Original scientific paper UDK 619:616.988.75:636.4

COMPARATIVE ANALYSIS OF DIFFERENT STRATEGIES FOR THE CONTROL OF CLASSICAL SWINE FEVER IN THE REPUBLIC OF SERBIA USING MONTE CARLO SIMULATION

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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 analyzed 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 epizootic 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 protection and surveillance zone proved to be the most effective measures to stop spreading and eradication of the disease. However, during the simulation, systematic implementation of biosecurity measures in all pig production clusters demonstrated to be appropriate strategy for sustainable

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control of CSF and setting up a stable epizootiological situation.

Key words: classical swine fever, Monte Carlo, biosecurity measures, control strategy

KOMPARATIVNA ANALIZA RAZLIČITIH STRATEGIJA ZA KONTROLU KLASIČNE SVINJSKE KUGE UPOTREBOM MONTE CARLO SIMULACIJE

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Kratak sadržaj

Nekoliko različitih strategija za kontrolu i iskorenjivanje klasične kuge svinja je upoređivano primenom modela simulacije zasnovanog na Monte Karlo metodi. Kontrolne strategije koje su obrađivane u ovom radu, pored opštih i posebnih mera suzbijanja KKS, uključuju i različite nivoe primenjenih biosigurnosnih mera na komercijalnim, porodičnim farmama i seoskim gazdinstvima na kojima se ga je svinje. Mere neškodljivog uništavanja obolelih životinja i životinja koje su bile u kontaktu sa obolelim životinjama, uspostavljanje zaštitnih zona pod nadzorom, kontrola i zaustavljanje prometa životinja i mehaničkih vektora (vozila i ljudi) unutar zona, rano otkrivanje bolesti i mera vakcinacije su bile uključene u simulaciju. Izlazni parametri kao što su: vreme trajanja epizootije, broj zaraženih gazdinstava i životinja, broj uništenih životinja, troškovi nadzora i direktne štete nastale zbog pojavljivanja bolesti s upoređivani tokom simulacije. Vakcinacija, neškodljivo uklanjanje obolelih životinja i rana dijagnostika su se pokazale kao najefektivnije mere zaustavljanja širenja i iskorenjivanja bolesti. Međutim, kao mera dugoročne strategije kontrole KKS i uspostavljanja stabilne epizootiološke situacije, tokom simulacije pokazala se mera planskog i sistematskog podizanja biosigurnosnih mera u svim klasterima proizvodnje svinja (komercijalne farme, porodične farme tipa A, porodične farme tipa B i seoska gazdinstva).

Ključne reči: klasična kuga svinja, Monte Karlo, biosigurnosne mere, kontrolna strategija

INTRODUCTION

Classical swine fever (CSF) is highly contagious disease of viral etiology affecting domestic and wild pigs. From economic aspect, CSF is the most severe threat to national pig industry in all countries. The disease is spread worldwide and is reported at all continents. Models and simulation of CSF epizootics enables assessment of disease dynamics as well as economic effects of implemented control measures. The objective of this article is to analyse potential control strategies for eradication of CSF in the Republic of Serbia based predominantly on improvement of biosecurity measures on a typical rural holdings and gradual upgrading of rural holdings to higher farm categories.

MATERIAL AND METHODS

Description of the simulation model

The simulation has been conducted in the territory of the municipalities of Sremska Mitrovica and Šid. The area is characterized by high density of pigs as well as substantially heterogeneous pig-breeding technology, production habits and policies as well as production scale. The simulation encompassed all pig-breeding holdings including commercial farms, family farms type A, family farms type B and backyard holdings. The data on the number of pigs, production categories, and geographical locations were collected during the field investigation or obtained from the Central Database of Ministry of the Agriculture. Data processing was performed using ARC GIS 10.0. software package (Gatrell, 2004; Stanojevic, 2014). In cases where data about geographical location of rural holdings were not accessible, these were obtained from the Central Database of Ministry of Agriculture and the geographic coordinates were determined in ARC GIS 10.0, by randomly selecting (Gatrell, 2004). The simulation was performed applying the North American Animal Disease Spread Model based on the Monte Carlo method. NAADSM is a computer program based on the Monte Carlo method and is developed for the simulation of contagious animal diseases. The software was developed by a team of experts of the Center for Epidemiology and Animal Health US Department of Agriculture from Fort Collins, Colorado (Jalvingh et al., 1999; Harvey et al., 2007; Reeves et al., 2012).

The basic idea underlying the Monte Carlo method is the approximation of the expected value E(*X*) by the arithmetic mean of the results of a large number of independent tests all with the same distribution as *X*. The stochastic simulations use random variables and are based on the law of random numbers (Jalvingh et al., 1999).The model simulates daily disease transmission between farms and rural holdings for pig production. The simulation includes both direct and indirect contacts. The events such as "contact between the various epizootical units – adequate contact" and "contact between the various units that caused the transmission of diseases – effective contact" are generated stochastically. The variability of the obtained results after 1,000 replications provide the information about the potential pattern of disease spreading (Gatrell, 2004; Engel et al., 2005; Harvey et al., 2007).At the beginning of the simulation, all backyard holdings and farms are considered "susceptible", except in cases where a number of pigs are vaccinated. Once acquiring the status "infected", a holding/farm has to pass through all other statuses predefined in the model. Table 1. describes the definition of the disease transition states.

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

Status	Definition of status
Susceptible	All animals in the herd not infected and can be infected in 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.

After a short period of latency, all infected pigs disseminate the virus among susceptible population. However, there are certain differences in probability of an outbreak of the disease after adequate contact. Such differences are determined by intensity of direct and indirect contact between animals, the type of the holding and farming system itself as well as the level of implemented biosecurity measures. Some potential scenarios entail that certain number of pigs is vaccinated, thus possessing artificially induced immunity, which makes them non-susceptible. Defining parameters for disease spread sets down the modelling of control measures, laid down by relevant regulations. Upon completing the simulation, the following data are analysed: total number of infected farms and holdings, total number of diseased and culled animals, number of farms and holding where euthanasia was performed, duration of the outbreak, financial data such as costs of euthanasia, disinfection and cleaning, expenses of safe disposal of carcasses, costs of laboratory examination etc. Depending on the scenario, several hypothetic situations were simulated including preventive vaccination of animals and no-vaccination scenario. The initial scenario describes actual status of CSF control in Serbia. Other scenarios simulated spread of the disease in conditions with no vaccination or emergency vaccination aimed at preventing virus transmission outside of infested area (Table 2).

Table 2. Scenario set up

No.	Preventive vaccination policy	Herd immunity	Protective vaccination (radius)	Depopulation: r= 500 m around infected farm	Depopulation: r= 100 m around infected farm	Depopulation: r= 50 m around infected farm	Biosecurity measures
1.	yes	49%	-	CF, A, B, RH1, SG2	-	-	-
2.	yes	49%	-	CF	A	B, RH1, RH2	-
3.	yes	49%	-	CF	-	A, B, RH1, RH2	-
4.	yes	49%	-	-	CF	A, B, RH1, RH2	-
5.	no	0%	ne	CF, A, B, RH1, SG2	-	-	-

6.	no	0%	10km	CF	A	B, RH1, RH2	-
7.	no	0%	3km	CF	A	B, RH1, RH2	-
8.	no	0%	10km	CF	-	A, B, RH1, RH2	
9.	no	0%	3km	CF	-	A, B, RH1, RH2	
10.	no	0%	10km	-	CF, A	B, RH 1, RH 2	-
11.	no	0%	3km	-	CF , A	B, RH 1, RH 2	-
12.	no	0%	3km	-	CF, A	B, RH 1, RH 2	no natural mating (NNM)
13.	no	0%	3km	-	CF , A	B, RH 1, RH 2	NNM & 25% indirect con-tacts
14.	no	0%	3km	-	CF, A	B, RH 1, RH 2	NNM & 50% indi-rect con-tacts

CF–commercial farm; A- family farm type A; B- family farm type B; RH1- rural holding category 1; RH2- rural holding category 2

Disease parameters

The diseases characteristics and input parameters, used for analysis with NAADSM are based on data from literature and results of retrospective analyses of CSF cases in the Republic of Serbia in 2005, 2006 and 2007 (Table 3) (Backer et al., 2011).

Table 3. Disease transmission parameters

Parameters	**Probability distribution**	**The mean value / standard deviation in days**
The latent period (Laddomada, 2000)	Poisson distribution	7(1); 8(1)
Subclinical period (Martinez-Lopez et al., 2011)	Poisson distribution	21
Infectious period (Baker et al., 2011)	Gamma distribution	Alfa: 13.5, beta: 1
Immune period after vaccination (Qui et al., 2006)	The normal Gaussian distribution	300/60
The number of direct contacts between animals daily- direct sales to owners *	Poisson distribution	*Type of farm* *Intensity* Industrial farms 0.07 Type A 0.009 Type B 0.0074 Back yard farm 0.0036
Number of contacts direct natural mating (mating animals) *	Poisson distribution	*Type of farm* *Intensity* Type B 0.016 Rural farm 0.0057
The probability of transmission of the virus through direct contact if the farm / farm source of infection (Karsten et al., 2005a)	Bernoulli distribution	*Type of farm* *Probability* Industrial farms 0.7 Type A 0.7 Type B 0.8 Rural farm 0.8
Number of indirect contacts per day *	Poisson distribution	*Type of farm* *Intensity* Industrial farms 0.1428 Type A 0.1428 Type B 0.0330 Rural farm 0.2850
Local spread of the virus (Karsten et al., 2005a)	Bernoulli distribution	*Distance from the farm* *Mean value* 150m 0.020 150-250m 0.010 250-500m 0.004 500-1000m 0.002

Parameters	Probability distribution	The mean value / standard deviation in days	
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	*Number of days*	*Probability*
		8	0%
		10	3%
		20	7%
		25	10%
		37	50%
		47	90%
		50	100%
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 findings pathoanatomic) (Klinkenberg et al., 2005)	Fixed value	*Number of days*	*Probability*
		1	20%
		2	30%
		3	40%
		4	50%
		5	60%
		6	70%
		7	80%
		8	100%
The probability of successful tracking of shipments of animals that have left an infected farm (**)	Bernoulli distribution	*Type of farm*	*Mean value*
		Commercial Farm	0.80
		Family farm type A	0.80
		Family farm type B	0.80
		Rural farm	0.40
The probability of successful detection and monitoring of indirect contact with infected farm (Martinez-Lopez et al., 2011)	Bernoulli distribution	*Type of farm*	*Mean value*
		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 CSF epidemic in Serbia in 2010

Figure 1. Latent period

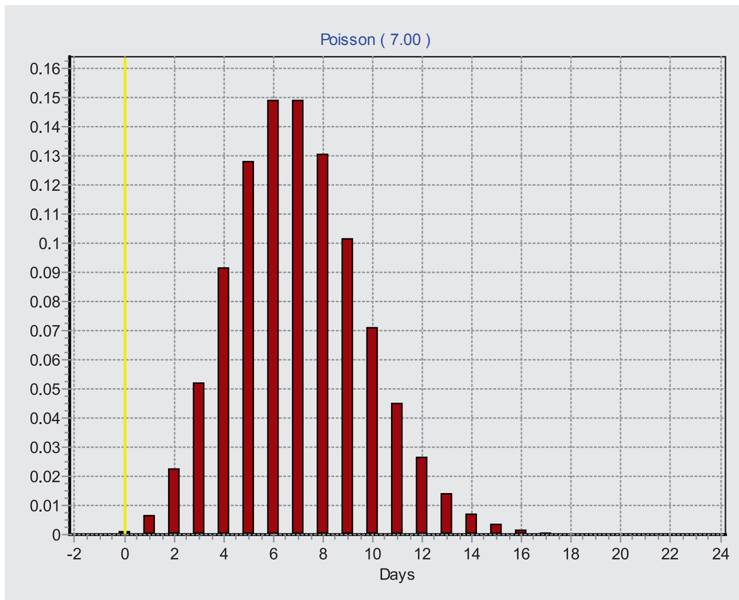


Figure 1. Clinical infectious period

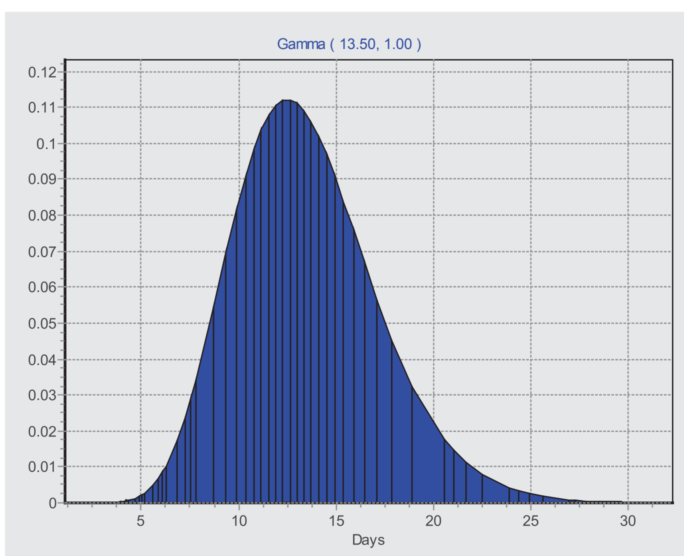
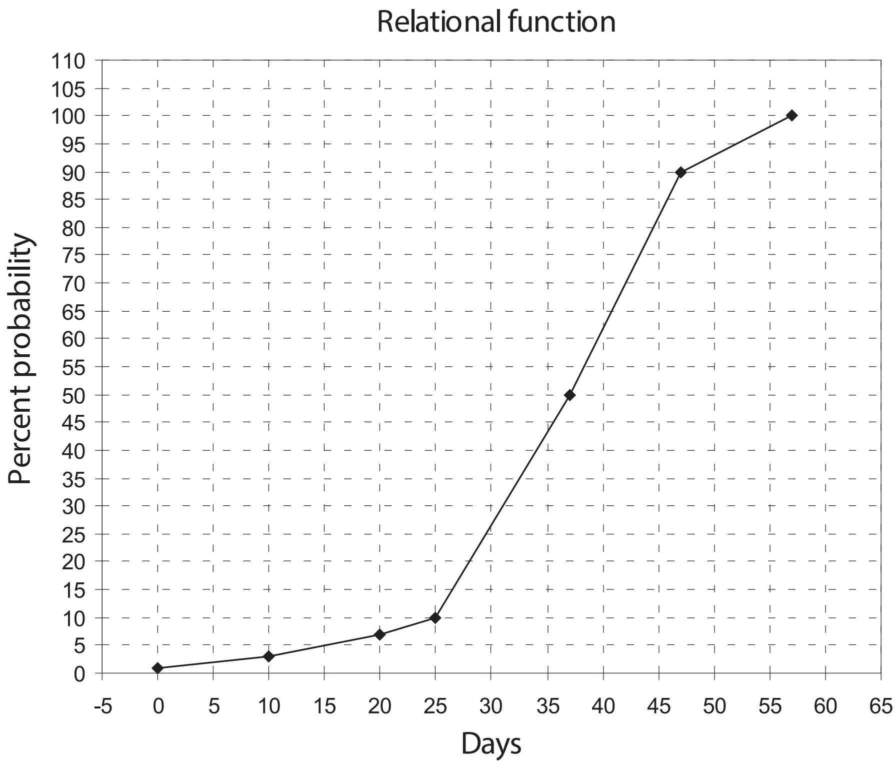


Figure 3. The probability of detection of first cases or observing clinical signs of CSF on industrial farm, type A, B and backyard farm. The detection probability was modeled as based on the results from Klinkenberg et al. (2005) and Engel et al. (2005) and available data from epidemics of CSF in Serbia between 2005 and 2010.



RESULTS

Simulation of the scenario No.1 entailed analysis of the effects of implementation of currently relevant measures for CSF control in case of disease outbreak, taking into consideration factors such as actual production conditions and capacities of field veterinary service. Scenarios 2-4 dealt with potential modifications of current control strategies and the assessment of their effects when applied in conditions of CSF control using preventive vaccination policy. In scenarios No. 5-14, hypothetical situations of no-vaccination CSF control were tested. The testing included also the hypothesis on CSF control using protective vaccination as well as the improvement of biosecurity measures on rural holdings and family farms type B such as restriction of natural mating and intensity of indirect contacts. Fourteen different hypothetical scenarios have been analysed (Table 2).

The analysis of obtained results revealed that CSF control using preventive vaccination strategy results in less direct economic losses, less number of diseased and culled animals as well as significantly shorter duration of the epizootic. The simulation indicated that the area for preventive euthanasia of pigs should be set to a radius of max 50m around extensive rural holdings and family farms type A and B, and 500m around commercial pig farms. The simulation also revealed no statistically significant differences regarding duration of epidemics, number of infected holding or animals even if the depopulation radius was limited to 100m around the infected commercial farm.

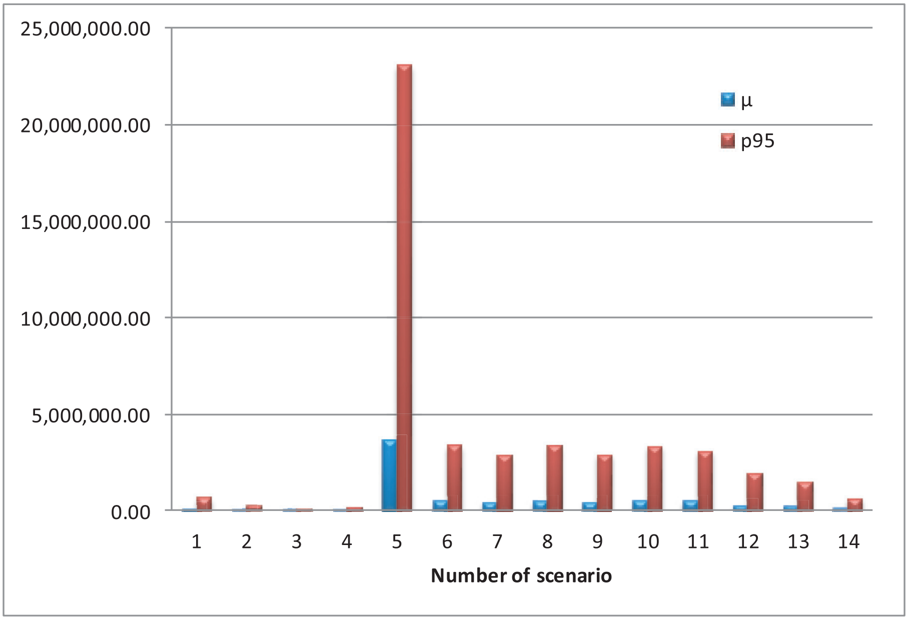
The most severe losses were observed in a scenario that was identical with the current field conditions, yet presuming cessation of vaccination program and absence of protective vaccination in case of CSF outbreak. In scenarios No. 12, 13 and 14 characterized by absence of preventive vaccination but with restricted natural mating and improved biosecurity measures on rural holdings and family farms type B, the results revealed statistically significant decrease in number of diseased animals as well as lower economic damage.

In conditions of termination of vaccination, the scenario No. 9 proved most appropriate, that is, the following measures are most effective: depopulation radiuses set to 500m and 50 m around commercial farms and rural holdings/family farms type A and B, respectively; implementation of protective vaccination policy and other measures laid down in relevant legislation. In all simulation models, there were no statistically significant differences between the effects of protective vaccination applied in the radius of 10km or 3 km around the commercial farms.

Table 4 depicts the results obtained in simulation models for 14 different scenarios. In scenarios No.1-4, potential modification of current CSF control strategy relying on preventive vaccination are analysed. The results obtained in simulation scenario No. 5 indicated that veterinary service is unable to control CSF without protective vaccination. As obvious from Table 4, implementation of controlled natural mating in case of CSF outbreak results in statistically significant decrease in number of diseased animals as compared with scenarios lacking this measure (scenario No. 12 in Table 4).

Furthermore, if controlled natural mating in case of an outbreak of CSF would be associated with a decrease in intensity of indirect contacts for 25% and 50%, the number of diseased animals would be even more decreased (scenarios No. 13-14, Table 4).

Graph 1. Comparative graph of total economic damage expressed in EUR



Legend:
- CFS control applying preventive vaccination (scenarios 1-4);
- No-vaccination CFS control (scenario5);
- CFS control applying protective vaccination as the alternative to mass pig (scenarios 6-11);
- CFS control applying protective vaccination and improvement of biosecurity measures at rural holding and family farms type B (scenarios 12-14).

Table 4. Results of the simulations applying various control strategies. Average values, standard deviation and 95.percentile for the total number of infected animals, total number of vaccinated animals, total number of slaughtered animals and duration of epizootics.

Scenario No.	Herd immunity	Total number of infected animals			Total number of vaccinated animals			Total number of slaughtered animals			Total number of examined blood samples			Duration of epizootics		
		μ	SD	p95	μ	SD	p95	μ	SD	p95	μ	SD	p95	μ	SD	p95
1.	49%	116	325	519	23,406	37,217	104,780	1,165	2,571	5,640	7,333	6,855	17,552	57	23	104
2.	49%	140	472	562	25,897	42,293	117,274	357	1,595	1,017	7,774	7,397	18,712	58	24	104
3.	49%	116	320	548	24,353	38,251	111,029	222	691	782	7,480	6,790	17,961	58	23	106
4.	49%	129	364	575	26,120	39,493	112,772	311	1,093	933	7,429	6,887	17,594	58	23	106
5.	0%	9,781	21,768	65,782	0	0	0	37,478	78,826	238,756	20,186	25,706	83,131	137	158	499
6.	0%	3,771	9,909	29,191	82,463	94,177	286,775	4,389	10,941	31,133	14,478	15,261	51,915	81	42	162
7.	0%	3,397	8,696	23,148	80,942	92,927	286,980	3,897	9,441	25,664	14,289	14,467	50,078	81	43	169
8.	0%	3,808	9,847	27,432	81,354	95,082	286,020	4,330	10,852	31,180	14,420	15,276	51,242	82	44	166
9.	0%	3,363	9,103	23,803	76,856	89,722	276,794	3,841	14,638	26,482	13,457	13,809	47,890	81	67	168
10.	0%	3,971	9,873	29,799	87,534	97,035	292,412	4,374	10,510	30,455	15,108	15,307	51,955	84	45	168
11.	0%	3,748	9,597	27,729	80,417	93,138	287,650	4,265	10,582	27,981	14,702	15,601	52,424	82	44	168
12.	0%	1,935	6,890	12,718	57,442	78,604	250,911	2,348	7,867	17,056	10,309	12,256	28,333	67	34	134
13.	0%	1,506	5,478	9,938	56,272	75,391	228,351	1,841	611	12,422	8,919	10,785	26,865	66	34	135
14.	0%	921	4,291	2,501	47,728	67,302	195,894	1,094	4,379	4,508	6,496	8,512	19,429	64	32	132

μ- average value within population; SD- standard deviation; p95- 95.percentil;

DISCUSSION

Simulation and mathematic modelling enable the pre-estimation of optimal control strategies, quantification of potential epizootic outcomes, adjustment of relevant control plans, assessment of veterinary service and necessary resources (Jalvingh et al., 1999; Karsten et al., 2005a). This research offered a review of potential outcomes of CSF outbreak in a limited area characterized by high pig density and highly heterogeneous pig production system. Potential dynamics of CSF epizootic as well as the level of consequent damage were described relating to different approaches to disease control and eradication. The simulation revealed that rural holdings are highly susceptible to CSF; however, in such holdings, the potential for virus spread over large distance is lower, which corresponds with simulation results reported in Bulgaria (Backer et al., 2011). Spread of the disease over large distances is mainly associated with family farms type A and B and commercial farms. Rural holdings producing pigs for their own needs are not considered to be of high potential risk for disease transmission. The simulation model also suggested that, when speaking of rural holdings, local transmission is the most common route of infection with CSF virus. As regards the farms type B, most common infection routes include both local spreading and indirect contacts. The obtained results correspond with the results of the study analysing the potential of local spread of CSF virus conducted in Holland during a CSF epidemics in 1997-1998 (Karsten et al., 2005b; Klinkenberg et al., 2005). The simulation emphasized the role of uncontrolled natural mating in disease spreading at settlement level. Occurrence of CSF on family farms type A is mostly associated with the purchase of animals for fattening from producers from family farms type B and rural holdings. When speaking of commercial farms, two potential risk factors are most commonly associated with CSF outbreaks – introduction of infected animals into the herd and contacts with rural holdings through the personnel employed at the farm, who have their own pigs at home. Safe elimination of animals and protective vaccination proved most effective. On the other hand, the least economic losses are observed in conditions of continuous maintenance of appropriate immunity status of animals. Improvement of biosecurity measures proved highly important for substantial reduction of both disease transmission and economic damage in case of epidemic outbreak. Combined with other biosecurity measures such as good on-farm production practices, controlled access of visitors and vehicles, elimination of unnecessary contacts with other pig owners and preventing contacts with wild boars contributes to substantial reduction of the risk for CSF outbreaks.

CONCLUSIONS

Based on the results obtained in this research, we may conclude as following:

1. In endemic areas with predominate extensive pig production, relying on CSF control, strategy based on preventive vaccination proved most cost effective.
2. Preventive slaughtering of pigs should be carried out in the radius of max 50 m around the infected rural holdings, whereas destruction radius for commercial farms is set to 100 m.
3. If selecting the no-vaccination CSF control policy, modified EU strategy based on protective vaccination and limited pig depopulation in a radius of 500m around infected commercial farms, i.e., 50 m around infected family farms type A and B and rural holdings, has proved most cost effective.
4. For all simulation models, where protective vaccination was used as control measures in combination with limited depopulation, there were no statistically significant differences between the effects of protective vaccination if applied within the radius of 10 km around infected farm as compared to the radius of 3 km.
5. Restriction of natural mating and its limitation to one's own herd significantly reduces the risk of virus transmission and CSF outbreak.
6. 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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Primljeno: 30.09.2016.
Odobreno: 10.10.2016.