}. The rolling average of the mean, the 5% percentile and 95% percentile is presented.

Description of the Verbeek Poultry International (VPI) compartment

The Verbeek Poultry International (VPI) compartment consists of 5 layer farms and one hatchery. The location of these farms and that of all poultry farms in the Netherlands is depicted in Figure 4. On the hatchery of VPI, solely dedicated to producing fertilized chicken eggs, no live animals (chicken) are present.

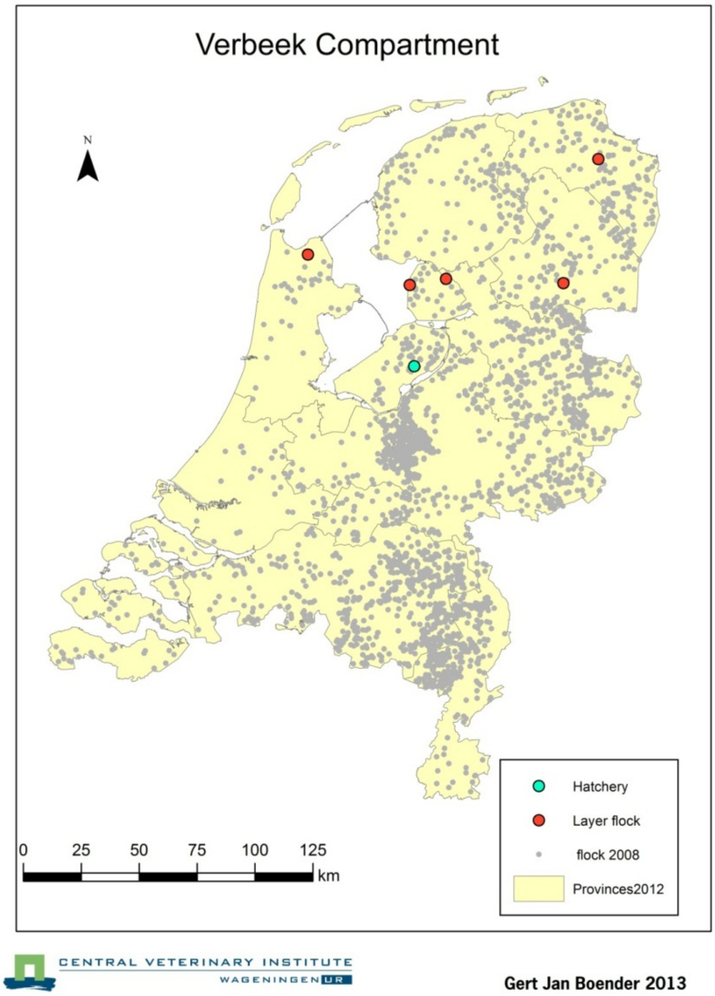

Figure 4. The location of the 5 layer farms and the hatchery of the compartment of Verbeek Poultry International (VPI) and that of other commercial poultry farms in The Netherlands (database of 2008).

Incubated eggs are transported from all five layer farms to the hatchery. From there, incubated eggs are transported to France, to be used for the production of vaccines against human influenza. The hatchery does not have live animals (chickens) on the farm, and no transport of animals occurs between the six farms of the VPI compartment.

Eggs are transported twice per week from each layer farm to the hatchery, by one-to-one transport between layer farm and hatchery. There is one truck for all egg transports within the compartment, and this truck is not used to transport eggs stemming from non-compartment farms. Also all egg trays are only used within the compartment. The truck leaves disinfected and empty from the hatchery to a layer farm, where the eggs are uploaded, and the truck is disinfected again before departure from the layer farm to the hatchery. After the eggs are delivered at the hatchery, the truck is disinfected again.

For feed delivery, each Monday one transport truck from outside the compartment visits all farms within the compartment, and then leaves the compartment again. So this happens with a frequency of once per week. After leaving a farm, the wheels and wheel arches of the truck are disinfected.

A technical supervisor visits all farms of the compartment throughout the first half of the week, at a frequency of once every 2 weeks. A veterinarian visits all farms of the compartment on a Monday, at a frequency of once per 3 weeks. A sample taker visits all farms of the compartment on a Monday, at a frequency of once per 15 weeks. Showering before and after each farm visit and wearing corporate clothing during a visit is compulsory for the technical advisor, veterinarian and sample taker.

To collect rendering material, a truck from outside the compartment visits all farms of the compartment on a Monday at a frequency of once per 4 weeks. After leaving a farm, the truck is disinfected.

A summary of biosecurity measures executed by VPI is given in Appendix I (in Dutch).

Parameter values used in the analysis for the VPI compartment

For the analysis of the VPI compartment, two transmission pathways in the generic model were set to 0: VPI does not transport live chickens from the compartment to farms outside the compartment, and VPI does not transport live chickens between farms within the compartment.

Table 1 summarizes the type of between-farm contacts within the VPI compartment, the frequency of these contacts in the compartment as described above, and the probability of HPAI transmission per contact type as estimated from the H7N7 HPAI epidemic in The Netherlands in 2003 by Ssematimba et al. (2012). Because one and the same truck is used for egg transport in the VPI compartment, each farm has contact with another farm twice a week by means of egg transport via the hatchery. As a worst-case estimate of HPAI transmission, and because the effect of biosecurity measures like truck disinfection on virus transmission in practice is not quantified, we first ignore in our analysis the effect of biosecurity measures executed by VPI in addition to the measures taken in the field in 2003.

Furthermore, as survival of the HPAI virus in the environment during at least a few days is very well possible, it is assumed that contacts between farms with the same truck are still infectious over a week. Without an extensive literature review on virus survival, we refer to Kandun et al. (2010) to support this assumption.

Most contacts between farms in the VPI compartment take place in one or a few days, usually on a Monday or during the first half of the week. This implies that infectious material attached to a person or a vehicle stays infectious during that short period of one or a few consecutive days. Again, as a worst-case scenario we ignore disinfection measures executed by VPI in the analysis (as far as these are more effective than the measures carried out across the HPAI outbreak areas in 2003). So it is assumed that upon infection a transport remains infectious during the full weekly period of transport within the VPI compartment.

Specific transportation routes which are repeated every week within the VPI compartment (trucks from farm A to B and from B to C etc.) are not known to us, and thus fixed contact structures among farms in the compartment were not incorporated in the analysis. We assumed random mixing where each farm has the same probability to infect another farm within the compartment.

We note that several of the contact event types that we included as specific for the compartment, and thereby contributing to the probability p_c, are in fact also allowed outside the compartment, so they are not an extra allowed contact: feed delivery, professional contact and rendering contact. However, because of the closed contact structure within the compartment (designed to minimize the risk of introduction of HPAI into the compartment), these contacts always occur between the same compartment farms, unlike the situation for farms outside the compartment, where these contacts occur to 'random' other farms and are thus taken into account into p_0.

Table 1. Overview of between-farm contact types within the VPI compartment, their frequency, and the probability of HPAI transmission per contact, as estimated from the H7N7 HPAI epidemic in The Netherlands in 2003. From these data, the transmission rate was calculated.

Type of Contact	Contact per day	Probability of HPAI transmission per contact [1)]	Transmission Rate (day^{-1})
Egg transport [2)]	2/7	0.308	0.088
Feed delivery	1/7	0.0414	0.0059
Professional contact	(1/2+1/3+1/15)/7 [3)]	0.133	0.017
Rendering Contact	(1/4)/7	0.246	0.0088
Animal transport	0	1 [4)]	0

[1)] From Ssematimba et al. (2012). The biosecurity measures executed by VPI in addition to the measures taken in the field in 2003 are not incorporated in these probabilities (worst-case). It is assumed that contacts between farms with the same truck are still infectious over a week.
[2)] Each farm has contact with another farm twice a week by means of egg transport via the hatchery.
[3)] Technical supervisor: 1 per 2 weeks; veterinarian 1 per 3 weeks; sampler 1 per 15 weeks
[4)] Assumed probability of transmission of 1 (worst-case).

Sensitivity analysis of biosecurity measures executed by VPI

The probabilities of HPAI transmission (Table 1) were estimated from the H7N7 HPAI epidemic in The Netherlands in 2003. Thus, these probabilities represent the biosecurity which surrounded the contact events between poultry farms at that time, i.e. any possible additional biosecurity realized through the measures taken by VPI to maintain their certified compartment status (see Appendix I) are not incorporated. Thus, these transmission probabilities are worst-case estimates. Unfortunately, quantitative data on the effect of biosecurity measures such as disinfection (of trucks, people etc.) are not available. To evaluate the effect of hypothetical improvements of biosecurity in comparison to the 2003 reference, a sensitivity analysis was carried out in which the probability of transmission of *each* of the pathways of Table 1 was reduced separately with 10%, 50% and 90%. The effect was also evaluated when *all* probabilities were reduced at the same time.

Results

Transmission risk from farms in the VPI compartment *(only egg transport, no animal transport).*

When using the given parameter values for the kernel in Figure 2 and probabilities as presented in Table 1, the probability of HPAI transmission between two farms in a compartment amounted to p_c = 0.59. So when, despite all biosecurity measures (as executed in 2003), HPAI would be introduced on one of the farms of the VPI compartment, the probability of infecting any one of the other farms of the compartment is high. Every farm of the compartment has a probability of 0.59 to become infected by the first-infected farm of the compartment (cumulative probability during the entire infectious period of the source farm). As explained above, this probability is a worst-case estimate, calculated when assuming identical biosecurity measures as during the 2003 HPAI epidemic in The Netherlands.

The between-farm transmission probability p_c of 0.59 is mainly due to the allowed contact events between compartment farms; the contribution of neighbourhood transmission is much smaller. For this reason the approximation of equation 7 applies. With p_c = 0.59 and N_c=5 farms with live chicken for the VPI compartment, the increase in the between-farm reproduction number of the each of the compartment farms is $\Delta R_{0,m} = 2.36$.

If the same VPI farms were not part of a poultry compartment, so when certain between-farm contacts of Table 1 are prohibited during an HPAI epidemic, the $R_{0,m}$ would be close to 0.05 for each of the VPI farms.

Transmission risk for a compartment including chicken transport

Now we consider a fictitious compartment of the same size and contact frequencies as VPI, but with an additional contact of 1 animal transport per month between two arbitrary farms within the compartment. This transport frequency of live chicken was chosen to reflect transport from rearing layer farms to layer farms, and leads to a frequency of 1 per 120 days that a farm will have contact with all other 4 farms. This yields a value of p_c = 0.62, based on using Equation 4 with parameter values of Table 1 with a contact rate by animal transport of 1/120 instead of 0. With N_c=5 for the size of the compartment we obtain $\Delta R_{0,m} = 2.48$, again using Equation 7. This risk difference is not very different from that calculated for the VPI compartment, because of the relatively low frequency of contact by animal transport compared to that of the other contacts of Table 1.

Risk of jumps of HPAI between areas via the VPI compartment

(no compartment farm in GV, egg transport and no animal transport in compartment)

As explained in the Material and Methods, the risk of jumps of HPAI from one area to another, due to the compartment, was evaluated by calculating the probability of jumps caused by 'single-event' transmission, that of jumps caused by 'triple-event' transmission via farms of the compartment, and the ratio between these probabilities. In Table 2 the results for the case of VPI are given. The ratio quantifies how much the 'triple-event' transmission contributes relatively to the 'single-event' transmission. If this ratio is small, than the contribution of 'triple-event' transmission can be neglected. If this ratio is of the order of 1 or higher, the contribution of 'triple-event' transmission is about the same as that of the 'single-event' transmission.

Table 2. The mean ratio of 'triple-event' transmission via the compartment and 'single-event' transmission by neighbourhood transmission, with the 5%-95% interval given between brackets. The range (min-max) of the probability for 'single-event' transmission and for 'triple-event' transmission are added.

Quantity	**Value (5%-95% interval)**
Ratio	0.0015 (0.0013 - 0.0017)
'Single-event' transmission probability	$1.2\ 10^{-6}$ - $1.6\ 10^{-5}$
'Triple-event' transmission probability	$3.6\ 10^{-10}$ - $5.1\ 10^{-8}$

As shown in Table 2, the 'triple-event' transmission via farms of the VPI compartment is 0.0015 times smaller than the 'single-event' transmission from a non-compartment farm in the Gelderse Vallei (GV) to a non-compartment farm outside the GV. Furthermore, this is a worst-case scenario, because biosecurity measures 'additional to the 2003 average' executed by VPI in the compartment were ignored in this analysis. In reality, this ratio will thus be even smaller.

Risk of jumps of HPAI between areas via a 'VPI-like' compartment in GV

(one compartment farm in GV, egg transport and no animal transport in compartment)

The risk of jumps was also evaluated for a fictitious compartment of the same size and contact frequencies as VPI, but with farms located in the GV as depicted in Figure 3b. The results for these jump probabilities are listed in Table 3.

Table 3. The mean ratio of 'triple-event' transmission via the compartment and 'single-event' transmission by neighbourhood transmission, with the 5%-95% interval given between brackets. The range (min-max) of the probability for 'single-event' transmission and for 'triple-event' transmission are added.

Quantity	**Value (5%-95% interval)**
Ratio	0.57 (0.46 - 0.69)
'Single-event' transmission probability	$1.1\ 10^{-6}$ – 0.01
'Triple-event' transmission probability	$1.2\ 10^{-7}$ - $8.9\ 10^{-5}$

In this case the 'triple-event' transmission via farms of the fictitious compartment adds about 50% (ratio of 0.57) to the risk caused by the 'single-event' transmission from a compartment farm now located in the GV to a non-compartment farm outside the GV. Thus, when one farm of the compartment is located in the GV, the ratio is much higher, so jumps of HPAI via the compartment farms becomes much more important.

Risk of jumps of HPAI between areas via a compartment in GV

(one compartment farm in GV, egg transport and animal transport in compartment)

Now we consider a fictitious compartment of the same size and contact frequencies as VPI, with farms in the GV and with transport of animals (chicken) and eggs. The frequency is again 1 animal transport contact per month between two arbitrary farms within the compartment, leading to a frequency of 1 per 120 days that a farm will have contact with all other 4 farms. In this case we find p_c = 0.61, and the jump probabilities are listed in Table 4.

Table 4. The mean ratio of 'triple-event' transmission via the compartment and 'single-event' transmission by neighbourhood transmission, with the 5%-95% interval given between brackets. The range (min-max) of the probability for 'single-event' transmission and for 'triple-event' transmission are added.

Ratio	0.62 (0.46 - 0.78)
Single-event transmission probability	$1.1\ 10^{-6}$ – 0.002
Triple-event probability	$1.2\ 10^{-7}$ - $1.2\ 10^{-4}$

The 'triple-event' transmission via farms of this fictitious compartment again adds about 50% (ratio of 0.62) to the risk caused by the 'single-event' transmission from a compartment farm now located in the GV to a non-compartment farm outside the GV. In other words, the total transmission probability of a jump from one area to another is increased with about 50% compared to that of the 'always occurring background' single-event transmission. When one farm of the compartment is located in the GV, and transport of live chicken occurs within the compartment, the ratio is similar as above in Table 3. Thus, the *location* of the compartment farm (whether or not in the GV) is most important, and not the transport of live chicken compared to that of eggs, due to its lower transport frequency.

Sensitivity analysis of biosecurity measures carried out by VPI

Table 5 shows the reduction in reproduction number $R_{0,m}$ of the VPI compartment farms, when the transmission probability of a specific transmission pathway within the compartment was reduced with 10, 50, 90%, due to biosecurity measures executed by VPI. When transmission of HPAI by egg transports can be reduced with 90% (i.e. a factor 10 reduction) by biosecurity measures such as disinfection of trucks and egg trays, the reproduction number $R_{0,m}$ will be reduced with 54%. With such a biosecurity improvement, corresponding to much better biosecurity than in 2003, the reproduction number is reduced to a value of 1.1, still leaving it at a much higher value than the value of 0.05 for a non-compartment farm at the same location. We note that even in the fictitious case of 100% biosecurity for the egg transports, the reproduction number remains much larger than 0.05, namely 0.9, if the biosecurity improvement is applied to the egg transports only. According to Table 5, egg transports are the most important pathway of HPAI transmission among farms within the compartment, due to its high transmission probability and high transport frequency (see Table 1). Focussing biosecurity measures on one contact type does only lead to a partial reduction of $R_{0,m}$.

Table 5. Relative reduction (in %) of reproduction number $R_{0,m}$ of the VPI compartment farms as function of the reduction in transmission probability (10, 50, 90%) of a specific route, due to biosecurity measures within the compartment.

Type of Contact	**10%**	**50%**	**90%**
Egg transport	4.6	26	54
Professional contact	0.9	4.4	8.1
Rendering Contact	0.4	2.2	4.0
Feed delivery	0.3	1.5	2.7

Figure 5 shows the reduction in reproduction number $R_{0,m}$ of the VPI compartment farms, when *all* transmission probabilities of the contact types of Table 1 were reduced with a certain percentage, due to improvement of biosecurity measures within the compartment. A biosecurity improvement of 0% represents the biosecurity status of poultry farms during the HPAI epidemic in The Netherlands in 2003. To reach an $R_{0,m}$ for the compartment farms twice as large as that for the non-compartment farms (0.10, thus in the same order of magnitude), a biosecurity improvement of 98% is needed for all contact types, corresponding to a factor 50 reduction by biosecurity measures like disinfection.

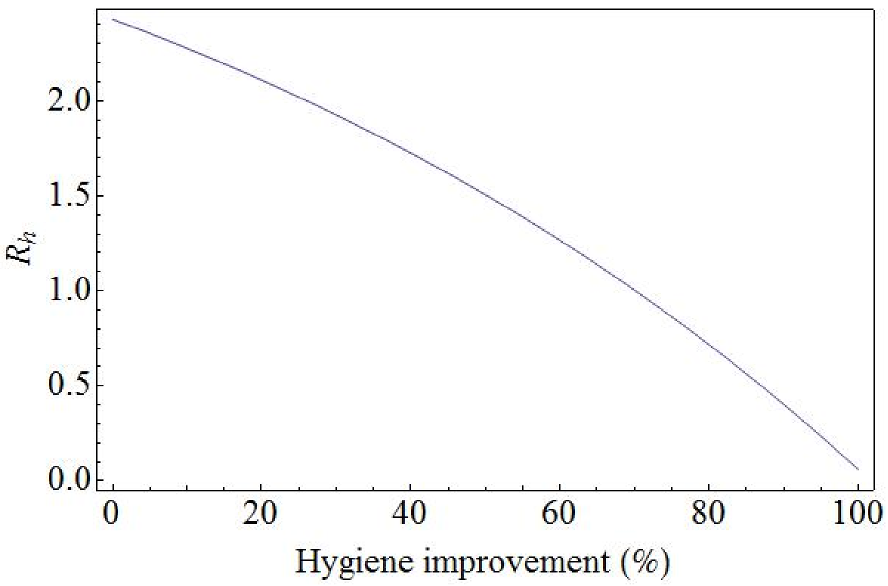

Figure 5. Reproduction number $R_{0,m}$ of VPI compartment farms, when *all* transmission probabilities of the contact types of Table 1 are reduced with a certain percentage, due to improvement of biosecurity measures within the compartment. A biosecurity improvement of 0% represents the biosecurity status of poultry farms during the HPAI epidemic in The Netherlands in 2003. A biosecurity improvement of 100% is a purely fictitious scenario of perfect biosecurity leading to zero risk.

Effect of distance of a compartment to the Gelderse Vallei (GV)

Figure 6 shows the ratio between 'triple-event' transmission via the compartment and the 'single-event' transmission, as function of the distance of a compartment farm to the nearest farm in the Gelderse Vallei (a densely populated poultry farm area). As already explained above, this ratio quantifies how much the 'triple-event' transmission contributes relatively to the 'single-event' transmission always occurring during standstill. If this ratio is small then the contribution of 'triple-event' transmission via compartment farms can be neglected. Figure 6 shows that if one of the compartment farms is located in or close to the Gelderse Vallei, the risk of HPAI transmission jumps via the compartment cannot be neglected anymore. It increases about tenfold when the distance to the Gelderse Vallei is reduced from 40 km to 0 km, reaching a value that is 1.5-1.6 times larger than the jump risk in absence of a compartment in the country. The mean ratio for the VPI compartment was 0.0015 (see Table 2), and this low value is due to the large distance of approximately 60 km of VPI to the Gelderse Vallei.

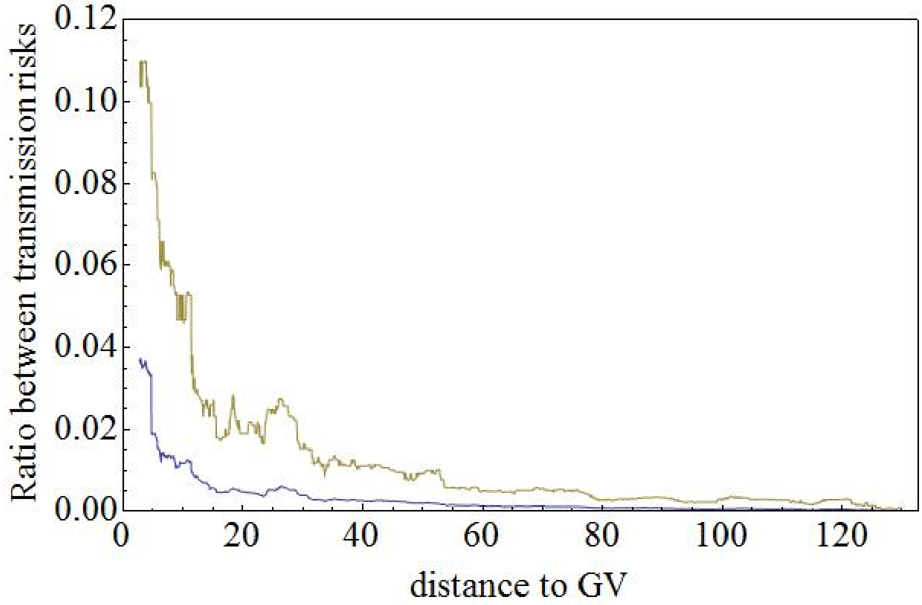

Figure 6. Ratio between ‘triple-event’ transmission via the compartment and ‘single-event’ transmission, as function of the distance of the compartment farm to the nearest farm in the Gelderse Vallei (a densely populated poultry farm area). Shown is a rolling average plot calculated with a window of {-2.5 km, 2.5 km}, based on a set of 10.000 pairs {distance, ratio} (see Material & Methods). The rolling average of the mean (blue line) 95% percentile (green line) are presented. The 5% percentile is equal to 0 throughout.

Effect of compartment size (number of farms)

According to Equation 7, the reproduction number $R_{0,m}$ of compartment farms increases linearly with the number of farms N_c (housing live chicken) in that compartment. This relationship only holds when all farms in the compartment have random contacts with each other, which implies that the number of contacts of a particular farm with other farms must increase likewise with increasing compartment size. The latter means that the same truck for egg transports (and for the other transports) visits all farms of the compartment, thus ‘connecting’ all farms within the compartment. When this is the case, the risk for the compartment farms ($R_{0,m}$) increases proportionally with increasing compartment size. However, this increase in risk could be avoided by introducing separate networks within the poultry compartment: for example when comparing a compartment size of 10 to that of 5 by using two trucks for egg transport, thus connecting only half of the farms by one truck and the other half of the farms by the other truck. For each of these specific situations, the generic model developed in this study can be adapted and used to evaluate the corresponding risks.

Discussion and conclusions

Epidemiological consequences of poultry compartments during an HPAI epidemic

The advantage of the presence of a poultry compartment is that it facilitates trade and business continued during a HPAI epidemic, but the disadvantage is that it may promote certain risks of between-farm transmission of HPAI; risks that are relevant when HPAI is introduced into the country. In this study we evaluated two such risks, comparing the situations with and without presence of a compartment in the country: (1) the local HPAI transmission risk from farms within the compartment, and (2) the risk of a 'jump' of HPAI via the compartment between different areas in the country. These risks were quantified using a worst-case assumption for the effectiveness of biosecurity measures, namely taken equal to that achieved during the HPAI epidemic in The Netherlands in 2003. Additional biosecurity possibly achieved by carrying out additional measures (see Appendix I for Verbeek Poultry International, VPI) had to be ignored in the calculation, because the effect of individual measures on virus transmission in practice has never been quantified. Instead, the effect of hypothetical improvements in biosecurity as compared to the 2003 reference was evaluated in a sensitivity analysis.

Firstly, the potential transmission rate of HPAI within the VPI poultry compartment was quantified. Under the assumed worst-case effectiveness of biosecurity measures, the combined risk of egg transport, feed delivery, professional contact and rendering contact among the VPI farms leads to a transmission probability (cumulative over the entire infectious period of the infected farm) to any given other farm in the compartment of approximately 0.6. So when HPAI were introduced in one of the farms of the VPI compartment, the probability of infecting any given other farms of the compartment would be high. The resulting between-farm reproduction number $R_{0,m}$ of the VPI farms increases with a factor 50 from 0.05 (when not part of a poultry compartment) to 2.4 (when part of a poultry compartment). The relatively high transmission risk within the VPI compartment arises as a result of the closed contact structure designed to keep HPAI introduction risks from outside the compartment as low as possible.

So the risk of the presence of a poultry compartment in the country is situated in the compartment itself. This implies that if one compartment farm is suspected of being infected with HPAI, all other farms of the compartment must be considered as dangerous contact farms. This finding supports the rationale of VPI policy to remove a compartment farm from the compartment as soon as it becomes part of a surveillance zone (10 km ring) around a detected non-compartment farm. A strategy deemed sensible when a compartment farm is located more than 10 km from a new HPAI outbreak (so not in the surveillance zone), is to visit this farm as last in the sequence of feed, rendering, and professional contacts.

Secondly, the risk of jumps of HPAI from one area via a poultry compartment to another area in the country was quantified. This risk was negligible for VPI. The reason for this low risk is the long distance of approximately 60 km between the VPI farms and the closest densely populated poultry livestock area (DPPA), which is the Gelderse Vallei in The Netherlands.

For the scenario where animal (live chicken) transport would take place within an otherwise VPI-like compartment, this risk remained negligible, due to the low frequency of chicken transport compared to that of eggs. If one of the compartment farms is located in or close to the Gelderse Vallei, the risk of HPAI transmission jumps via the compartment cannot be neglected anymore. It increases about tenfold when the distance to the Gelderse Vallei is reduced from 40 km to 0 km, reaching a value that is 1.5-1.6 times larger than the jump risk in absence of a compartment in the country.

Focussing the biosecurity measures within VPI on the transport of eggs yields the strongest reduction of the between-farm reproduction ratio $R_{0,m}$ of the VPI farms. This is due to the high frequency of these transports in VPI. But even when HPAI transmission by egg transports was fully blocked by biosecurity measures, the $R_{0,m}$ of the VPI farms is reduced by 63% to a value of 0.9, still much higher than the mean $R_{0,m}$ of farms in the same locations not being part of a compartment (0.05). Thus, in order to reduce risks further, the biosecurity measures must be aimed at *all* contact possibilities together between farms within VPI, like egg transports, feed delivery, professional contacts and rendering contacts. Even then, in order to reach an $R_{0,m}$ for the compartment farms in the same order of magnitude as when not in a compartment, a biosecurity improvement of 98% is needed. Thus, a factor 50 of risk reduction compared to the 2003 crisis biosecurity level would need to be achieved by the biosecurity measures executed by VPI in the compartment.

The closed contact structure of the VPI compartment is an aspect that deserves close scrutiny. As a consequence of this contact structure, each farm within the compartment has frequent (indirect) contact to all of the other farms, yielding ample HPAI transmission possibilities. The importance of strict biosecurity measures applied to vehicles and professionals going from one compartment farm to the next has been confirmed in this study. Also, any options for reducing the number of connections in the contact network deserves to be scrutinized. One strategy could be to aligning all regular transport and visitor routes as much as possible to one fixed route along the compartments farms. Another strategy of interest is to set transport routes such that farms located closest to high-risk areas are visited last on the day.

The reproduction ratio $R_{0,m}$ of the VPI farms is linearly proportional to the number of farms within the compartment. This means that for a larger compartment the within-compartment transmission risk will be proportionally larger. This risk could be reduced by introducing separate networks within the poultry compartment: for example when comparing a compartment size of 10 to that of 5 by using two trucks for egg transport, thus connecting only half of the farms by one truck and the other half of the farms by the other truck. For each of these specific situations, the generic model developed in this study can be adapted and used to evaluate the corresponding risks.

In this study a generic mathematical model was developed, describing HPAI transmission risks between poultry farms in The Netherlands, of which certain specific farms belong to a poultry compartment. Two risks were quantified: (1) the local HPAI transmission risk from farms within the compartment, and (2) the risk of a ‘jump’ of HPAI via the compartment to other (free) zones in the country. These risks were now quantified for the poultry compartment VPI, but the generic model can be adapted for any compartment in the future.

Socio-economic consequences of poultry compartments during an epidemic

A distinguishing feature of a poultry compartment is that during an epidemic their farms, in an infected area (but for VPI outside the 10 km surveillance zones), can continue with business as usual, provided that none of the compartment farms becomes infected. In contrast, other farms in an infected area are confronted with stringent movement restrictions. This study has shown that the additional transmission risk caused by a compartment is mainly borne by the compartment farms themselves, and other farms are not more exposed, provided that the compartment farms are all located sufficiently far away from DPPA. If one or more compartment farms are located in or close to a densely populated poultry livestock area (DPPA), the compartment will substantially increase the probability of a jump of HPAI from a DPPA to another region. If such a jump causes the newly infected area to be subjected to export restrictions it will thereby severely affect all non-compartment farms in the newly infected region.

Decision criteria for granting compartment status to applicants

From this study a number of strategies emerge for limiting transmission risks associated with compartments, other than the obviously important strategy of applying stringent biosecurity measures to all contact events. These strategies could be considered as or translated into requirements on compartments, i.e. used as criteria that should be met by applicants in order to obtain compartment status. These strategies are as follows:

- Avoiding the inclusion in a compartment of farms located in or close to a densely populated livestock area;
- Aligning all regular transport and visitor routes as much as possible to one fixed route (physically) along the compartments farms;
- Setting the transport/visitor route(s) such that compartment farms located closest to high-risk areas are visited last on the day.

Regarding strategies during an HPAI epidemic, the analysis supports the rationale of VPI policy to remove a compartment farm from the compartment as soon as it becomes part of a surveillance zone (10 km ring) around a detected non-compartment farm. A strategy deemed sensible when a compartment farm is located more than 10 km from a new HPAI outbreak (so not in the surveillance zone), is to visit this farm as last in the sequence of feed, rendering, and professional contacts.

Acknowledgements

The work described in this report is part of project BO-08-010-011 Maatschappelijk aanvaardbare dierziekten bestrijding (MAD), financed by the Dutch Ministry of Economic affairs (EZ). The method and progress of the project was discussed with Annemarie Bouma and Jeroen Bonet of the Ministry of Economic affairs (EZ), with Martine Laurijssens and Harry Rozendaal of the Netherlands Food and Consumer Product Safety Authority (NVWA), and with Marcel Berendsen of Verbeek Poultry International. Guus Koch (CVI), Annemarie Bouma, Martine Laurijssens and Marcel Berendsen are acknowledged for critically reading the manuscript.

Literature

Anon. 2004. Dierziektebeleid met draagvlak. Advies over de bestrijding van zeer besmettelijke dierziekten. Deel 2 – Onderbouwing van het advies. Gezamenlijke uitgave van de Raad voor het Landelijk Gebied en de Raad voor Dier-Aangelegenheden. Publicatie RLG 03/8, en RDA 2004/01, Januari 2004, 88 pp. [In Dutch]

Anon. 2007. Beleidsdraaiboek Aviaire Influenza. Contingency plan from Ministry of Agriculture, Nature and Food Quality, v. 1.0., 226 pp. [In Dutch]

Boender, G.J., T.J. Hagenaars, A. Bouma, G. Nodelijk, A.R.W. Elbers, M.C.M. de Jong, and M. van Boven, 2007. Risk maps for the spread of highly pathogenic avian influenza in poultry. PLoS Comput Biol 3, e71 (2007).

Kandun IN, Samaan G, Harun S, Purba WH, Sariwati E, 2010. Chicken Faeces Garden Fertilizer: Possible Source of Human Avian Influenza H5N1 Infection. Zoonoses and Public Health 57: 285-290.

PVV, 2013. Vee, vlees en eieren in Nederland; kengetallen 2012; http://www.mijnpve.nl /wdocs/dbedrijfsnet/up1/ZkfdylwII_432680PVEpromoNL_LR_definitief.pdf

Ssematimba, A., A.R.W. Elbers, T.J. Hagenaars, M.C.M. de Jong, 2012. Estimating the per-contact probability of infection by highly pathogenic avian influenza (H7N7) virus during the 2003 epidemic in the Netherlands. PLoS ONE 7(7): e40929. doi:10.1371/journal.pone.0040929

Appendix 1. Biosecurity maatregelen in het compartiment VPI

- Bezoekers / begeleiding wisselen schoeisel en desinfecteren handen op de oprit van het bedrijf (specifieke parkeerplaats)
- Pluimveehouder / begeleiding / bezoekers douchen voor betreden van het bedrijf en bij het verlaten van het bedrijf.
- Na de in douche complete kledingwissel, sieraden en telefoons blijven in kleedruimte.
- Voor het betreden van de stal / afdeling (daar waar dieren zitten) nogmaals een wissel van schoenen en handen desinfecteren met alcoholhoudende gel.
- Voerleverancier: levering start op maandag met een auto die sinds de vrijdag niet meer op pluimveebedrijven komt en voor aanvang van de leveringen gereinigd/ gedesinfecteerd is, daarnaast automatische wielkastontsmetting en dragen een schone wegwerpoverall.
- Op de voerbon wordt aangegeven dat de auto is gereinigd en gedesinfecteerd voor aanvang van de rit.
- De chauffeur maakt gebruik van de bedrijfseigen zuigslang om het voer in de silo's te blazen.
- Voor opzet worden voldoende gebruiksmaterialen (luzerne, grit, etc) binnen gebracht en vervolgens gedesinfecteerd.
- Al het andere externe vervoer dat op het bedrijfsterrein komt, bv mestwagens, moeten aantonen dat zijn gereinigd en gedesinfecteerd zijn.
- Verzamelde 1ste soort eieren worden geplaatst op gereinigde/gedesinfecteerde trays, daarnaast worden deze eieren 1x op het bedrijf gedesinfecteerd.
- De 2de soort eieren is een aparte stroom, maar gaan wel mee met het 1-op-1 transport (zie verder).
- Eiertransport vindt 1-op-1 plaats, de specifieke chauffeur komt allen in de eieropslag, trekt schone bedrijfskleding en schoenen aan, en handen worden gedesinfecteerd. Na afleveren van de eieren op de broederij wordt de binnenkant van de vrachtauto (laadgedeelte) opnieuw gereinigd/gedesinfecteerd.
- De gebruikte eiertrays worden gereinigd en gedesinfecteerd om vervolgens weer naar de bedrijven te gaan.
- De uiteindelijke bebroede eieren gaan op andere trays, die nooit op pluimveebedrijven komen, om naar de klant te vervoeren.
- Op diernivo een all in – all out principe, na afvoer van de dieren volledige schoonmaak en desinfecteren. In deze stand-still vindt ook het onderhoud plaats.
- Specifieke Rendac route, kadavers verzamelen in de vriezer, na 4 weken afvoeren, dieren worden dan bevroren in een kliko + papierenzak gedaan, vooraan de weg gezet en vervolgens door de Rendac opgehaald, kliko's gereinigd/gedesinfecteerd.