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[1]Institut für Tierzucht und Tierhaltung der Christian-Albrechts-Universität zu Kiel, Germany
[2]Institut für Variationsstatistik der Christian-Albrechts-Universität zu Kiel, Germany
[3]Friedrich-Löffler Institut, Wusterhausen, Germany

SUSANNE KARSTEN[1], GERHARD RAVE[2], JÜRGEN TEUFFERT[3]
and JOACHIM KRIETER[1]

Evaluation of Measures for the Control of Classical Swine Fever Using a Simulation Model

Abstract

A stochastic and temporal simulation model has been developed to simulate the spread of classical swine fever among herds within a certain area due to farm contacts and local spread. Due to spatial as well as on-farm level heterogeneities in pig production the model allows for the importing of individual farm data. The control measures movement restrictions within protection and surveillance zones, pre-emptive slaughter in proximity to detected farms and animal contact tracing with subsequent culling, applied additionally to stamping-out infected farms, were compared in relation to their effect on the size and the duration of possible epidemics. Additionally, the effects of varying efficiency in contact tracing were analysed.

An area with 2986 pig farms and a density of 1.34 farms per km² was generated stochastically for the analysis. When stamping-out infected herds was applied as a single measure, 532 farms became infected on average. The additional application of restriction zones led to a mean epidemic size of 8 infected farms. When all control measures were applied, 5 outbreaks occurred on average. However, the high number of herds depopulated in total curtailed the relative priority of this control strategy. Thus, the presented results point out the necessity to weigh up the advantages and disadvantages in the determination of the optimal control strategy. The simulation model is shown to be a good method to assess the possible consequences of different control measures. The control measures laid down in the EU Council Directive 2001/89/EC (stamping-out infected herds, contact tracing and implementation of restriction zones) seemed to be sufficient for the eradication of classical swine fever epidemics in a region of such farm density. A further reduction in the mean number of outbreaks could be observed when tracing efficiency increased and animal contacts were traced more quickly.

Key Words: classical swine fever, simulation model, epidemic, control, tracing

Zusammenfassung

Titel der Arbeit: **Vergleich verschiedener Bekämpfungsmaßnahmen gegen die Klassische Schweinepest mit einem Simulationsmodell**

In der vorliegenden Studie wurde ein Simulationsmodell für die Ausbreitung des Klassischen Schweinepest-Virus entwickelt. Die räumlichen Ausbreitungsmechanismen des Virus und die sehr heterogenen räumlichen Strukturen setzten die Berücksichtigung von einzelbetrieblichen Daten voraus. Die folgenden Bekämpfungsstrategien wurden verglichen: Keulung aller infizierten Betriebe, Bewegungsrestriktionen innerhalb der Sperr- und Beobachtungszonen sowie präventive Keulung von Kontaktbetrieben und im direkten Umkreis um einen Seuchenherd. Zusätzlich wurde die benötigte Zeit für die Kontaktrückverfolgung variiert. Die unterschiedlichen Bekämpfungsstrategien wurden mit der mittleren Anzahl der gesperrten/gekeulten Betriebe und der mittleren Epidemiedauer bewertet. Die Ausbreitung der Schweinepest wurde für 2.986 Betriebe mit einer Dichte von 1,34 Betrieben je km² simuliert. Wurden nur die infizierten Betriebe gekeult, waren 532 Betriebe von der Tierseuche betroffen. Die Einrichtung von Restriktionszonen reduzierte die mittlere Zahl der infizierten Betriebe auf 8. Wurden alle Kontrollmaßnahmen durchgeführt, waren durchschnittlich 5 Betriebe infiziert. Die hohe Gesamtzahl an Betrieben, auf denen die Tiere getötet wurden, vermindert allerdings die relative Vorzüglichkeit dieser Variante. Eine weitere Abnahme der Zahl infizierter Betriebe wurde mit einer effizienteren Kontaktrückverfolgung erreicht. Die Ergebnisse verdeutlichen, dass die Vor- und Nachteile der verschiedenen Bekämpfungsstrategien gegeneinander abgewogen werden müssen. Hierfür ist die Simulationsstudie ein Mittel der Wahl. Die von der EU vorgesehenen Bekämpfungsmaßnahmen scheinen für die ausgewählte Region und Betriebsstruktur geeignet zu sein.

Schlüsselwörter: Klassische Schweinepest, Simulationsmodell, Epidemie, Bekämpfung, Kontaktrückverfolgung

1. Introduction

Contagious viral diseases such as classical swine fever (CSF) have posed a great threat for animal production for a long time, especially in countries with high animal density (FRITZEMEIER et al., 2000; MOENNIG, 2000). Economic losses are enormous when the epidemic gets out of control as shown in the 1997/98 epidemic in the Netherlands with 429 outbreaks. Direct and consequential losses on farms and related industries amounted to US $2.3 billion (MEUWISSEN et al., 1999). Increasing international trade and animal transport over long distances enlarge the risk of the virus spreading into hitherto free regions (MOENNIG, 2000). The most important routes of transmission of the CSF virus are the sale of living pigs, neighbourhood contacts and vehicles and persons that had visited an infected farm during its infectious period and subsequently visited a susceptible farm. Virus spread via artificial insemination is also possible but took place only during one epidemic (ELBERS et al., 1999). NISSEN and KRIETER (2003) established the relative importance of six risk factors for the spread of classical swine fever in a survey of experts. The highest impact was observed for animal trade.

Early identification of infected herds and the prevention of further spread are important to minimise the losses and maximise the effectiveness of control measures (ELBERS et al., 2001). By back-tracing contacts from where the virus may have originated and forward-tracing to where the virus might have spread, possibly infected herds may be detected as fast as possible.

Computer simulation represents a possibility to investigate risk factors such as the route of virus transmission and spatial structures. In the present study, a stochastic, temporal and spatial simulation program was developed to model the spread of CSF virus between farms within a certain region. Control strategies were evaluated with regard to the number of outbreaks and the number of farms affected by control measures. In the present study, the depopulation of infected farms and farms after animal contact as well as the culling and the restrictions of herds in the immediate vicinity of an infected herd were also applied. The influence of the speed of contact tracing on the epidemic pattern was evaluated as well.

2. Material and Methods

2.1. Simulation model

In the simulation model, the Monte Carlo method was applied, thus variation and uncertainty in the factors influencing virus spread were considered as probability distributions. Random numbers determined whether an event occurred, for example, how many contacts an infectious farm had that particular day. The results obtained after several simulation runs represented the range of possible epidemic patterns as well as the “mean epidemic” and the “worst case” under the given assumptions. A specific description of the model is given by KARSTEN and KRIETER (2005).

Virus spread was simulated on a daily basis. The farms in the data set were characterised by a unique farm-identifier, herd size and farm type, and the geographical position as GIS (Geographical Information System) co-ordinates. These data were stored in a database. Additionally, each farm was described by disease attributes such as disease state. First, all farms were in the state ‘susceptible’. The user defined a primary outbreak where virus spread started. The disease state of this farm then changed to ‘infected’. Virus transmission among farms occurred via the transmission routes animal, person and vehicle contacts, as well as contaminated sperm and local spread. For each contact, one contact farm was selected randomly that must not be ‘detected’, ‘culled’ or ‘restricted’, and a random number described whether the contact led to infection of the contact farm. A constant infectivity of the infectious herd was assumed until culling. Generally, the risk of a secondary outbreak by means of local spread decreases by distance (STAUBACH et al., 1997; STEGEMAN et al., 2002). Thus, for several circular zones around infected farms, the infection risk per farm and day could be specified by the user.

In the model, detection of infected farms occurred normally by means of clinical signs. After the expiration of the incubation period, it was tested daily by means of a random number to determine whether the infected farm was diagnosed. After the first detection of an infected farm, a higher daily detection probability was assumed than before because farmers might have paid more attention to the observation of their pigs. The day after detection all animals on the farm were culled.

2.2. Calibration of parameters

The number of contacts between an infected herd and uninfected herds, the infectivity of these contacts and the susceptibility of the contact herds determine whether the virus will spread among herds (ELBERS et al., 2001). The assumptions in the present model concerning the infectivity of the farm contacts were based upon the results of STEGEMAN et al. (2002). They were calculated by means of the data observed during the CSF epidemic in 1997/98 in the Netherlands transmission rates. However, the transmission rates were most likely an underestimation of the transmission rates during periods before an outbreak is detected. NIELEN et al. (1996), STÄRK (1998a) and KARSTEN (2002, unpublished data) quantified the numbers of daily farm contacts. In order to adapt both parameters to German conditions, the transmission rates and the mean numbers of daily contacts had to be calibrated. For this calibration, the real proportions of the infection routes vehicle, person and neighbourhood contacts as well as animal transport in outbreaks in Germany in the years 1990–1998 (FRITZEMEIER et al., 2000) were used. The parameters were modified until the real proportions were nearly reflected by the simulated ones. The assumed mean numbers of daily contacts away from a farm as well as the transmission rate per contact are shown in Table 1. In the present model it was assumed that an infected farrowing farm could transmit the virus to fattening farms via infected piglets from the day after virus introduction onwards. In contrast, person and vehicle contacts as well as local spread and artificial insemination were assumed to be infectious 7 days after infection on average with a standard deviation of one day.

Normally, clinical signs of CSF are often non-specific and several animals need to show symptoms before suspicion of classical swine fever is raised (KOENEN et al., 1996; FRITZEMEIER et al., 2000). Therefore, a log-normally distributed herd incubation period with a mean of about 28 days and a standard deviation of 11 days was assumed in the model.

The daily probability of detection of an infected farm by means of clinical signs was assumed to be 0.035 prior to the first detection of an outbreak. After that day, the daily detection probability remained constant at a higher level of 0.06.

A simulation run was stopped when all infected farms had been culled or after a time horizon of two years. For each alternative, 100 replications were performed.

Table 1
Mean number of farm contacts per farm and day (according to NIELEN et al., 1996; STÄRK, 1998a; KARSTEN, 2002, unpublished data) depending on the control measure moving ban, and the transmission rates per contact (modified after STEGEMANN et al., 2002) (Anzahl der Kontakte je Betrieb und Tag)

Type of contact	Number of contacts per farm and day		Transmission rate per contact
	without ban	with ban	
Animal contact	0.21	0.00	0.753
Vehicle contact	0.30	0.06	0.021
Person contact	0.40	0.24	0.017

2.3. Data

Because no detailed data on size and location of individual German farms were available, a uniform distribution of farms over an example area was assumed. The number of farms and the size of the area related to statements of the NIEDERSÄCHSISCHES LANDESAMT FÜR STATISTIK (1999). 2986 pig farms were randomly distributed over an area of 2230 km² leading to a farm density of 1.34 pig farms per km². The 2986 farms consisted of 1896 fattening farms, 543 farrowing farms, 546 farrow-to-finish farms and one artificial insemination centre. In order to study the effect of farm type of the primary outbreak, both a farrow-to-finish farm and a farrowing farm in the middle of the area were arbitrarily determined to be the primary outbreak in simulations.

2.4. Control measures simulated

The simulations were used to compare the effectiveness of four different control measures. Infected farms were obligatorily banned the day of detection and stamped out the day after (SO). This control measure was supplemented subsequently by other control measures, either as single measures or as combinations. All herds within the 1000 m zone around detected farms were slaughtered pre-emptively because they stood a high risk of having become infected because of their proximity to the infected farm (PS). Movement restrictions were implemented in protection and surveillance zones with a radius of 3 km and 10 km, respectively. No animal contacts were allowed and the vehicle and person contacts (Table 1) as well as local spread were reduced. The restrictions in protection zones expired after 30 days and the ones in the surveillance zones after 20 days. When the time period had elapsed, examinations took place in order to detect potentially infected herds within the zones. A sensitivity of 1 of the tests was assumed, thus all infected farms within the zones were detected after the expiration of movement control (MR). The selling and purchasing of infected piglets were mentioned as contact types with the highest risk of transmitting the virus (DEPNER et al., 1994; STEGEMANN et al., 2002). Animal contacts on and off the detected farm which took place in the 30 days prior to detection were traced and the contact farms culled the day after. In the base scenarios, all animal contacts were traced within 3 days (CT). To evaluate the possible influence of speed in animal contact tracing on epidemic size both the daily probability of successful animal contact tracing and the number of days for tracing were varied. Thus, in the best case, all animal contacts were traced within one day and in the worst case within five days.

2.5. Statistical analysis

SAS-procedure Genmod (SAS, 2003) was used to fit a probability distribution to the response variables (the number of infected, culled and restricted farms, as well as the duration of the epidemic) and to estimate means and confidence intervals (95%). The goodness of model fit was assessed by the criteria that a deviance approximately equal to its degrees of freedom is an indication of a good model fit. The analysis of the data showed that a model assuming a negative binomial distribution and a log link function fitted best to the observations and was therefore used for calculations.

3. Results

3.1. Routes of virus transmission

The mean proportions of the simulated routes of transmission after 100 simulation runs are presented in Table 2 as well as the proportions observed by FRITZEMEIER et al. (2000). In the simulations, two control options were distinguished: a) culling of infected herds only and b) culling of infected, contact and neighbourhood herds and establishment of restriction zones with a total radius of 10 km. Since it was more realistic to apply all four control measures, the routes of transmission under the assumption of all control measures applied were fitted to the empirically determined ones. The simulated and empirical numbers corresponded well.

Table 2
Proportions of routes of transmission in epidemics in Germany between 1990 and 1998 (FRITZEMEIER et al., 2000) and in simulation results for two control alternatives (Übergangswege bei den Epidemien in Deutschland (1990 bis 1998) und der Simulationsstudie für zwei Kontrollstrategien)

Type of contact	SO	SO + PS + MR + CT	FRITZEMEIER et al. (2000)
Animal contact	43%	35%	34%
Vehicle contact	18%	14%	15%
Person contact	20%	21%	21%
Neighbourhood contact	19%	29%	30%
Artificial insemination	0%	1%	0%

SO = Culling of infected farms, PS = Culling within 1000 m zone, MR = Movement restrictions within 10 km zone, CT = Culling after tracing

3.2. Consequences of control measures

3.2.1. Outbreaks and farms affected by control measures

Primary outbreak on farrow-to-finish farm

The control measures stamping-out, movement control, culling of contiguous and of contact farms were compared relative to their effect on the mean numbers of infected, culled and restricted farms (Table 3). Additionally, confidence intervals (95%) and ranges of outbreaks per scenario are shown. In the basic scenario, when only infected herds were culled (SO), 532 holdings were infected on average. Tracing of animal contacts and the subsequent culling of the traced farms (SO + CT) reduced the mean number of outbreaks significantly to 153. A mean number of 81 outbreaks was observed in the alternative with stamping-out infected herds and farms in the neighbourhood (SO + PS). More efficient was the control option affecting the farms within the 10 km radius of infected herds that led to a mean epidemic size of 8 outbreaks (SO + MR). As expected, combinations of three or four control measures had the greatest effect on the epidemic pattern, but the means of 5 to 6 did not differ considerably from the alternative SO + MR.

But as a price for the low number of infections, a great number of herds may have been affected by pre-emptive slaughter and moving restrictions. When pre-emptive slaughter of herds in the neighbourhood was applied (SO + PS), about 240 herds were depopulated in total. This was threefold as many farms as infected. The resulting large number of farms culled although healthy was reduced significantly when pre-emptive culling was supplemented by movement restrictions. But even then four times the number of infected farms were culled in total (25).

Table 3
Mean number of outbreaks ($\bar{x}$), culled and restricted farms during one epidemic depending on the applied control strategy and on farm type infected first (Mittlere Anzahl Ausbrüche, gekeulte und gesperrte Betriebe während einer Epidemie in Abhängigkeit von der Kontrollstrategie und dem Indexbetrieb)

Control option	Number of outbreaks					Herds	
	$\bar{x}$	CL_l	CL_u	Min	Max	Culled	Banned
Farrow-to-finish farm infected first							
SO	531.6	337.4	837.4	1	2726	506.5	0
SO+PS	81.1	54.3	121.2	1	1039	237.7	0
SO+CT	153.0	103.1	227.1	1	1716	157.7	0
SO+MR	7.6	6.0	9.7	1	58	7.6	930.6
SO+MR +PS	5.9	4.7	7.3	1	43	25.0	862.4
SO+MR+CT	5.8	4.7	7.3	1	53	6.2	863.7
SO+MR +PS +CT	5.0	4.1	6.1	1	35	21.1	802.5
Farrowing farm infected first							
SO	1328.2	933.9	1888.8	2	2764	1295.3	0
SO+PS	245.3	178.2	337.5	2	1095	722.4	0
SO+CT	159.4	113.0	224.9	2	1592	163.8	0
SO+MR	16.5	13.8	19.6	1	100	16.5	1668.1
SO+MR +PS	15.4	13.0	18.2	2	77	60.5	1628.4
SO+MR+CT	9.3	8.0	10.9	2	58	9.6	1414.4
SO+MR +PS +CT	8.3	7.2	9.6	1	35	35.1	1328.0

CL_l and CL_u = Lower and upper confidence limit (95%), SO = Culling of infected farms, PS = Culling within 1000 m zone, MR = Movement restrictions within 10 km zone, CT = Culling after tracing

When movement control was applied, more than 900 farms were affected by movement control. Movement restrictions may lead to animal welfare problems due to overcrowding, shortage of farrowing pens for sows and of food, and additional economic consequences may develop. When movement restriction was supplemented by contact tracing, as laid down in EU Directive 2001/89/EC, negligibly more herds were slaughtered than infected and 864 herds on average were under control. The least number of herds was affected by the moving ban when all four measures were installed.

Primary outbreak on farrowing farm

Table 3 shows the effects when the primary outbreak occurred on a farrowing farm. This farm type has a great chance of spreading the virus by selling infected piglets to fattening farms. As expected, the mean number of outbreaks during an epidemic increased compared to epidemics when the farrow-to-finish farm was infected first. When movement restrictions were applied, 17 farms became infected on average instead of 8 farms when the farrow-to-finish farm was infected first. In contrast to cases when the farrow-to-finish farm was infected first, animal contact tracing was a more successful supplement to movement restrictions than pre-emptive slaughter (9 outbreaks). Again, the combination of stamping-out, pre-emptive slaughter, moving ban and contact tracing was most effective and led to 8 outbreaks in the mean with 1328 farms restricted.

3.2.2. Epidemic duration

Primary outbreak on farrow-to-finish farm

The influence of the control measures on the mean duration of epidemics is shown in Table 4.

Movement restriction reduced the mean duration from 240 to 91 days. When stamping-out and movement control were supplemented by either contact tracing or pre-emptive slaughter, the mean epidemic lasted about 81 days. When both measures were applied additionally, the mean duration amounted to 70 days.

Primary outbreak on farrowing farm

When the farrowing farm was infected first, animal contact tracing was more successful in reducing the duration of the epidemic (246 days) than pre-emptive slaughter within a radius of 1000 m (332 days). When movement control was applied, the epidemic lasted 130 days in the mean. The combination of stamping-out, movement control and contact tracing led to an duration of 87 days. Additional pre-emptive slaughter reduced the duration by a further 16 days to 71 days.

Table 4

Mean duration of an epidemic in days ($\bar{x}$), confidence interval and range depending on the applied control strategy and on farm type infected first (Mittlere Epidemiedauer, Konfidenzintervall und Schwankungsbreite in Abhängigkeit von der Kontrollstrategie und dem Indexbetrieb)

Control option	Duration					# Epidemics
	$\bar{x}$	CL_l	CL_u	Min	Max	not eradicated
Farrow-to-finish farm infected first						
SO	239.9	195.9	293.8	25	730	23
SO+PS	154.1	126.1	188.3	15	730	8
SO+CT	226.5	185.9	275.8	21	730	17
SO+MR	90.7	81.2	101.3	19	256	-
SO+MR +PS	80.9	72.1	90.7	18	330	-
SO+MR+CT	81.6	72.6	91.8	18	263	-
SO+MR +PS +CT	69.7	62.9	77.2	16	230	-
Farrowing farm infected first						
SO	441.0	375.2	518.3	49	730	48
SO+PS	332.4	280.8	393.5	36	730	25
SO+CT	246.4	204.3	297.1	28	730	16
SO+MR	130.3	118.2	143.7	24	371	-
SO+MR +PS	107.7	98.4	117.8	32	306	-
SO+MR+CT	86.7	78.6	95.7	23	198	-
SO+MR +PS +CT	70.5	64.2	77.3	17	166	-

CL_l and CL_u = Lower and upper confidence limit (95%), SO = Culling of infected farms, PS = Culling within 1000 m zone, MR = Movement restrictions within 10 km zone, CT = Culling after tracing

3.3. Varying efficiency in contact tracing

3.3.1. Outbreaks and farms affected by control measures

Primary outbreak on farrow-to-finish farm

Table 5 presents the results when culling of infected and of traced contact holdings were applied as control measures (SO + CT) and the time to detection by animal contact tracing was varied between five and one days. The mean number of outbreaks was reduced by 100 from on average 164 to 65 outbreaks per epidemic when tracing efficiency increased. When all four control measures were applied (SO, PS, MR, CT), the efficiency in contact tracing did not have such a large impact on epidemic size as in the case above (Table 6). Cutting down the tracing period from five to one day reduced the mean number of outbreaks by one from 5.3 to 4.2.

Primary outbreak on farrowing farm

The same tracing options were tested under the assumptions that the primary outbreak occurred in a farrowing farm. Again, the mean epidemic size was reduced considerably from about 300 to 110 outbreaks when only stamping-out and contact tracing were applied (Table 5). When all four control measures were applied, major differences between the alternatives with rapid tracing (7 outbreaks) and slow tracing (10 outbreaks) were observed than when a farrow-to-finish farm was infected first (Table 6). This greater difference can also be seen in the number of herds culled or restricted.

Table 5

Influence of different tracing efficiencies on the mean number of outbreaks ($\bar{x}$), restricted and culled farms and epidemic duration assuming culling of infected herds and of traced farms after animal contact (SO + CT) and depending on farm type infected first (Einfluss einer unterschiedlichen Kontaktrückverfolgung auf die Anzahl der Ausbrüche, gesperrten und gekeulten Betriebe sowie auf die Epidemiedauer in Abhängigkeit vom Indexbetrieb (Kontrollstrategie: Keulung der infizierten Betriebe und Kontaktbetriebe))

Number of days	Number of outbreaks					Duration	Herds	
for tracing	$\bar{x}$	CL_l	CL_u	Min	Max	(days)	Culled	Banned
Farrow-to-finish farm infected first								
5	164.3	108.9	248.1	1	1771	213.3[a]	163.3	0
3	153.0	103.1	227.1	1	1716	226.5[a]	157.7	0
1	65.0	45.1	93.9	1	975	182.4[b]	68.6	0
Farrowing farm infected first								
5	293.4	203.0	424.0	1	2140	279.8[c]	300.5	0
3	159.4	113.0	224.9	2	1592	246.4[d]	157.7	0
1	110.0	78.4	154.3	2	1278	226.2[e]	115.0	0

CL_l and CL_u = Lower and upper confidence limit (95%), [a] = 17 of 100 epidemics not eradicated within 730 days, [b] = 10 of 100 epidemics not eradicated within 100 days, [c] = 25 of 100 epidemics not eradicated within 730 days, [d] = 16 of 100 epidemics not eradicated within 100 days, [e] = 15 of 100 epidemics not eradicated within 100 days

Table 6

Influence of different tracing efficiencies on the mean number of outbreaks ($\bar{x}$) restricted and culled farms and epidemic duration assuming culling of infected, contiguous and traced farms after animal contact as well as moving restrictions within the 10 km zone (SO + PS + CT + MR) and depending on farm type infected first (Einfluss einer unterschiedlichen Kontaktrückverfolgung auf die Anzahl der Ausbrüche, gesperrten und gekeulten Betriebe sowie auf die Epidemiedauer in Abhängigkeit vom Indexbetrieb (Kontrollstrategie: Keulung der infizierten Betriebe, Nachbarschafts- und Kontaktbetriebe))

Number of days	Number of outbreaks					Duration	Herds	
for tracing	$\bar{x}$	CL_l	CL_u	Min	Max	(days)	Culled	Banned
Farrow-to-finish farm infected first								
5	5.3	4.3	6.5	1	41	70.8	22.6	851.7
3	5.0	4.1	6.1	1	35	69.7	21.1	802.5
1	4.2	3.5	5.1	1	26	68.1	18.2	765.3
Farrowing farm infected first								
5	9.8	8.5	11.4	2	49	79.7	40.0	1525.9
3	8.3	7.2	9.6	1	35	70.5	35.1	1328.0
1	6.9	6.1	7.8	2	27	61.2	29.4	1228.9

CL_l and CL_u = Lower and upper confidence limit (95%), MR = Movement restrictions within 10 km zone

3.3.2. Effect on epidemic duration

Primary outbreak on farrow-to-finish farm

Whereas in the case of the combination of stamping-out infected, contact and neighbourhood farms and movement control, the epidemic length was reduced only from 71 to 68 days (Table 6), in the case of the culling of infected and contact farms, the mean length was reduced from 213 to 182 days (Table 5).

Primary outbreak on farrowing farm

Again, the differences between fast and slow contact tracing were higher in the alternative with two control measures implemented, where the duration was reduced by 54 days from 280 to 226 (Table 5), than in the alternative with four measures, where epidemic duration decreased from 80 to 61 days (Table 6).

4. Discussion

4.1. Calibration of parameters

The results a model produces depend strongly on the assumed parameters. Publications concerning the quantification of virus transmission parameters are rare and the few results cannot be easily transferred to other regions. Thus, the model parameters were assigned based on results mentioned by NIELEN et al. (1996), STÄRK (1998a), KARSTEN (2002, unpublished data) and STEGEMANN et al. (2002) and by fitting the proportions of the simulated infection routes to those determined for the epidemics in Germany (FRITZEMEIER et al., 2000). About one third of the outbreaks with known source in Germany between 1990 and 1998 were caused by animal contacts and local spread, respectively. Vehicle and person contacts caused 15% and 21% of the outbreaks. These frequencies were fitted well by the simulations. However, several combinations of daily contacts and transmission rates per contact may also produce these results so that the real transmission rates and numbers of farm contacts might have differed from the supposed ones.

When parameters are difficult to estimate, sensitivity analysis determines whether the factors have a significant effect on output and should therefore be estimated more accurately (JALVINGH et al., 1997). STÄRK and PFEIFFER (1999), MANGEN et al. (2002) and KARSTEN et al. (2005) mentioned an influence on the epidemic size and duration of both the number of contacts and the probability of infection by contact. This emphasises the necessity of further investigations to quantify these risk factors more accurately.

The random generation of the co-ordinates of the farms led to a homogeneously spatial distribution of the farms that did not represent reality correctly. As a result, local spread might have been underestimated. To take the non-clustered distribution of farms leading to less farms in proximity into account, the probability of local infection per farm might be assigned with a too high value. However, the probabilities of local infection were in agreement with assumptions of STÄRK (1998b), JALVINGH et al. (1999) and MANGEN et al. (2002), who assumed transmission rates between 0.003 and 0.04, 0.0057 and 0.01, as well as 0.004 and 0.0122 within the 1000 m zone, respectively.

The assumed mean duration of the herd incubation period of 28 days was rather high considering that detection by means of clinical signs may take an additional number of days. But especially strains of moderate virulence cause vague clinical signs that may not be recognised (KOENEN et al., 1996) or be mistaken for signs of other diseases (FRITZEMEIER et al., 2000). FLOEGEL-NIESMANN et al. (2003) reported a difficulty of clinical diagnosis in pigs up to 14 days post infection although clinical signs may start at about 7 days post infection. In the present study, the incubation period was defined as the interval between the infection of at least one animal in the herd and the appearance of noticeable symptoms in several animals and was therefore assigned with in the mean 28 days.

4.2. Outbreaks and farms affected by control measures

Due to the uniform distribution of the farms in the area under observation, the effect of control measures that should reduce local spread might be underestimated. By means of importing real GIS (Geographical Information System) data, such biases will be avoided and regional differences will be considered in a better way. Nevertheless, the results showed a significant reduction in the mean number of outbreaks as well as the mean duration of the epidemic when control measures affecting farms in the surrounding were applied. According to MANGEN et al. (2002) and SAATKAMP et al. (1996), pig and pig farm density in the region under observation influence the course of the epidemic and the effect of control measures, respectively. In areas with low animal density, control measures, according to the EU Council Directive 2001/89/EC (ANONYMOUS, 2001), may be sufficient to control an epidemic, whereas in densely populated areas pre-emptive slaughter or emergency vaccination may be additionally necessary. In the present study, a region with a pig farm density of 1.34 farms/ km² was analysed. The application of protection and surveillance zones and of stamping-out infected and contact farms was successful in keeping the epidemic under control. The mean number of outbreaks per epidemic amounted to 6 and 9, respectively, depending on farm type of primary outbreak. The slightly positive effect of establishing further measures on the number of outbreaks confirms the statements of SAATKAMP et al. (1996) and MANGEN et al. (2002). However, parameters such as farms depopulated in total or restricted have to be taken into account as well.

For an overall evaluation, a calculation of economic consequences is necessary but ethical problems should also be considered. STEGEMANN et al. (1999) and ELBERS et al. (1999) recommended pre-emptive slaughter of contiguous herds, in addition to stamping-out infected and contact herds and movement restrictions by means of their analyses of the CSF epidemic in the Netherlands in 1997/98. However, even if culling within a radius of 1000 m may be optimal relative to the epidemic size, pre-emptive culling could lead to enormous financial losses in regions of high pig density. Thus, a reduction in the radius may have drastic consequences on the economic impact of the disease (STAUBACH et al., 1997). In KARSTEN et al. (2005), pig herd density in the area under observation had a significant influence on the number of farms infected during the epidemic and the number of days the epidemic lasted. More outbreaks occurred in a densely populated area than in a sparsely populated area. In their sensitivity analysis, stamping-out infected, contact and neighbourhood farms as well as applying a moving ban was assumed. An interaction between control strategy and farm density was imaginable. Without pre-emptive slaughter the effect of farm density might have been even larger but was not calculated.

In the present paper, the farm type of the primary outbreak significantly influenced mean epidemic size and duration. This is contrary to the results of MANGEN et al. (2002), who could not prove an impact of farm type but observed a small tendency for smaller epidemics when a fattening farm was infected first and larger epidemics when the primary outbreak was at a breeding farm. This smaller effect, when compared to the present results, can be explained by the fact that in the assumptions of MANGEN et al. (2002) farrow-to-finish farms sold animals apart from farrowing farms. The present results also showed an influence of farm type of primary outbreak on effectiveness of contact tracing. When a farrow-to-finish farm was infected first, the number of infected farms did not differ considerably between the alternatives when stamping-out infected farms and movement control were supplemented by contact tracing (5.8 outbreaks) and pre-emptive slaughter (5.9 outbreaks). Likewise, the mean numbers of restricted farms did not differ (863 farms). In the alternative, with farrowing farm being infected first, less (9.3) herds were infected when movement control was combined with contact tracing, compared with movement control supplemented by pre-emptive slaughter (15.4 farms). Furthermore, the alternative with contact tracing was better in regard to the number of restricted farms (1414 versus 1628).

4.3. Varying efficiency in contact tracing

When contact and neighbour farms are to be slaughtered pre-emptively in an epidemic getting out of control a shortening of resources and a delay in the execution of the measures is to expected (PLUIMERS et al., 2002). Both the delayed application of control measures as well as the limited resources could not be modelled with the present model but the day after detection of an infected herd or successful tracing of a contact farm, all animals on the farm were slaughtered and disposed of. Therefore, an overestimation of the success of the control measures was to expected (c.f. HOWARD and DONNELY, 2000). Furthermore, destruction of infected or suspected herds and safe disposal of carcasses occurred simultaneously in the model which in reality may be transacted on several days.

Rapid contact tracing is an important tool in the control of contagious animal diseases as confirmed by SAATKAMP et al. (1996). A delay in locating high risk contacts would give the chance of more unnoticed virus spread. When several outbreaks occur at a day resources in disease control are limited. The farm contacts have to be ranked in priority order of transmission risk (KRAMER et al., 2000; MORRIS et al., 2002). Therefore, in the model, the tracing of animal contacts only and the culling of the contact farms the day after contact detection were assumed. In order to keep the model simple, contacts that had occurred within the 30 days prior to detection were traced obligatorily. The time needed to trace all animal contacts had an influence on the success of the control measures and on the time period between infection and detection (data not shown). This reflects its great impact in disease control. When other control measures were additionally applied, the positive effect of more rapid tracing was reduced. The outcome confirms the results of SAATKAMP et al. (1996), who mentioned an influence of the applied control strategy on the effect of the identification and recording system in the success of disease control.

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Corresponding Author
Prof. Dr. JOACHIM KRIETER
Institute of Animal Breeding and Husbandry
Christian-Albrechts-University
Hermann-Rodewald-Str. 6
24118 KIEL /GERMANY

E-Mail: jkrieter@tierzucht.uni-kiel.de