Spatial and stochastic modelling of emergency vaccination strategies for the Dutch 97/98 Classical Swine Fever epidemic

Mangen M.-J.J.[a*], *M. Nielen*[a], *A.W. Jalvingh*[a], *M. Mourits*[a]

[a] *Farm Management Group, Department of Social Sciences, Wageningen University, Hollandseweg 1, 6706 KN Wageningen, The Netherlands.*

Abstract

Two alternative emergency-vaccination strategies with a marker vaccine that could have been applied in the 1997/98 Dutch Classical Swine Fever (CSF) epidemic were evaluated in a modified spatial, temporal and stochastic simulation model, InterCSF. In strategy 1, vaccination would only be applied to overcome a shortage in destruction capacities. Destruction of all pigs on vaccinated farms distinguishes this strategy from strategy 2, which assumes intra-community trade of vaccinated pig meat.

InterCSF simulates the spread of CSF between farms through local spread and 3 contact types. Disease spread is affected by control measures implemented through different mechanisms. Economic results were generated by a separate model that calculated the direct costs (including the vaccination costs) and consequential losses for farmers and related industries subjected to control measures. The comparison (using epidemiological and economic results) between the different emergency-vaccination strategies with an earlier simulated preventive-slaughter scenario led to some general conclusions on the Dutch CSF-epidemic. Both emergency-vaccination strategies were hardly more efficient than the non-vaccination scenario. The intra-community trade strategy (vaccination strategy 2) was the least costly of all three scenarios.

Keywords: Classical Swine Fever; Pig-microbiological disease; Simulation model; Disease control; Emergency vaccination; Economics

1. Introduction

Outbreaks of animal disease such as classical swine fever (CSF) may have severe consequences on the national economy and ask for adequate and immediate response. Preventive vaccination is forbidden in the EU and emergency vaccination is only allowed if all other measures to eradicate CSF failed. However, with the imminent introduction of a marker vaccine, offering the possibility to serologically distinguish infected from vaccinated pigs, emergency vaccination is discussed again as a possible supplementary control measure.

We improved the simulation model InterCSF, which was developed to simulate the 1997/98 Dutch CSF epidemic, (Jalvingh et al., 1999) by adding emergency-vaccination as a disease-control mechanism. InterCSF specifically was developed to answer "what-if" questions (Nielen et al., 1999). Vaccination costs were incorporated in EpiLoss (Meuwissen et al., 1999) for the present study, to be able to calculate the direct costs and consequential losses for farmers and related industries subjected to control measures.

The main goal of this paper was to analyse the epidemiological and economic consequences of two possible emergency-vaccination campaigns that could have been used in the Dutch CSF 1997-98 epidemic. They are compared with an earlier simulated preventive-slaughter strategy (Nielen et al. 1999), which we will call (in this paper) the "non-vaccination" (NV) scenario.

* Corresponding author: Tel: *31-317-484065; Fax: *31-317-482745;
E-mail-address: Marie-Josee.Mangen@alg.abe.wag-ur.nl

2. Material and Methods

2.1 General outline

InterCSF is a spatial, temporal and stochastic simulation model (Jalvingh et al., 1999). InterCSF simulates disease spread from day to day from infected farms through 3 contact types (animals, vehicles, persons) and through local spread up to 1000 m. All Dutch pig farms are known by their geographical co-ordinates. The main disease-control mechanisms that influence the disease spread in InterCSF are: diagnosis of the infected farms, depopulation of infected farms, movement control areas, tracing and preventive slaughter (see Jalvingh et al. (1999) for more details). Emergency vaccination was incorporated in the base scenario such that it reflected the start situation of the real epidemic as closely as possible (see Mangen et al. (2000) for further details).

2.2. Vaccination effects

Vaccination has two effects: reduction in virus spread of an infected farm and protection against infection of a susceptible herd.

For virus reduction on an infected farm, two kinds of infected farms were distinguished. The first category consisted of infected farms that were never vaccinated and of farms that were first infected and later vaccinated. The second category was farms that were vaccinated and became later infected.

For the first category of infected farms, we assumed no reduction in virus spread. All parameters remained as described in Jalvingh et al. (1999). In short, the infectious period started between 5 and 10 days after infection. The infectivity of the farm remained the same for the total infectious period, which ended on the day that the farm was depopulated. The interval between infection and detection was modelled with a single probability distribution, based on observations of the real Dutch CSF epidemic. The selected interval could be influenced downward by certain events (see Table 1). The detection probabilities of non-vaccinated farms were used as a base to estimate the detection probabilities for all vaccinated farms (Table 1). Vaccination as such could also influence detection because infected farms could be detected earlier due to clinical inspection on the vaccination day. The detection probability depended on the time since infection and the source of infection (Table 2). For a direct animal contact we defined a higher probability of detection for the first weeks after infection than for all other contacts. If an infected farm was not detected during vaccination, we assumed that the virus was spread mechanically and massively over the farm during vaccination. After the incubation time of 1 week, the large number of sick animals could again lead to a possible earlier detection (Tielen; Personal communication). In both cases, we assumed that 2 days after suspicion, the diagnosis was established. For all other events, more time consuming tests are necessary; so, we defined 7 days after suspicion before diagnosis would be given (de Smit et al, 1999).

Table 1.
Probability of detection based on a control event (such as traced contacts, surveillance, preventive slaughter, end-screening and welfare slaughter) depending on the time since infection and the farm specific vaccination status in a movement-restricted zone.

Time since infection (days)	Probability of detection by control event (diagnosis date 7 days after event)														
	Traced contacts[a]			Surveillance (3 km radius)[a]			Preventive slaughter[a b]			End-screening[b]			Welfare slaughter[b]		
	NV[c]	IV[d]	VI[e]	NV[c]	IV[d]	VI[e]	NV[c]	IV[d]	VI[e]	NV[c]	IV[d]	VI[e]	NV[c]	IV[d]	VI[e]
0-14	0	.9	0	0	.9	0	0	.9	0	0	.9	0	0	.9	0
15-28	1	1	0	0	1	0	1	1	.5	.25	1	.5	0	1	.5
29-42	1	1	0	.25	1	0	1	1	1	.5	1	1	0	1	1
>42	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1

[a] Based mainly on clinical inspection.
[b] Based mainly on serology.
[c] NV: No vaccination; farm already has an (undetected) infection (Jalvingh et al., 1999).
[d] IV: Vaccination of a farm already infected (but not yet detected).
[e] VI: Vaccination of a farm which later becomes infected

Table 2.
Probability of detection due to vaccination, relative to the time since infection on an (undetected) infected farm and depending on the source of infection

Time between infection entrance and vaccination (days)	Probability of detection related to vaccination (diagnosis date 2 days later)		
	Vaccination day[a]	Vaccination day[b]	1 week after vaccination
0 – 14	0.25	0.05	0.9
15 – 28	0.9	0.5	0.95
29 – 42	0.99	0.9	1
> 42	0.99	0.99	1

[a] Farm infected by direct animal contact.
[b] Farm infected by transport or person contact.

For vaccinated farms infected after vaccination (the second category), a reduction in virus spread was expressed by a reduction factor. This reduction factor depended on the time interval between vaccination and infection and was modelled with a probability distribution, based on EU experiments (see Appendix in Mangen et al. (2000)). The reduction factor was multiplied by the probabilities of transmission for a simulated contact and for local spread.

For the farms in the second category, we assumed no change in the latent period but the infectious period was reduced to at most 1 month. Only small outbreaks typically are expected on vaccinated farms. Assuming that vaccinated pigs show no or few clinical signs when infected, detection could only be by serological screening (Table 1).

Susceptible farms also were classified in two categories: non-vaccinated and vaccinated farms. We defined a non-vaccinated susceptible farm as one without protection against a possible infection, whereas a vaccinated susceptible farm was partly protected. The degree of protection depended on the time interval between vaccination and a possible infection and was expressed as a protection factor, modelled by a probability distribution (See Appendix in Mangen et al. (2000)). Similar to the reduction factor, the protection factor was multiplied by the probabilities of transmission for a simulated contact and for local spread. However, if an infectious pig was moved to a susceptible vaccinated farm, the protection factor was not considered. We assumed that this farm always became infected but could hardly ever become infectious.

In the EU field experiments, horizontal transmission was significantly reduced 3 weeks after vaccination for both marker vaccines (Anonymous, 1999). In our base emergency-vaccination scenarios, we assumed that maximum protection and reduction was reached after 21 days. For sensitivity analysis (not shown in this paper), this time interval was reduced by 5 days to 16, as well as increased by 5 days to 26 days. In an additional analysis, only 1 week was assumed to be needed to build up the maximum protection level (simulating a live-virus vaccine).

2.3 Simulated emergency vaccination alternatives

Two emergency vaccination strategies were simulated, the delayed destruction strategy (DD) and the Intra-Community trade strategy (ICT). DD assumed no acceptation of vaccinated pig meat as fresh meat, the actual EU policy. Destruction of all vaccinated herds distinguished DD mainly from ICT, which assumed intra-community trade of vaccinated pig meat. For more details see Mangen et al. (2000).

2.4 Vaccination costs

To be able to compare the emergency vaccination alternatives with each other, both epidemiological and economic parameters were needed. A separate model (EpiLoss) using the output of the InterCSF model as input generated economic results. EpiLoss calculated the direct costs related to the specific events on pig farms (e.g. depopulation, welfare slaughter...) and the consequential economic losses suffered by the farmers and by the related industries, subjected to control measures. For details see (Meuwissen et al., 1999). Vaccination related costs were considered as a separate cost factor. Preparation costs travel costs and bio-security costs were estimated to be EUR 272 per farm visit of a vaccination team. The vaccine and the vaccination application costs were estimated to be EUR 3.10 per treated pig (EUR 2.27/vaccine and EUR 0.83/application). In the case of ICT, vaccination continued on sow farms until the movement restrictions were lifted. Extra costs to vaccinate breeding sows and newborn piglets were assumed to be EUR 0.19/farrowing place/day.

3. Simulation results and discussion

In earlier simulated non-vaccination strategies, see Nielen et al (1999), starting preventive slaughter on the first day of detection was the most effective scenario (Table 3). In the real epidemic preventive slaughter started only 2 months later.

Table 3.
Key features of the real and the simulated 97/98 Dutch CSF epidemic and of the preventive slaughter scenario, now called non-vaccination scenario (for more details see Jalvingh et al. (1999) and Nielen et al. (1999)).

Real epidemic or simulated scenario	Key features (median for simulations)			
	# Detected farms	# Preventively slaughtered farms	Duration of epidemic (days)	Costs $*10^6$ EUR
Real CSF epidemic	429	1247	>365	2124
Simulated CSF epidemic	374	743	306	1137
Non-vaccination scenario (NV)	70	450	164	590

Table 4.
Comparison of two emergency vaccination strategies for the Dutch 1997-98 CSF epidemic.

	Delayed destruction (DD)		Intra-community trade (ICT)	
	50 %	5% - 95 %	50 %	5% - 95 %
# Detected farms	58	48-92	68	57-133
# Preventively slaughtered farms	1177	1084-1930	-	-
Duration of epidemic (days)	108	99-177	258[a]	236-322
# Vaccinated farms	1038	958-1602	1135	1043-1961
Direct costs paid for ($*10^6$ EUR):				
Stamping out infected herds	7	5-10	10	8-15
Preventive slaughter	141	130-184	-	-
Welfare slaughter	169	157-250	290	253-423
Breeding prohibition	5	4-7	-	-
Costs of organisation	39	36-54	44	39-66
Consequential losses ($*10^6$ EUR)	201	185-276	138	123-206
Vaccination costs ($*10^6$ EUR)	3	3-4	5	5-8
Total ($*10^6$ EUR)	567	522-769	484	429-708

[a] The epidemic length was 138 days + 120 days extra (post-vaccination zone), see (2) for more details.

Both emergency vaccination strategies were as effective as NV, but the 95 percentile was less severe for DD and ICT (Table 4) than for NV (232 detected farms). DD was more effective than ICT or NV, as can be seen by the lower number of detected farms and the shorter duration of the epidemic, Tables 3 and 4. In case of ICT, no farm was preventively slaughtered. ICT was less costly than DD or NV. In case of DD, the costs for preventive slaughter and the consequential losses for farmers and related industries are higher than for ICT. The cost for welfare slaughter in DD is lower compared to ICT. In case of DD, all vaccinated farms had to be preventively slaughtered, leading to high preventive slaughter costs; but the reduced length of the epidemic and the increased number of empty farms were leading to low welfare slaughter costs. In case of ICT, extra costs for preventive slaughter were avoided; farms and related industries, subjected to control measures, could partly continue with their business, which reduced their consequential losses.

Assuming no extra costs or losses for the post-vaccination zone could lead to an underestimation of the calculated costs for the ICT strategy. Further we used average pig prices of 1997 for welfare slaughtering and assumed rational consumer behaviour. All three assumptions may be too optimistic and could lead to an under- or overestimation of the calculated costs and losses, depending on the market reactions and the consumer behaviour.

4. Conclusion

The comparison of different emergency vaccination alternatives may lead to some general conclusions on the Dutch 1997/98 CSF-epidemic. First of all vaccination costs are minor compared to all other costs and losses that occur during an epidemic. Both emergency vaccination strategies were at least as effective as the earlier simulated most effective non-vaccination strategy. Emergency vaccination seems to be a safety strategy, having less severe worst replications than earlier simulated non-vaccination scenarios. DD was more effective than ICT, but ICT was less costly than DD.

This paper could give us an idea what might have happened, if we would have applied emergency vaccination as an additional control measure in the specific 97/98 Dutch CSF epidemic. On the one hand, a highly densely populated pig area. On the other hand, 37 undetected infected farms on the day of the first detection.

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