Simulation of a classical swine fever outbreak in rural areas of the Republic of Serbia

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ABSTRACT: Several different strategies for control and eradication of classical swine fever (CSF) were compared using a Monte Carlo method-based simulation model. The control strategy analysed in this paper, in addition to other CSF control measures, includes application of biosecurity measures on pig farms and rural backyard holdings. Elements of the control strategy are based on applicable regulations and include the simulation of detection of the disease, setting up the protected and surveillance zones, standstill of pig movements and restricted movement of animals, vehicles, equipment, and people with strong control measures in protection and surveillance zones, euthanasia of susceptible pigs, protective vaccination of pigs, compensation etc. During the simulation, different output parameters were compared such as: duration of epidemic of a disease, number of affected holdings and animals, direct costs such as those for dead or culled animals, costs of surveillance, disposal of infectious materials, cleaning and disinfection. Depopulation of affected animals with early diagnostics and vaccination in the protection and surveillance zone proved to be the most effective measures to stop the spread and for the eradication of the disease. Moreover, during the simulation, systematic implementation of biosecurity measures in all pig production clusters was demonstrated to be an appropriate strategy for sustainable control of CSF and the establishment of a stable epidemiological situation.

Keywords: Monte Carlo simulation; classical swine fever; biosecurity measures; control strategy

From an economic standpoint, classical swine fever (CSF) is the major threat to pig production in any country. The financial consequences depend strongly on the number of outbreaks, the duration of the epizootic and on the type and effectiveness of applied control measures. By means of simulation models, possible patterns, different pig production operations, risk factors, economic impact and control strategies can be simulated using different simulation models. In most cases these are mass-action, state-transition Monte Carlo simulation models. For example, Jalvingh et al. (1999) and

Martinez-Lopez et al. (2011) used a similar model to simulate a CSF epizootic and thereby to evaluate control measures. Durand and Mahul (2000) used state-transition models to analyse the impact of herd density and control measures on virus spread. Models are usually very flexible and the user can easily control different input parameters such as: production types, spatial data, disease spread parameters, control parameters etc. (Karsten et al. 2005a; Karsten et al. 2005b).

In this paper, a stochastic simulation model is described that was developed to simulate a CSF

epidemic in two municipalities in the Republic of Serbia. The objective was the analysis of possible control strategies for CSF eradication, based on raising the level of implemented biosecurity measures, gradual transition of low-biosecurity-level holdings to high-biosecurity-level categories of farms and the increasing of the effectiveness of this approach in the case of a CSF outbreak.

MATERIAL AND METHODS

Geographical area and tested population. The study was conducted in the territory of the Serbian municipalities of Sremska Mitrovica and Sid. This is an area with a relatively high density of pigs but also with significant diversity in pig-breeding technology, including backyard production. The study included high-biosecurity-level pig farms (commercial farms, family farms type A) and low-level-biosecurity pig farms and holdings (family farms type B and rural backyard holdings). According to stratification based on biosecurity, a commercial farm means any farm that has almost two of the following characteristics: animals slaughtered in approved abattoirs, the presence of a farm veterinarian, national or international market-oriented with high biosecurity measures such as no swill feeding, no contact between the pigs and other susceptible animals, the owner/keeper changes clothes on entering the stable and leaving the stable, no visitors are allowed to enter, etc.

Based on biosecurity criteria, pig farms are divided into four categories:
– Commercial farm: is a holding where pigs are kept according to all regulated conditions for pig breeding; it is enlisted in the Farm Register; all health protection measures are implemented, with the highest level of biosecurity and hygiene
– Family farm type A: is a holding where there is a number of animals (in any case more than 11), which delivers live pigs to the market and where all animal health protection measures with the highest level of biosecurity and hygiene are implemented
– Family farm type B: is a holding where there is a number of animals ≥ 11; delivers live pigs to the market; required hygienic and health protection measures are not fully implemented, or not implemented at all, with a consequent insufficient level of biosecurity

– Backyard holding: is a holding where there is a small number of animals ≤ 10 kept for owner's purposes (consumption); the levels of animal health protection, biosecurity and hygiene are low and inefficient

Source of data. The data on the number of pigs, production categories, and geographical locations were collected during the field investigation. In cases where data were not accessible, these were obtained from the Central Database of Ministry of the Agriculture and the geographical coordinates were determined in ARC GIS 10.0, by random selection (Gatrell 2004).

Structure and description of the simulation model. The simulation was performed using the computer-based North American Animal Disease Spread Model (NAADSM) version 4.0.11, a temporal and spatial stochastic model based on the Monte Carlo method (Harvey et al. 2007).The basic idea underlying the Monte Carlo method is the approximation of the expected value E(X) by the arithmetic mean of results of a large number of independent tests (simulations) all with the same distribution as X. The stochastic process in the simulation uses random variables and is based on the law of random numbers, for which purpose random numbers with specific distribution need to be generated. This is achieved using computer programs specifically developed for this purpose. The essence of each of these programs is a random number generator, or a semi-random number generator, while the quality of simulation directly depends on the quality of the random number generator. In this regard, the Monte Carlo is the method of choice by which the system can be simplified in order to analyse the dynamics of disease and possible outcomes of the epidemic. The data describing the disease and the mode of transmission can be changed and adapted to the real environment. The model parameters are data that are taken from the literature, obtained during field studies, retrospective analysis of previous epidemics or taken from expert opinion. Mode of transmission of the virus and disease dynamics are mathematically described and transferred into the model. To ensure the reliability of the model and at the same time avoid excessive complexity, the model is a simplified imitation of important natural phenomena and factors that contribute to the emergence and spread of diseases (Stanojevic 2014).

NAADSM is a computer program based on the Monte Carlo method and is developed for the simu-

lation of contagious animal diseases such as foot-and-mouth disease, avian influenza, New Castle disease, classical swine fever and other highly contagious diseases. The software was developed by a team of experts of the Centre for Epidemiology and Animal Health at the US Department of Agriculture in Fort Collins, Colorado (Veterinary Services Science, Technology, and Analysis Services-Centre for Animal Health and Epidemiology-VS-Ceah STAS) (Harvey et al. 2007).

The spread of disease and the mode of transmission of a virus in nature have elements of a stochastic event, but there are also certain patterns. Since the progression of an epidemic largely depends on environmental factors, the host and the pathogen, risk factors that are associated with this epidemiological triangle influence each epidemic and make them different (Harvey et al. 2007; Harvey and Reeves 2010).

NAADSM is a herd-based, geo-spatial state transitional model. One state is assigned to each simulated herd: susceptible, latent, subclinical infectious, clinical infectious, naturally immune, vaccine immune or dead. The stochastic spread mechanisms act spatially by use of the geographical location of farms. The farm is considered as an epidemiological unit and model dose not simulate spread of CSF within farms.

The model simulates the transmission of disease between farms with different statuses: susceptible to infection, latently infected, subclinical infection, clinical infection, euthanised animals, and farms with immune (vaccinated) pigs (Figure 1).

Table 1 describes the definition of the disease transition states. The model of each scenario started with one latent herd and the rest were susceptible. A latently infected herd was selected randomly from the list of holdings and farms in the region under the study.

Each simulation was performed in 1000 replications. The model simulates the daily spread of classical swine fever virus between farms and backyard farms. The units (farms and backyard farms) interact with each other. The model simulates the direct and indirect contacts, whether they are apart or are in close proximity. These contacts are related to transport of animals from one farm to another and indirect contacts through vehicles and people. The model also simulates the local spread of the disease (Harvey et al. 2007; Stanojevic 2014).

Simulation was performed under assumptions that all susceptible pigs were equally susceptible. All infected pigs spread the virus throughout the herd, and all infected pigs eventually showed clinical signs. However, there are differences in the
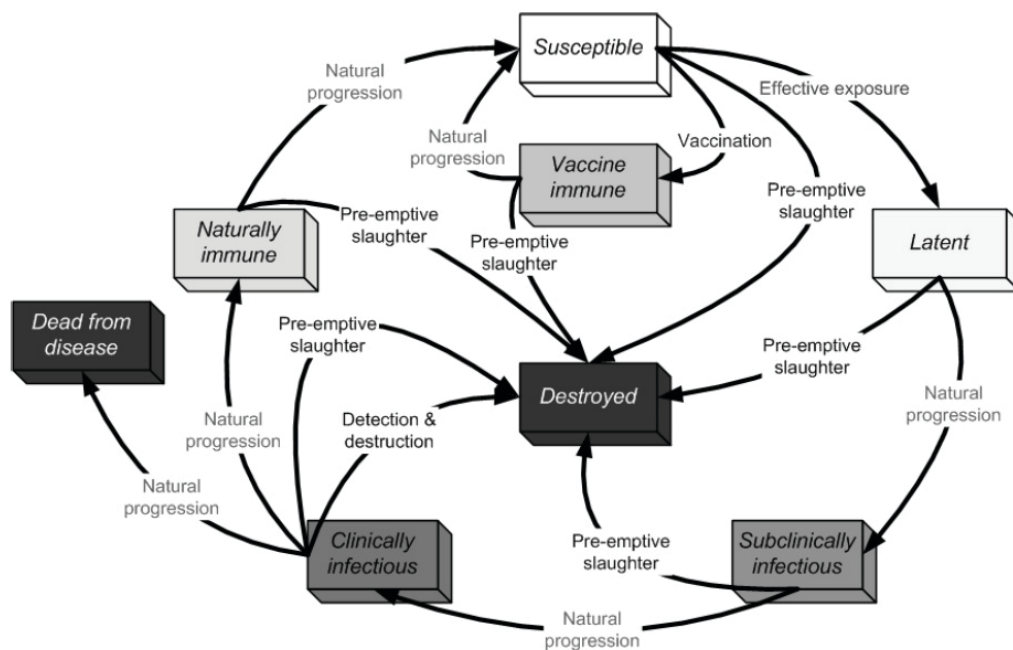

Figure 1. States and transitions simulated by NAADSM. Without intervention, units will follow the state progression indicated in the outer loop. Upon the implementation of disease control measures, intervening actions may alter the normal disease cycle, as shown inside the loop (Reeves et al. 2012; with author's permission)

Table 1. Definition of statuses through which animals pass in the model

Status	Definition of status
Susceptible	all animals in the herd not infected but can be infected in the case of contact with a diseased animal
Latent	period between exposure and infection. Some animals in the herd are infected, but still do not shed the virus
Subclinical infection	some animals in the herd are infected and shed the virus. No clinical symptoms
Clinical infection	some animals in the herd are infected, shed the virus, and show a clinical image of the disease
Vaccinated	animals in the herd are vaccinated and are not susceptible to CSF
Dead from disease	animals died due CSF
Culled	all animals in the herd are culled during implementation of CSF eradication measures

probability of developing the disease after the occurrence of adequate contact. These differences in the probability are conditioned by the type of the farm, production of the pigs (open or closed type of production) and the level of biosecurity measures introduced. In some scenarios a number of pigs are vaccinated and have artificially induced immunity, which makes them resistant to the disease. Given that the model is based on the Monte Carlo method, the events "contact between the various units – adequate contact" and "contact between the various units that caused the transmission of diseases – effective contact" are stochastically generated using a random number generator. Adequate contact does not necessarily mean an infection with the virus and outbreak of disease. Only effective contact initiates the disease transmission and outbreak of CSF on a farm. These rules apply to both types of contacts, direct and indirect. At the beginning of the simulation all farms in the region have the same status, "susceptible", except in those cases where it simulates a case where on a number of farms and rural farms preventive vaccination of pigs has been conducted.

The stochastic and spatial simulation of the spread of CSF starts with an initialisation phase, in which farm-specific data like geographic location, numbers of animals, farm type and infected herd or herds (index cases) are introduced into the model.

On each day of a simulated outbreak, every infectious unit will have direct contact with some number of other units in the population. Only movements from infectious (infectious subclinical, or infectious clinical) units that have not been quarantined are recorded. Once the total number of contacts that will occur is established, the model then determines which units will receive those contacts as well the effects of each contact. After the source units for each direct contact are established, recipient units for each contact are determined, based on the distance of potential recipients from a source. If a susceptible recipient unit is selected for a contact, a stochastic process determines whether that source unit will become infected (Harvey et al. 2007).

When an epidemiological unit acquires the status of "latent infection", during the simulation it then passes through the other statuses predefined in the model. At the same time, by defining the parameters that describe the disease, control measures are also modelled. These measures may differ in different scenarios, depending on the chosen strategy of control. Basically, the "infected" farms, after acquiring the status of "discovered" in the framework of a pre-determined time frame, undergo measures related to the depopulation of animals. In this way the infectious period of the farms ends and they no longer can serve as a source of infection for other farms. The control strategy in some scenarios also includes the possibility of preventive depopulation of animals, control of movement, the establishment of protection and surveillance zones around the infected farms, active surveillance in the protection and surveillance zones, sampling for the purpose of laboratory tests, etc.

Control measures are defined simultaneously. Measures can differ in the different model scenarios, depending on the selected control strategies. To avoid computational complexity, the infectious and clinical sign states were simulated at the farm level and any other causes of mortality were assumed to be negligible. The model puts a special accent on measures that help in reducing the probability of occurrence of CSF. Farms and holdings are clas-

sified into categories and are organised into four strata. Each stratum is higher and better than the previous one with respect to the level of biosecurity. All infected pigs, after a short latent period, spread the virus throughout a susceptible population. Differences in probability of an outbreak after exposure to adequate contact are conditioned by the level of implemented biosecurity measures and type of pig production. Biosecurity measures involve measures such as artificial insemination, good practice on the farms, improved breeding technology, cleaning and disinfection, wearing protective clothes etc. In the first scenario, which emulates the present environment, some pigs are vaccinated which makes them non-susceptible. In other scenarios a non-vaccination policy is assumed. Emergency vaccination is used as an alternative to preventive slaughter. The model designed in this way shows the worst case scenario.

The results obtained after 1000 replications are expressed in terms of mean values, standard deviations, minimum amount, the maximum amount and quintiles, providing the information on the number of infected animals and farms, outbreak duration, culled animals, and costs related to the control of the disease. After simulation, a set of epidemiological data were analysed to evaluate the most effective strategy.

Disease parameters. The characteristics of the disease and the assigned attributes are based on data from the literature and the results of retrospective analyses of CSF cases in the Republic of Serbia in 2005, 2006 and 2007 (Tables 1, 2) (Backera et al. 2011).

For incorporation of the disease parameter into the model probability density functions were used. Probability density functions are distributions of values representative of the natural range of possible values for model parameters, e.g. the time

period in which an infected herd is latent or clinically infectious (Figure 2 and Figure 3). During the simulation, values are drawn randomly from probability density functions as a simulation runs.

Transmission of disease (efficient contact): The following modes of transmission are simulated: direct contact between diseased and susceptible animals, indirect contact through contaminated vehicles, equipment, workers. Contact rate is based on average values and the process is simulated using a Poisson distribution.

During a field visit, information about the movement of animals was collected. Average movements were calculated for movements to and from markets and then recalculated into an average daily number of movements. Further, which herd types deliver pigs to other herds also plays a role. For example, a commercial farm can receive pigs only from other commercial farms whereas family farms could interact with different types of farms etc.

Contact rates vary for different types and categories of holdings, expressed on a daily level. The direction of movement of animals, people and vehicles to and from holdings are random, and the distances of movement were based on two probability density functions, one for direct contact and the other for indirect contact. The distance distributions for direct and indirect contact were assumed to each be a triangular density function with a minimum, most likely, and maximum distance.

Transmission by wind is not included in the model, since it is seldom described in the literature and is unlikely to be of any epidemiological importance.

Control strategy: Detection of disease. The model includes detection of clinical cases only. There are two basic parameters simulated by the model with respect to diagnostics and detection of CSF cases on a holding: (1) probability of detection of first cases of the disease (Figure 4) and
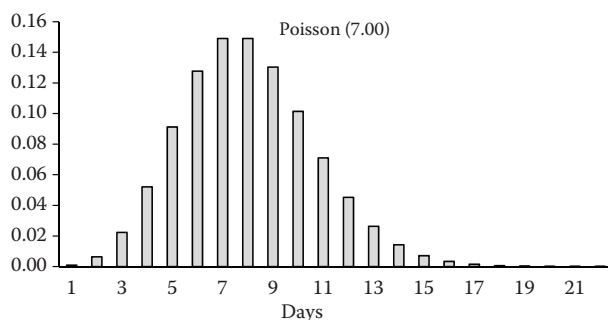

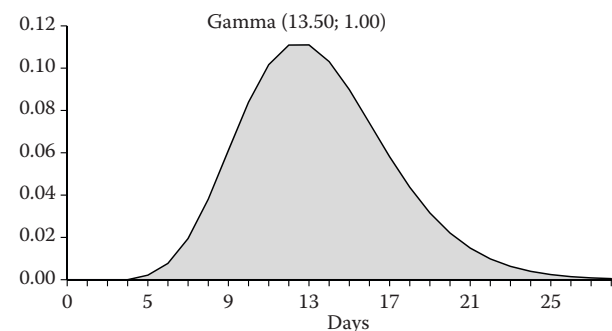Figure 2. Latent period (Stanojevic 2014)

Figure 3. Clinical infectious period (Stanojevic 2014)

Table 2. Disease transmission parameters and probability distribution function used in the stochastic model

Parameters	Probability distribution	The mean value/standard deviation in days	
The latent period (Laddomada 2000)	poisson distribution	7(1); 8(1)	
Subclinical period (Martınez-Lopez et al. 2011)	poisson distribution	21	
Infectious period (Backer et al. 2011)	gamma distribution	alfa: 13.5, beta: 1	
Immune period after vaccination (Qiu et al. 2006)	the normal Gaussian distribution	300/60	
		Type of farm	Intensity
The number of direct contacts between animals daily – direct sales to owners*	poisson distribution	industrial farms	0.07
		type A	0.009
		type B	0.0074
		back yard farm	0.0036
		Type of farm	Intensity
Number of contacts direct natural mating (mating animals)*	poisson distribution	type B	0.016
		rural farm	0.0057
		Type of farm	Probability
The probability of transmission of the virus through direct contact depending on what type of farm was the source of infection (Karsten et al. 2006)	bernoulli distribution	industrial farms	0.7
		type A	0.7
		type B	0.8
		rural farm	0.8
		Type of farm	Intensity
Number of indirect contacts per day*	poisson distribution	industrial farms	0.1428
		type A	0.1428
		type B	0.0330
		rural farm	0.2850
		Distance from the farm	Mean value
Local spread of the virus (Karsten et al. 2006)	bernoulli distribution	150 m	0.020
		150–250 m	0.010
		250–500 m	0.004
		500–1000 m	0.002
		Number of days	Probability (%)
The probability of detecting the first appearance of clinical symptoms of CSF from the moment when the farm became infectious (Engel et al. 2005)	fixed value	8	0
		10	3
		20	7
		25	10
		37	50
		47	90
		20	100
		Number of days	Probability (%)
The probability of detecting cases of death due to infection by the CSFV from the time of occurrence of the first cases of death (placing suspected on the basis of the pathoanatomic findings) (Klinkenberg et al. 2005)	fixed value	1	20
		2	30
		3	40
		4	50
		5	60
		6	70
		7	80
		8	100

Table 2 to be continued

Parameters	Probability distribution	The mean value/standard deviation in days	
		Type of farm	Mean value
The probability of successful tracking of shipments of animals that have left an infected farm**	bernoulli distribution	commercial Farm	0.80
		family farm type A	0.80
		family farm type B	0.80
		rural farm	0.40
		Type of farm	Mean value
The probability of successful detection and monitoring of indirect contact with an infected farm (Martinez-Lopez et al. 2005)	bernoulli distribution	commercial Farm	0.95
		family farm type A	0.90
		rural farm	0.20
Sensitivity and specificity of diagnostic tests	fixed value	sensitivity	99%
		specificity	99%

*data collected in the field; **data based on a 2010 CSF epidemic in Serbia

(2) probability of reporting the detected cases based on information that the disease is present on holding (Reeves et al. 2012).The probability of detection of first cases or observing clinical signs represents the probability that the farmer or the veterinarian would report suspicious signs of CSF to the competent authority given that infection had been present in the herd for a certain number of days (Reeves et al. 2012). If an infected unit successfully detected and reported to the competent authority, it was automatically quarantined and destroyed if positive laboratory results were revealed. In contrast, if a farm is not detected, it will continue to spread the disease.

Control strategy: Control measures. Elements of the control strategy are based on applicable

Figure 4. The probability of detection of first cases or observing clinical signs of CSF on industrial farms, type A, B and backyard farms. The detection probability was modelled as based on the results of Klinkenberg et al. (2005) and Engel et al. (2005) and available data from epidemics of CSF in Serbia between 2005–2010

measures prescribed in Serbian national legal acts and include the setting up of protected and surveillance zones, complete cessation of pig movements, restricted movement of vehicles, equipment, and people, implementation of control measures in protection and surveillance zones, tracing back of all movements, epidemiological investigation of the disease, euthanasia of susceptible animals on infected and contact holdings, vaccination of animals in defined zones, indemnification of costs, etc.

The current strategy of control and eradication of CSF in the Republic of Serbia is based on the transposition of EU legislation and scientific attitudes that member states of the EU apply in cases of the occurrence of CSF (Plavsic et al. 2012).

Council Directive 2001/89/EC (Anonymous 2001) provides for measures to control CSF, which must be applied in the event of a disease outbreak in the EU. These measures are minimum measures. However, some EU countries, specifically in areas with a high density of pigs, include the destruction of all pigs within a radius of 500 m around the site of an outbreak as an additional measure. In fact, EU member states often opt for culling all pigs in areas with a radius significantly wider than 500 metres. In Serbia, there are plans to stop the implementation of preventive vaccination against CSF in the near future. However, there are no concrete data to show any positive effects that can be expected in the case of application of these measures, and it also remains unclear what the risk of disease and uncontrolled spread of the virus throughout susceptible populations in the case of cessation of vaccination would be. In this sense, for the purpose
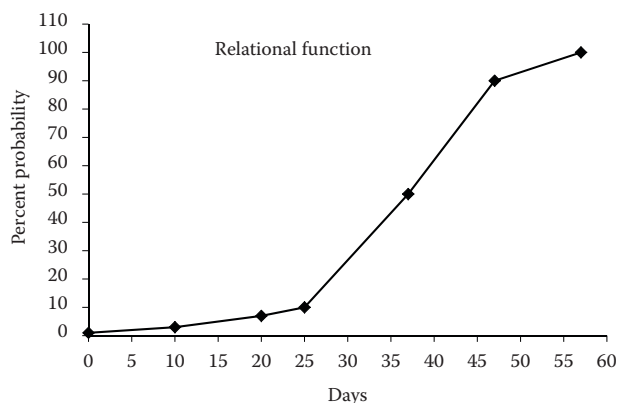
of simulation, this strategy has been modified and incorporated into the model. The modified control strategy which has been challenged through the simulations consists of depopulation of infected herds, surveillance and movement restriction in zones with radiuses of 3 km and 10 km and active surveillance in contact herds. It differs from the original with respect to the depopulation strategy and use of alternative measures such as emergency vaccination. The destruction radius around a commercial farm in the case of an outbreak is set to 100 m instead of 500 m and for family farms depopulation is only limited to the affected farm and farms in the immediate neighbourhood. Emergency vaccination is an alternative to preventive slaughter.

Control strategy: Tracing. In the model, a trace-forward investigation is conducted for all types of farms and backyard holdings. The tracing occurs immediately and traces the direct and indirect contacts. If a recipient of contact was successfully traced, it is automatically quarantined and destroyed if positive laboratory results are achieved for CSF. The trace direct contacts were simulated at 21 days before detection with 100% probability of trace success for commercial farms and 80% for the other production types. Indirect contacts were simulated 21 days (Anonymous 2002) before detection with an 80% probability of trace success on commercial farms, family farms types A and B, and 40% for backyard holdings.

Control strategy: Depopulation of diseased animals. The timeframe and capacities of the veterinary service for euthanasia and safe destruction of animals are pre-set according to specific circum-stances in the regions. Depopulation is limited only on infected holdings and immediate neighbourhood holdings, as well as on infected commercial farms and farms in the surrounding area (100 m radius).

Control strategy: Vaccination. Depending on the scenario, several different hypothetical situations were simulated, including the application of preventive mass-vaccination measures, the no-vaccination CSF control policy and emergency vaccination. Vaccination campaigns were simulated for all production types. For emergency vaccination one diseased unit of any production type must be detected before the vaccination program begins. The delay in unit immunity followed vaccination was four days (Kaden and Lange 2001; Qiu et al. 2006). The vaccination priorities were based on reason for vaccination, production type and days holding. The timeframe, radius of vaccination zone and capacities of the veterinary service for vaccination are known in advance and pre-set. In all scenarios emergency vaccination is an alternative to preventive slaughter. The radius of the ring of vaccination in the case of emergency vaccination was set to 10 km around the affected farm.

Setting up the scenario. Different scenarios were formulated and defined during the simulation process (Table 3). One thousand iterations of each scenario were run. This study compared the current CSF control strategy in the Republic of Serbia with different hypothetical scenarios. Output statistics of simulations varied in the number of farms, holdings and infected animals, animals depopulated, number of herds and animals vaccinated, duration of outbreaks based on the mitigation strategy ap-

Table 3. Definition of the different scenarios

	Scenario			
	1	2	3	4
Number of commercial farms	3	3	9	9
Number of family farms type A	35	35	145	175
Number of family farms type B	116	116	26	623
Number of backyard farms	1 053	1 053	1 027	400
Total number of holdings and farms of all types included in the simulation	1 207	1 207	1 207	1 207
Total number of animals in the simulation	36 370	36 370	36 370	36 370
Number of holdings with non-vaccinated animals	751	1 206	1 206	1 206
Number of non-vaccinated animals	10 224	36 361	36 361	36 361
Number of holdings with immune animals	455	0	0	0
Number of vaccinated animals at the beginning of the CSF epidemic.	2 6137	0	0	0
Percentage of vaccinated animals at the beginning of the CSF epidemic	72.00%	0.00%	0.00%	0.00%

Table 4. Summary of the simulation results after 1000 iterations

	Scenario 1			Scenario 2			Scenario 3			Scenario 4		
	p95	μ	δ	p95	μ	δ	p95	μ	δ	p95	μ	δ
Total number of holdings with clinically diseased animals during the simulation	24	9	8	57	25	17	36	17	10	75	31	23
Total number of clinically diseased animals during the simulation	481	176	155	1 906	807	584	1 122	549	335	1 003	406	324
Total number of holdings where euthanasia was carried out	37	14	12	148	52	45	113	45	34	176	63	56
Total number of culled animals	1 000	341	334	5 181	1 707	1 580	3 452	1 456	1037	3 123	1 074	992
Total number of holdings where pig vaccination was performed	1 202	1 113	194	1 202	1 178	66	1 202	1 178	82	1 202	1 178	64
Vaccinated animals	36 323	33 406	5 939	36 329	35 552	2 135	36 327	35 562	2 596	36 331	35 725	2 020
Total examined blood samples	1 548	542	513	3 446	1 429	1 065	5 095	1 742	1 618	2 492	824	784
Total holdings in the simulation	1 208			1 208			1 208			1 208		
Total pigs in the simulation	36 370			36 370			36 370			36 370		

plied, etc. When destruction and vaccination were complete, the outbreak was considered over with no more latent or infected farms and holdings.

The basic assumption was that upgrading the biosecurity level on a number of holdings and farms would result in different hypothetical situations with respect to the present condition and possible outcomes. The control strategy was modified and adjusted to fit the specificity of rural areas with extensive and heterogeneous pig production in terms of depopulation policy and application of emergency vaccination. At the same time a hypothesis was made that, depending on the level of established biosecurity measures, in conditions where all other control strategy factors are the same, there is a meaningful difference between possible outcomes. Four hypothetical scenarios were formulated in this way:

– Scenario 1: current condition. Control strategy starts from the assumption that preventive vaccination against CSF is performed constantly, with different performance level
– Scenario 2: current condition, but without implementation of preventive vaccination. Emergency vaccination and limited depopulation of diseased animals were applied
– Scenario 3: a number of family farms type A and type B are upgraded to commercial farms and family farms type A. Non-vaccination policy was implemented. Emergency vaccination and limited depopulation of diseased animals were applied
– Scenario 4: a number of family farms type A, type B and rural holdings are upgraded to com-

mercial farms, family farms type A and family farms type B. Non-vaccination policy was implemented. Emergency vaccination and limited depopulation of diseased animals were applied

Sensitivity analysis. In order to validate the model, sensitivity analysis was performed. For the purpose of sensitivity analysis the worst case scenario was selected (scenario number 2). Parameters like direct contact rate, probability of transmission of the virus via indirect contact, movement control and probability of success for the direct tracing of direct contacts for sensitivity analysis were changed from the baseline value. Values of selected parameters were changed from baseline values in a sensitivity analysis to assess their independent influence on the disease modelling results. For each variable independent simulation was run. The baseline probability of transmission given indirect contact was changed ± 25%. Sensitivity analysis of the contact rates was also completed with the direct contact rates adjusted to ± 25% of the baseline rate parameter. The influence of movement controls was assessed by changing the baseline movement control by −20% and −40%.

RESULTS

By analysing the results, it was determined that preventive vaccination would result in less direct damage, a lower number of diseased and culled animals, and a shorter duration of the epidemic in

Table 5. Summary of economic indices of the simulation after 1000 iterations (95th percentile)

	Scenario			
	1	2	3	4
Number of holdings with initially diseased animals at the beginning of the epidemic	1	1	1	1
Initially diseased animals at the beginning of the epidemic	9	9	9	9
Total number of holdings where euthanasia was carried out (p95)	37	148	113	176
Total number of culled animals (p95)	1000	5181	3452	3123
Total number of holdings where the animals were vaccinated (p95)	1202	1202	1202	1202
Total number of vaccinated animals (p95)	36 323	36 329	36 327	36 331
Total examined blood samples	1548	5095	3446	2492
Costs of cleaning and disinfection (EUR)	12 100	48 400	36 970	56 560
Costs of euthanasia (EUR)	1610	8350	5560	5030
Compensation for damage (EUR)	73 620	381 420	254 140	229 960
Safe destruction-rendering plant (EUR)	7850	40 690	27 110	24 530
Costs of vaccination (EUR)	43 690	43 690	43 690	43 690
Costs of surveillance (EUR)	4560	15 010	10 150	7340
Total costs (EUR)	143 430	537 560	377 620	367 110

the case of a CSF outbreak. When setting up all four scenarios, meaningful differences were observed in the applied strategies. The measure of depopulation of animals proved to be an effective measure in all cases, as well as the measure of ring vaccination. On the other hand, it was observed that the lowest economic losses are present when preventive vaccination is practiced and stable immunity of animals is maintained.

The greatest losses occur in the simulations of the second scenario, where preventive vaccination is forbidden. In the third and fourth scenario, also with no vaccination but with an improvement in the biosecurity level on pig farms/holdings, the results have indicated that there is a significantly lower number of diseased animals and less economic loses (Tables 4 and 5).

The results obtained during the simulation are shown in Tables 4 and 5. The data were presented in the form of descriptive statistics: mean, standard deviation and the 95th percentile. The epizootiological and economic values of four different strategies (scenarios) were obtained during the simulation and compared in Tables 4 and 5. Epidemiological and economic data clearly indicate the existence of statistically significant differences between the different scenarios and application of different CSF control measures. The tables show that the application of the measures included in scenario num-

ber 1 give the best results in terms of the number of diseased animals and costs. Scenario number 1 comprises the CSF control measures based on preventive vaccination, which is appropriate for the present situation. By analysing the results obtained during the simulation of CSF and implementation of measures included in the scenarios 2, 3 and 4, the relationship between the level of biosecurity measures introduced on the farms and the number of infected pigs and scope of economic damages could be determined. In scenario number 2 here, which emulates the present situation in term of pig production and hypothetical situation of CSF control without vaccination, the economic damage and the number of infected animals are the greatest. In scenarios 3 and 4, where the level of biosecurity measures were raised, the number of infected pigs, culled pigs and economic damages decrease gradually.

The results underline the importance of biosecurity, especially in commercial and family farms type A and indicate that a non-vaccination policy should be associated with implementation of biosecurity measures. All scenarios have demonstrated that an increase in the level of biosecurity measures reduces the spread of disease and economic damage. Due to more intensive movement of animals on commercial farms the risk for rapid spread is higher if CSF emerges on a commercial farm or family

farm type A. An epidemic starting on a commercial farm will last longer and have larger economic consequences. On the other hand, if the epidemic emerges in rural areas on family farm type B or on a backyard holding, the outbreak of disease could be unnoticed for a longer period of time and undetected infected farms or backyard holdings will continue to spread the virus.

Sensitivity analysis results

When the direct contact rate was changed by ± 25% from the baseline value, this had little influence on outbreak duration, but it did influence the number of destroyed animals and depopulated herds. When contact rate was decreased by 25%, the number of destroyed animals (p95) decreased by 67% and the number of depopulated herds (p95) decreased by 37%. Opposite effects was noted when the contact rate was increased. When the probability of transmission, following indirect contact, was changed by ± 25%, it had little influence on the duration of the outbreak. Changes of probability of transmission following indirect contact was more influential on the number of herds depopulated and animals destroyed than on the outbreak duration (e.g. the number of destroyed animals (p95) increased by 31% and the number of depopulated herds (p95) increased by 47%). The opposite effect was noted when the probability decreased.

Altering the effectiveness of movement controls was very influential. When indirect movement controls were decreased by 20%, the numbers of herds depopulated decreased by 65% (p95). When indirect movement controls decreased by 40% the number of herds depopulated increased by 180%.

DISCUSSION

This study presented possible outcomes of CSF outbreaks in a limited area with high-to-moderate pig density and under conditions of very heterogeneous pig production. It does not reflect the situation in the entire territory of the Republic of Serbia, but it does indicate possible approaches to long-term eradication of CSF in this country. The model applied in this simulation has certain limitations, considering that it implies random movement of animals, which is not always the case, especially

when closed systems of pig keeping are concerned. One of the potential sources of error is the system assumption that vaccinated pigs are 100% protected against a CSF, which is not the case under normal conditions. Although the models cannot fully emulate a biological system, they are capable of emulating such systems within the range of statistically acceptable errors, thus providing useful results (Moutou and Durand 2002). The simulation did demonstrate that crucial traditional measures control the disease well. It was observed that the lowest economic losses are incurred when preventive vaccination is practiced and stable immunity of animals is maintained. However, this measure cannot be implemented indefinitely, and it also brings some economic consequences in cases of intensive production and the potential export of pork.

Good governance of veterinary services, appropriate collaboration within the veterinary profession, active participation of pig owners and traders in the control of CSF, early detection of disease symptoms and improvement of implementation of biosecurity measures in pig farms are prerequisites for successful eradication of CSF. Transfer of responsibility for disease prevention to the owners is a must, particularly in terms of a long-term CSF eradication strategy, accompanied with national animal disease compensation fund development. Increasing agricultural subsidies will contribute to enhanced motivation of the owners to take an active part in solving the issues of CSF control. In underdeveloped countries the depopulation of animals on infected holdings is also very effective, but in a situation with a relatively low density of animals there is no need for extensive preventive culling of animals. Under the present conditions in the Republic of Serbia, based on the results, it is not reasonable to implement a CSF control strategy based on cessation of vaccination, particularly on rural holdings and family farms with lower levels of implemented biosecurity measures. Cessation of vaccination should be preceded by the analysis of economic consequences and the capability of the industry to export pork and pig products on the markets where a condition for sale is the cessation of vaccination (e.g. EU). Upon the analysis of the economic feasibility and sustainability of such a program, the next step should be adoption of a strategy of cessation of vaccination in stages (phases), where actions would be simultaneously taken to establish good agricultural and veterinary

practices, to introduce high-level biosecurity measures on holdings and farms where pigs are kept, and to cease vaccination in those zones. Money that could be saved due to cessation of vaccination would have to be redirected to the compensation fund, crisis response, early diagnostics, surveillance of natural reservoirs, awareness campaigns, and for increasing the level of biosecurity measures.

Also, it is important to stress that simple transposition of CSF control strategies which are developed for intensive pig production is not always appropriate for underdeveloped countries with low levels of pig production.

The EU strategy of control and eradication of CSF and regulations do not treat the specifics of extensive production and demographic characteristics of countries with extensive pig production. Taking into consideration the fact that the current policy of the EU is not universal and cannot be successfully applied in all circumstances, the strategy should be adjusted for specific pig production and the economic situation of the country.

Based on the results, we conclude that a strategy consisting of the minimum control measures stipulated by the EU legislation supplemented with limited depopulation of contact herds and preventive vaccination is the most effective among the evaluated strategies with respect to limiting the size, duration and cost of the epidemic.

In the case of the cessation of vaccination, regarding the number of culled animals, the vaccination-to-live strategies appear to be more effective. Epidemics become larger and last longer if the index case is a commercial farm. This implies that biosecurity is extremely important in preventing the transmission of CSF, especially on commercial farms. Stamping-out modified with emergency vaccination-to-live or stamping-out modified with emergency vaccination-to-slaughter strategies appear to be more effective and appropriate for developing countries. The selection of the strategies depends on the desired CSF-status after an outbreak and capabilities of export of pig meat and live animals. In areas with a moderate-to-low density of pigs, there is no need for extensive preventive culling of animals, especially in villages with predominantly backyard or low intensive production of pigs. Depopulation can be limited only on infected holdings and immediate neighbourhood holdings with strict movement control, tracing of indirect and direct contacts and wide surveillance in the zones.

The simulation has shown the possible dynamics of an epidemic and the extent of the possible scale of costs, when different approaches to control the disease are applied. The simulation revealed that the measure of depopulation should be circumscribed to the epidemiological situation and density of pigs. The model showed that backyard farms are very sensitive to the occurrence of CSF; however, the potential for spreading the virus from backyard farm over a larger distance is limited. The spread of disease over long distances is more frequently associated with type A, type B and commercial farms. The model also showed that the most common route of transmission of the CSF virus from a backyard farm is local spreading while on category B farms local spread and indirect contacts are the predominant routes of transmission.

The simulations have shown that uncontrolled natural mating when boars, so-called "walkers", are used for the mating of sows occupies a special place in the spread of the disease at the level of settlements. The occurrence of CSF on Type A family farms is usually associated with the purchase of animals for fattening from manufacturers from the category of type B and backyard farms. Outbreaks on commercial farms are commonly associated with the introduction of infected animals into the herd and contact with backyard farms through workers who work on a farm and have their pigs at home. Measures of safe disposal of animals and also protective vaccination proved to be effective in all cases. The least economic damage occurs in conditions where preventive vaccination is practiced, and maintains immunity in animals. However, this measure cannot be applied indefinitely. It also carries certain economic consequences and affects export potential for pigs and pork meat in markets where the control of CSF without vaccination is required.

Simulations have shown that raising the general hygiene and biosecurity measures on farms and backyard farms significantly reduced the spread of disease, the number of infected animals and the amount of economic damages in the event of a epidemic. In combination with other measures of biological protection, such as good management practices on the farm, controlled access of people and vehicles, eliminating unnecessary contacts with other owners of pigs, artificial insemination, avoiding contact with wild pigs, such measures contribute to significantly reducing the risk of oc-

currence of CSF. Investment in rearing pigs and raising the level of biosecurity measures on family farms type B and backyard farms are crucial for the eradication of the disease.

Tight control of natural mating and the avoidance of unnecessary indirect contacts on type B farms and backyard farms, contributes to a significant reduction of risks arising from CSF. When natural mating is only allowed to fertilise sows that are raised on the same farm in the simulation, e.g. male does not leave the farm, the number of infected pigs was lower by 43–59%, and the economic damages were reduced by 34–36%. The epidemic had an average duration of 67 days. This total was 14 days shorter compared to a scenario where natural breeding was not controlled.

CONCLUSIONS

Based on the results, we conclude that a strategy consisting of the minimum control measures stipulated by the EU legislation supplemented with limited depopulation of contact herds and preventive vaccination is the most effective among the evaluated strategies with respect to limiting the size, duration and cost of CSF epidemics.

In the case of cessation of vaccination, regarding the number of culled animals, the vaccination-to-live strategies appear to be most effective. Epidemics become larger and last longer if the index case is a commercial farm. This implies that biosecurity is extremely important to avoid transmission of CSF, especially on commercial farms.

Stamping-out modified with emergency vaccination-to-live or stamping-out modified with emergency vaccination-to-slaughter strategies appear to be most effective and appropriate for developing countries. The selection of the strategies depends on the desired CSF-status after an outbreak and capabilities of export of pig meat and live animals.

In areas with a moderate-to-low density of pigs, there is no need for extensive preventive culling of animals, especially in villages with predominantly backyard or low intensive production of pigs. Depopulation can be limited only to infected holdings and immediate neighbourhood holdings with strict movement control, tracing of indirect and direct contacts and wide surveillance in the zones.

Under the present conditions in the Republic of Serbia, it is not reasonable to implement a SCF

control strategy without vaccination, particularly on rural holdings and family farms with lower levels of implementation of biosecurity measures.

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