# THEORETICAL BASIS FOR THE REDUCTION OF THE RISK OF FARM-TO-FARM TRANSMISSION

De Jong M.C.M.[1], Diekmann O.[2], Metz J.A.J.[3]

*Afin de discuter et quantifier l'effet de différentes mesures de lutte contre la transmission des agents infectieux, il est important de comprendre comment ces mesures agissent sur la transmission. Par exemple, l'effet de la réduction du nombre d'élevages qui serait en contact avec un certain élevage sur la transmission n'est pas très clair. Pour réduire la transmission, il faut diminuer aussi bien la moyenne du nombre de contacts avec les fermes que sa variance. Des effets importants sur la transmission sont observés lorsque le nombre de contacts est faible (moins de 4-5).*

## INTRODUCTION

A theory for the population dynamics of infectious diseases in farmed animals is of great importance both for the fight against outbreaks of some of these diseases as in attempts to eradicate others. This is the case because discussions on which control measures to choose so that particular targets will be achieved can be hampered by lack of insight on what the effect of particular control measures is. Theory is then needed to clarify the discussion and to allow quantifying of the effect of control measures from observational and experimental data. For example in another paper (De Jong & Kroese, 1997) presented at this meeting we describe how effects of certain control measures like vaccination can be quantified in laboratory experiments.

The first step towards a theoretical framework is to distinguish the factors that influence transmission of infectious agents. These are (after Koopman & Longini, 1994): (1) susceptibility of not-infected individuals, (2) infectivity of the infected individuals, (3) the quantity and quality of agent transferred by the different routes of transmission, (4) the number of contacts per unit of time (for the different routes), and (5) the number of different individuals with which there is contact (for the different routes). Vaccination for example influences 1 and 2 and its effect can be measured under conditions where the other factors that influence transmission are not changed. The influence of changes in the floor of the housing on transmission is an example of 3.

The last factor mentioned, i.e. the number of different individuals with which there is contact is often less readily understood. In veterinary epidemiology this factor is important to understand the transmission between farms. In outbreaks of infections like Classical Swine fever it is often clear that the large number of trade contacts that some farms have is of great consequence to the spread of the infection. Limitations to the number of trade contacts are often suggested as a measure to reduce transmission. Here we study with the use of mathematical models how such measures have their effect on transmission between farms. Note that the total number of animals that are moved from one farm to another is not necessarily changed but only the number of different farms is changed.

For reasons explained before (Diekmann et al., 1990, De Jong & Diekmann, 1991, De Jong, 1995) it is importnat to know how the changes in number of contacts influences the reproduction ratio R which is the average number of secondary cases caused by a typical infectious individual. In short: when R<1 the infection will fail to spread massively when introduced and the infection will go extinct when R become less than one during the time that the infection is present in the population.

## MODELLING

Assume that the contacts between farms do not change in time and that farms have k contacts where k can have a different value for each farm (k=1,2,3,4 ... etc.). Note that only farms with one or more contacts can play a role in a chain of infections. Assume that the fraction of farms with k contact-farms is $m_k$ ($Sm_k$=1). Furthermore, assume that each time a farm is infected the contact-farm will become infected with probability q (0£q<1). Also assume that contacts between farms are at random with respect to number of contact-farms.

The derivation of R is now as follows. First of all note that for a random farm the number of contact-farms equals:

$$\nu_k = \frac{k\mu_k}{\bar{k}}$$

Where $\bar{k}$ is the average number of contact-farms ( $\sum_{k=1}^{\infty} k\mu_k$ )

[1] ID-DLO, Epidemiology, Statistics & Modelling group, Dept. Pathobiology & Epidemiology, P.O. Box 65, 8200AB Lelystad, The Netherlands, [2] Dept. of Mathematics, University Utrecht, The Netherlands, [3] Dept. Theor.Biol. Univ. Leiden, The Netherlands.

Hence, the average number of cases caused by a typical infected individual (R) equals:

$$R=q\sum_{k=1}^{\infty}(k-1)v_k$$

From which it follows that:

$$R=q(\frac{var(k)}{\bar{k}}+\bar{k}-1)=q(c.v.+\bar{k}-1)$$

In Fig. 1 and Fig.2 the critical value of q is shown for which R=1 for two different values of coefficient of variation (c.v.): for c.v. equals zero and for c.v. equals one.

**Figure 1**
**The probability of infection upon contact for given average number of contact farms for which R=1 (here for c.v. = 0). Below the indicated line R<1**

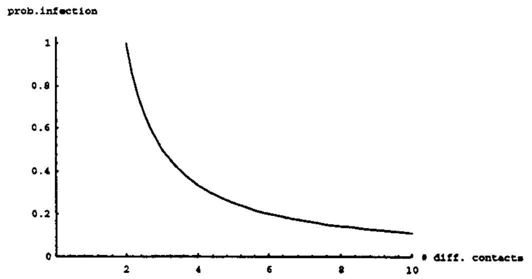
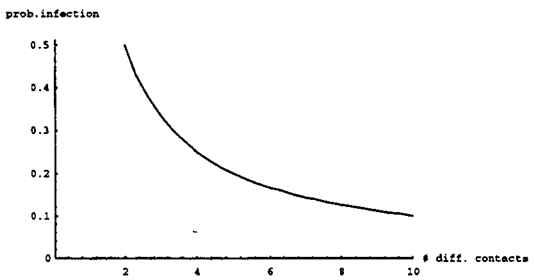



**Figure 2**
**The probability of infection upon contact for given average number of contact farms for which R=1 (herefor c.v. = 1). Below the indicated line R<1**




## CONCLUSIONS AND DISCUSSION

If the contacts of farms are with a limited number of different contact-farms contacts that lead to transmission of the infection are lost because: (1) each contact farm can only be infected once (q<1), (2) a farm that becomes infected has one contact-farm that was already infected and thus contact with that farm is a loss for the transmission of the agent. The example of all farms having exactly two contact-farms is illustrative in this respect: in that case R is always below one because there is only one contact-farm that can be infected and this contact=farm will be infected with probability q thus R=q and therefore R is always less than one.

From the formula for R it follows that R does not only depend on the average number of contact-farms but also on the variance. The value of R is minimal for minimal variance. In other words the farms with higher number of contact-farms have a disproportional influence on the transmission between farms. This is the case because these farms are more likely to become infected and are more likely to pass the infection on to other farms.

Hence, there are two implications to measures that aim to reduce contacts between farms: (1) also the variance in number of contact-farms should be reduced and in addition from numerical exploration of the formula for R it follows that (2) greatest impact of such measures is to be expected when k's are small (less than 4-5).

## REFERENCES

De Jong, M.C.M. and Diekmann, O., (1992) A method to calculate -- for computer-simulated infections the threshold value $R_0$, that predicts whether or not the infection will spread. Prev. Vet. Med., 12:269-285.

De Jong, M.C.M., (1995) Mathematical modelling in veterinary epidemiology: why model-building is important. Prev.Vet.Med., 25:183-194

Diekmann, O.Heesterbeek,J.A.P.,Metz,J.A.J.,(1990) On the definition and the computation of the basic reproduction ratio $R_0$ in models for infectious diseases in heterogeneous populations J.Math.Biol., 28:365-382

Koopman, J.S., and Longini Jr., I.M., (1994) The ecological effects of individual exposure and nonlinear disease dynamics in population. Am.J.Public Health, 84:836-842.