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A quantitative modeling approach to estimate the risks posed by the smuggled animal products contaminated with Foot-and-Mouth Disease (FMD) virus

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Abstract : A quantitative risk assessment tool was used to provide estimates of the probability that foot-and-mouth (FMD) virus-contaminated, smuggled animal products are fed to susceptible swine in Korea. Sensitivity analyses were conducted to attempt to distinguish between parameter uncertainty and variability, using different assumptions on the effect of cooking at home, the effect of the fresh meat, and the effect of heat treatment at garbage processing facility. The median risk estimate was about 20.1% with a mean value of 27.4%. In a scenario regarding all beef and pork were considered as fresh meat the estimated median risk was 3.4%. The risk was greatly dependent on the survival parameters of the FMD virus during the cooking or heat treatment at garbage processing facility. Uncertainty about the proportion of garbage that is likely contaminated with FMD had a major positive influence on the risk, whereas conversion rate representing the size of a load had a major negative effect. This model was very useful in assessing the risk explored. However, the model also requires enhancements, such as the availability of more accurate data to verify the various assumptions considered such as FMD prevalence in a specific country, proportion of garbage which is recycled as feed, proportion of food discarded as garbage. Other factors including the effect of selection of animals for slaughter, ante- and post-mortem inspection, the domestic distribution of the smuggled products, and susceptible animals other than pigs, are need to be taken into account in the future model development.

Key words : risk assessment, foot-and-mouth disease, simulation, animal product, garbage

Introduction

Foot-and-mouth disease (FMD) is a highly contagious viral disease that primarily affects cloven-footed animals. The disease is characterized by the formation of vesicles on the skin. The nostrils, lips, oral mucosa, coronary bands and interdigital space of the feet typically are affected [15]. Affected animals often drool and may be lame [9]. The importance of FMD lies not so much in its killing power, for mortality usually is not great, but in morbidity losses of milk and long periods in which affected animals are not productive [8]. The most significant effect of an outbreak of FMD in developed countries is the widespread restriction on trade in susceptible animals and animal products imposed by FMD-free trading partners [2, 5, 7]. For this reason, FMD is regarded as one of the most important non-zoonotic animal disease and categorized as listed disease by Office International des Epizooties (OIE).

There are several animal diseases which could be introduced into a country by means of smuggled animal products. In 1995, Centers for Epidemiology and Animal Health (CEAH) of the United States Department of Agriculture (USDA) [3] performed a risk assessment on swill feed practice for FMD, classical swine fever (CSF), African swine fever (ASF) and swine vesicular disease (SVD). Canada also has its own primary disease lists which should be considered first in risk assessment related with animal and/or their products and those lists include FMD and bovine spongiform encephalopathy for bovine meat and edible offal and FMD, SVD, ASF and CSF for swine meat and edible offal [1].

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Under the Agreement on Sanitary and Phytosanitary Measures (SPS) member countries can employ measures to protect human, animal or plant health provided that these measures are based on scientific evidence [12]. With regard to the importation of a commodity, the main aim of the SPS is to provide importing countries with an objective and defensible method of assessing the disease risks associated with the importation of animals and animal products, and can be achieved by use of import risk analysis [14].

With this background the authors performed a risk assessment to answer the question: what is the probability that at least one load of garbage which is contaminated with FMD virus (FMDV) and smuggled into Korea from foreign country, will be insufficiently treated and ultimately fed to Korean swine in a year? To the author's knowledge the answers are of value to the government authorities as they continue to develop quarantine policy to reduce the disease risks associated with illegal imports, emphasizing the need to maintain high standards of biosecurity in Korea.

Materials and Methods

Scenario and Monte Carlo simulation

The scenario considered in the present study was basically originated from a model conducted by CEAH, USDA [3]. Overall, the scenario consisted of 5 steps of conditional probabilities. Briefly, the initiating event is the selection of meat or meat products to be smuggled into Korea. Branch point 1 is the probability (F1) that the animal which was selected for slaughter and the meat or meat product to smuggle into Korea is infected with FMDV. The probability of F1 is associated with the prevalence of FMD in the country of origin. Branch point 2 is the probability (F2) that the items carry FMDV, given that the animal from which the item was made is infected with the virus in specific country. The probabilities, F1 and F2 correspond to release assessment that assesses the probability that the FMDV can be released into Korea by those items. Branch point 3 is the probability (F3) that the item contains FMDV even after heat treatment in households or cooking facilities. Branch point 4 is the probability (F4) that the item is discarded with FMDV as garbage and collected by garbage collector to use as recycled feed and holds the virus after heat treatment in the collectors' facility. Finally, branch point 5 is the probability (F5) that the item is likely fed to susceptible swine in Korea, given that it holds the FMDV. The probabilities, F3, F4 and F5 correspond to exposure assessment which assesses the probability that FMDV can be exposed to swine in Korea. Overall probability gives us the estimate for total probability that smuggled animal products contaminated with FMDV is fed to Korean swine.

The formulas and probability distributions used in the model are described in Table 1. The model was written in Microsoft Excel (Microsoft, Seattle, WA) and run using @Risk (Palisade, Newfield, NY) Monte Carlo simulation software with 10,000 iterations with Latin hypercube sampling.

Modeling methods

(1) Input parameters

① F1 (FMD prevalence)

The prevalence of FMD in the country of origin was estimated by Annual Animal Health Information using Handistatus of the OIE. In this assessment, the prevalence of the country in which there was no outbreak of the disease in 1998-2002, was assigned as 'negligible' and in which there was only one year when it had outbreaks of the disease, as 'low'. The countries of origin which had had 2 or 3 years when it had outbreaks of the disease was categorized into 'medium' prevalence, and the countries which had had 4 or 5 years when it had had outbreaks, into 'high' prevalence. To incorporate the uncertainty of the prevalence, the probability distributions were estimated for each level of prevalence using triangular distribution. FMD prevalence in negligible risk group was designated as F1n, in low risk group as F1l, in moderate risk group as F1m and in high risk group as F1h.

② CAM (amount of animal products smuggled)

CAM is the amount of animal products which are smuggled into Korea from other countries without detection. This was inferred from the amount of animal products which were detected by National Veterinary Research and Quarantine Services (NVRQS) upon entry into Korea [13]. In 2003, NVRQS detected about 36,000 kg upon entry which was decided as inappropriate to pass and all of them were dealt mainly by burning. Assuming that between 50-90% of contraband food of animal origin in passenger baggage at airports escapes interception [3], estimated minimum CAM was 36,000 kg and maximum 180,000 kg.

Table 1. Description of model inputs and outputs

Description of variables	Notation	Formula used with @Risk (the notations of MS Excel are being used)
Input parameters		
FMD prevalence in specific country group	F1	Negligible = 0
		Low = RiskTriang (0,0.0005,0.001)
		Medium = RiskTriang (0.001,0.03,0.05)
		High = RiskTriang (0.05,0.1,0.2)
The amount of animal products smuggled	CAM	RiskUniform (36000, 180000)
Proportion of intercepted animal products	PCAM	Negligible = 0.3138
		Low = 0.1289
		Medium = 0.3792
‘		High = 0.1781
Proportion of each product	F2	F2bb: beef (low=0.33; med=0.38; high=0.264)
		F2bp: pork (low=0.1; med=0.17; high=0.11)
		F2c: ham. Sausage, bacon (low=0.5; med=0.35; high=0.59)
		F2ao: other meat (low=0.028; med=0.057; high=0.01)
		F2ap: poultry (low=0.042; med=0.043; high=0.026)
Proportion of FMDV contaminated SAP	PCA	RiskOutput(((F2bbl+F2bpl+F2lc*(1-F3))*F1l*PCl +(F2bbm+F2bpm+F2mc*(1-F3))*F1m*PCm +(F2bbh+F2bph+F2hc*(1-F3))*F1h*PCh))
The amount of FMDV contaminated SAP	CA	RiskOutput (CAM*PCA)
Effect of home cooking	F3	0.85
Effect of heat treatment at garbage facility	F4	0.5
Total food consumed in households in Korea	TF	26,018,900 ton
Total garbage in Korea per year	TG	4,101,505 ton
Proportion of garbage which is recycled as feed	PG	0.3
Proportion of food discarded as garbage	DR	TG/TF
The amount of likely FMDV-contaminated garbage	AP	CA*F3*F4*DR
Proportion of garbage that is contaminated with FMDV	TP	RiskOutput (RiskUniform(0, AP/TG))
Loads of garbage fed to swine	F	TG/CR
Conversion rate	CR	RiskTriang (0.06, 3.58, 26)
Output parameters	P	$1-(1-TP)^F$

Abbreviation: SAP, smuggled animal products.
Refer to texts for detailed description for each notation.

③ PCAM(proportion of intercepted animal products)

The proportion of intercepted animal products from specific countries group was calculated directly from the NVRQS report [13]. After the amount of animal products from each group was divided by total amount, the resulting proportion for negligible risk group was designated as PCn, for low risk group as PCl, for medium risk group as PCm and for high risk group as PCh.

④ F2 (proportion of each product)

The period of FMDV persistence is strongly affected by the type of animal products and by processing that may occur. To incorporate this, animal products was divided into beef, pork, ham, sausage, bacon, poultry and other meats. The proportions of the amount of each product type per specific group of countries were calculated by the amount of each product type divided by sub-total amount per specific group. Poultry and other meats (type A) were considered not to have potency to carry FMDV. Beef and pork (type B) was considered to have equal potency to carry FMDV. Ham, sausage and bacon (type C) were cooked by different method and considered to have less potency. The proportion of type A-related animal products in low risk group was designated as F2la, that of type B as F2lb and that of type C as F2lc. The proportion of each product type for other group of countries was designated as same pattern.

⑤ PCA (proportion of FMDV-contaminated, smuggled animal products upon entry) and CA (amount of FMDV-contaminated, smuggled animal products)

PCA is affected by processing techniques that are often aimed at preserving the meat, including canning, freezing, chilling, smoking, salting, drying, or any combination of these. Considering Type A was thought not to carry FMDV the prevalence for type A was set to zero. For type B and C which could carry the virus, the survivability of the FMDV in that product was evaluated relative to the assumed transit time of 14 days, which means the time interval from the point that the meat or products had been prepared such as slaughter to the point that the garbage which had been derived from the meat or products were fed to swine in Korea [3, 4]. The effect of frozen or chilling was compared in scenario 2. There could be heating below the standards required or contamination with strains from more heat-resistant sub-population, and thus 85% of type C was estimated free from FMD prevalence.

The PCA was calculated using the nested probability. In Fig. 1, because the sum of each row should be one, and thus the following equations are valid: PCn+PCl+PCm+PCh = 1; F2la+F2lb+F2lc = 1 and F1l+(1-F1l) = 1. To calculate the PCA for low risk group of countries, following equation is used: (0×F2la)+(F1l×F2lb)+(F1l×F2lc×SR) = PCAl. Total PCA is calculated from the following equation: PCAn+PCAl+PCAm+PCAh = PCA. CA represents the amount of FMDV-contaminated, smuggled animal products from foreign countries and was calculated from the equation: PCA×CAM.

⑥ F3 (effect of home cooking) and F4 (effect of heat treatment at garbage processing facility)

F3 is the value to incorporate the effect of home cooking into this assessment. Based on the literatures [16] who reported 15% of incidence of food handling malpractices at home cooking, it was assumed that 85% of FMDV contaminated smuggled animal products could be FMDV-free after home cooking. This value may not appropriate for the situation in Korea. F4 represents how much proportion of the garbage would be FMDV-free after heat treatment at garbage facility. Since credible data was not available at the time of performing this assessment, we assumed roughly 50%.

⑦ TF (total food consumed in households in Korea)

TF is the amount of food which is consumed in Korean household in a year. Based on the annual report on food supply by Korean Rural Economic Institute (KREI) [10], the data for the year of 2002 was used as 26,018,900,000 kg. The authors consider that if the real food consumption is less than the above-mentioned figure, this change may contribute risk-reducing effect.

⑧ TG (total garbage in Korea per year), PG (proportion of garbage which is recycled as feed) and DR (discard rate)

TG is the amount of garbage in Korea per year and PG is the proportion of garbage which is recycled as livestock feed. Municipal waste management division of the Korean Ministry of Environment [11] reported

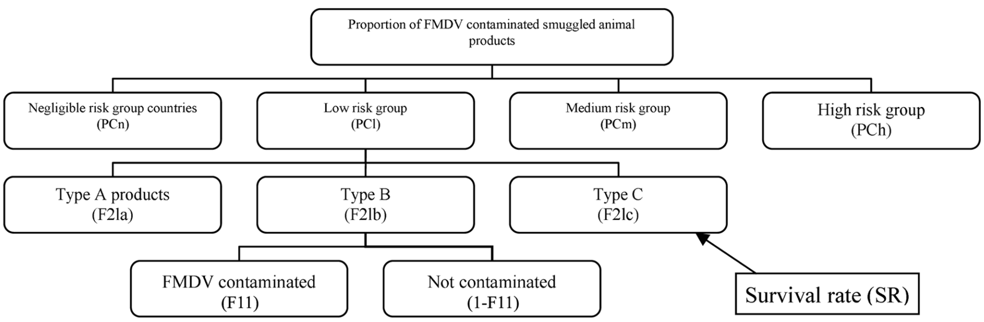

Fig. 1. Schematic diagram of estimating the proportion of FMDV-contaminated, smuggled animal products upon entry in each level of risk.

the total garbage occurred in 2001 was about 4,101,500 kg, recycling rate of garbage is 56.8% and the proportion of feeding in recycling is 53.3%. Based on this information, TG was estimated as 4,101,500 kg and PG is 56.8%×53.3% = 30.3%. DR, the proportion of food discarded as garbage, was calculated TG divided by TF.

⑨ AP (amount of likely FMDV-contaminated garbage) and TP (proportion of Korean garbage that is likely contaminated with FMDV)

AP is the amount of garbage which is likely FMDV-contaminated garbage from foreign country and TP is the proportion of AP in total garbage per year. AP was calculated from following equation: AP = CA×(1-F3) ×F4×DR. It was assumed that smuggled animal products are discarded at a rate equal to or less than domestic food products [3]. TG was modeled as a uniform distribution using minimum of 0 (DR for smuggled products = 0) to a maximum of AP/TG (DR for smuggled products = DR for domestic food products).

⑩ F (loads of garbage fed to swine) and CR (conversion rate)

The probability of exposure of pigs to FMDV-contaminated garbage will be related to the number of exposure opportunities that may occur. The exposure opportunity is a load which is related to the size of a load (CR) [3, 6]. The number of loads which is likely contaminated with FMDV was calculated using the number of loads of garbage (F) which are fed to swine in a year and the median probability that garbage could be likely contaminated with FMDV. The distribution for CR is bounded by the minimum (0.06 kg) and maximum (26 kg), and allowed to vary between these with a most likely value of 3.58 kg, and modeled using the triangular distribution (Table 2).

(2) Output parameters

The output value was calculated from the equation: $P = 1\text{-}(1\text{-}TP)^F$, where TP is the proportion of garbage per year that is contaminated with FMDV until fed to swine and F is the number of loads which is theoretical value that means average weight of the mass which is fed to swine as a whole per year.

Table 2. Triangular distribution for each level of prevalence

Prevalence	Minimum	Most likely	Maximum
Negligible	0.000	0.0000	0.000
Low	0.000	0.0005	0.001
Medium	0.001	0.0300	0.050
High	0.050	0.1000	0.200

(3) Model assumptions

A number of assumptions were employed for the model depending on the data available and its validity or reliability.

Although FMD affects cloven-footed animals, we considered only domesticated pigs as susceptible animals to the FMDV for simplicity of the model. The amount of animal products which are smuggled into Korea from other countries without detection was estimated from the amount of confiscated animal products by quarantine officials at entry into Korea. Due to lack of reliable data, we assumed that between 50% and 90% of smuggled animal products in passenger baggage at entry escapes confiscation by NVRQS.

Although some smuggled products could be directed to restaurants or markets for consumption, we assumed that all smuggled animal products were consumed only at home. It was also assumed that all garbage was collected by garbage collectors and heat-treated before being fed to swine. Since the effect of selection of animals for slaughter, ante- and post-mortem inspection was not considered for simplicity of the model, this may contribute risk-increasing effect on overall estimates.

Results

The estimated probability that FMDV-contaminated, smuggled animal products are fed to Korean swine

The median risk estimates of FMD from smuggled animal products is about 20.1% and the mean is 27.4% (Fig. 2). Based on the histogram to represent uncertainty about the true probability, 95 percentile of the estimate is 78.5%. This uncertainty means our confidence in the result, so we are 95% confident that the risk estimate is same or less than 78.5%.

The effect of the assumption that all beef and pork were fresh, not frozen

In all scenarios, we assumed transit time of 14 days. In addition, all beef and pork were considered as frozen so the virus could survive till the garbage was being fed to swine. In scenario 2, all beef and pork were

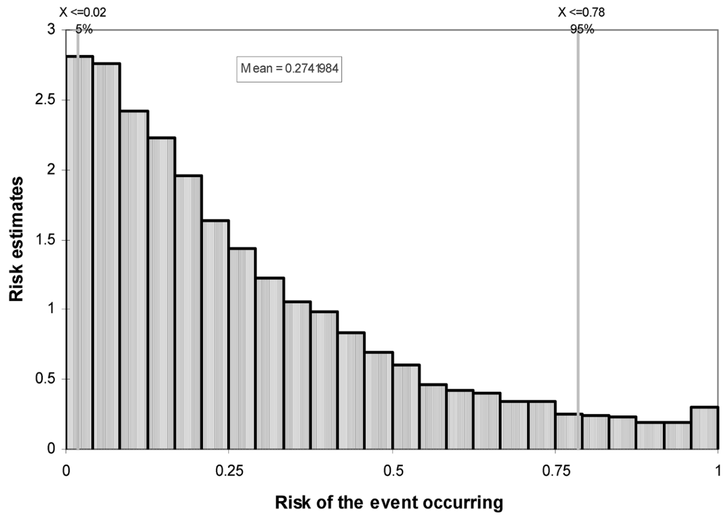

Fig. 2. The estimated probability that FMDV-contaminated, smuggled animal products are fed to susceptible swine in Korea.

considered as fresh so that FMDV didn't survive to be fed to swine. The estimated risk was 3.4% (Table 3, Fig. 3).

Table 3. The effect of secondary process to the estimated risk

Parameter	Scenario 1	Scenario 2
25th percentile	0.090	0.014
50th percentile (median)	0.204	0.034
75th percentile	0.395	0.073
100th percentile (maximum)	1.000	0.987
Mean	0.274	0.060
Skewness	1.139	3.776

Assumption: 14 days of transit time were used for analysis. In scenario 2, all beef and pork were considered as frozen so the virus could survive till the garbage was being fed to swine.

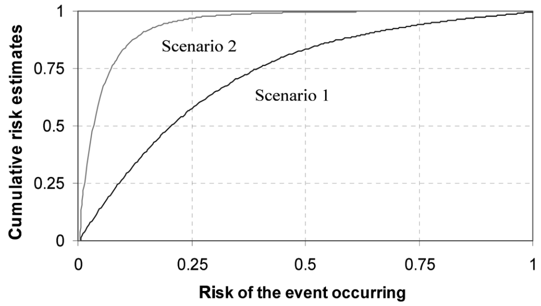

Fig. 3. The estimated risk which FMD virus could be introduced into Korea through the smuggled meat and meat products, assuming that all were fresh meat.

The effect of cooking at home

Initially, the proportion of products which remained contaminated after initial processing were later cooked at home sufficiently to inactivate the virus prior to being discarded was assumed 85% in scenario 1, 70% in scenario 3 and 92.5% in scenario 4. While scenario 3 increased the estimated risk by over one and a half to 36.7%, scenario 4 decreased the estimated risk by a half to 10.8% (Table 4, Fig. 4).

The effect of heat treatment at garbage processing facility

In scenario 1, the effect of heat-treat at garbage processing facility was taken into account as 50% of the FMDV-contaminated garbage is sufficiently heat-treated to inactivate the virus, and the estimated risk was 20.4%. While scenario 5 (assuming 25% inactivation)

Table 4. The effect of cooking process

Parameter	Scenario 1	Scenario 3	Scenario 4
25th percentile	0.090	0.173	0.046
50th percentile (median)	0.204	0.367	0.108
75th percentile	0.395	0.631	0.221
100th percentile (maximum)	1.000	1.000	1.000
Mean	0.274	0.416	0.165
Skewness	1.139	0.458	1.924

Assumptions: 14 days of transit time for all scenarios. Percent of product free of the virus was 85% in scenario 1, 70% in scenario 3, and 92.5% in scenario 4.

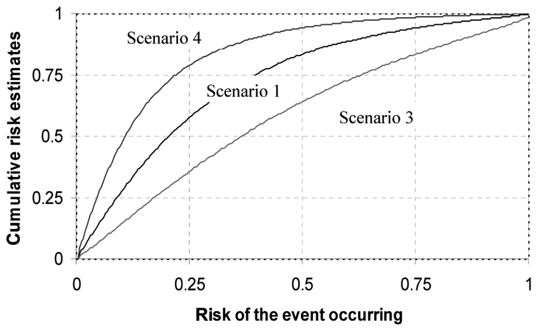

Fig. 4. The cumulative risk estimates which FMD virus could be introduced into Korea through the smuggled animal products, by the effect of cooking at home to the estimated risk.

Table 5. The effect of heat treatment at garbage processing facility

Parameter	Scenario 1	Scenario 5	Scenario 6
25^{th} percentile	0.090	0.133	0.046
50^{th} percentile (median)	0.204	0.291	0.108
75^{th} percentile	0.395	0.468	0.223
100^{th} percentile (maximum)	1.000	1.000	1.000
Mean	0.274	0.354	0.166
Skewness	1.139	0.727	1.912

Assumptions: 14 days of transit time for all scenarios. Percent of product free of the virus was 50% in scenario 1, 25% in scenario 5, and 75% in scenario 6.

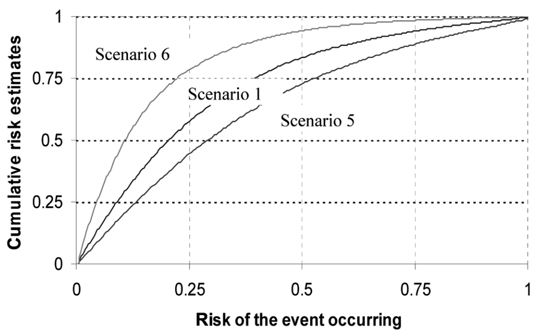

Fig. 5. The results of the estimated risk which FMD virus could be introduced into Korea by smuggled meat and their products, by the effect of heat-treat at garbage processing facility.

increased the estimate by about one and a half to 29.1%, scenario 6 (assuming 25% inactivation) decreased the risk to 10.8% (Table 5, Fig. 5).

Table 6. Number of contaminated loads and probability that any loads could not be contaminated with FMDV

No. of loads	Probability
0	0.817
1	0.165
2	0.016
3	0.001
4	0.000
5	0.000

Number of loads which is likely contaminated with FMDV

The probability that any loads could not be contaminated with FMDV was 81.7%. The probability that more than 5 loads could be contaminated with FMDV was found to be very small (Table 6).

Discussion

The result of this assessment documents the risk of exposure to FMDV in Korea associated with the practice of feeding untreated garbage to domesticated swine. The estimated risk was calculated using the formula: $1\text{-}(1\text{-}p)^F$. There are two major factors which influence the risk, p and F. Firstly, p means the probability that the illegally carried meat and their products have been contaminated or infected with FMDV and have not been intercepted on port of entry and have not been cooked or processed enough to inactivate the virus and have been collected to garbage process facility and have not been heat-treated enough and have been fed to swine. As p increases, the estimated risk increases as well. The major factors which influence on the estimated risk include the proportion of products of each commodity that could be contaminated, the effect of secondary cooking or treat, the effect of heat-treat at garbage processing facility and the proportion of garbage that is recycled as feed to swine. As for the proportion of products of each commodity that could be contaminated, it is up to people who carry the meat or meat products into Korea. To include the uncertainty about the amount of illegally smuggled meat and meat products, it was estimated that only 10 to 50% of the amount was intercepted on entry. There should be more investigation about this. As for recycled feed, Korea has recommended people to recycle more swill, because of its limited land and soil or water contamination problem. So to decrease the risk which FMD could be introduced into Korea, strenuous efforts are thought to be concentrated on heat treatment at garbage processing facilities. Secondly, F means the loads which are fed to swine and one load was defined as one discrete unit of waste. The size of a load used in the models ranged from 0.06 to 26 kg. But as the amount of swill feed to swine was 4.77%, the number of loads was high. In sensitivity analysis of estimated risk, TP has largest positive effect to the risk and conversion rate has largest negative effect. That means the larger TP the larger risk we get and the larger CR the less risk we get. Therefore, to reduce the risk we need less TP and larger CR. CAM and estimated prevalence for each group of countries has contributed positive effects to TP. To get more objective estimate of the risk, more accurate prevalence is needed. In addition, CAM should be decreased to reduce the risk. Increasing the effect of heat treatment at garbage facilities would reduce the risk. Although larger CR would reduce the risk, CR estimated in this assessment seems to be large.

This risk assessment focuses mainly on release and exposure assessment in that the probability that FMDV could released into Korea and exposed to swine by smuggled animal products. According to the SPS agreement and OIE guidelines, relevant economic factors such as the potential damage in terms of loss of production of sales in the event of the entry, establishment or spread of a disease, should be taken into account in risk assessment and consequence assessment describe the potential consequences of a given exposure and estimates the probability of them occurring. Thus the number of loads which is likely FMDV contaminated is calculated using the number of loads and the probability that the load could be contaminated with FMDV. The estimate of the probability that any load was not contaminated with FMDV was 81.7%. This result would be used in consequence assessment as estimating how many pigs or farms could be infected with FMDV and estimating the resultant losses or the expense which is taken to prevent the FMD spread.

This preliminary analysis may have some inherent limitations, particularly in associated with scenario or parameters used in the model. For CAM calculation, we included only inappropriate or fail-to-pass animal products, resulting in decrease the total risk estimate. Since useful data for the estimates of F3 and F4 were not available at the time of performing this assessment the resultant probability can clearly be affected, depending on the values employed for the model. There could be several limitations with CR and F. The values for the distribution of CR were estimated from the NVRQS detection result. Maximum CR is the maximum amount detected by NVRQS in 2003. Thus the estimated conversion rate may not precisely reflect the real garbage size fed to swine. This estimation decreases F, resulting in risk-reducing effect. In considering the effect of F to risk, more detailed data should be obtained. The authors are attempting to develop more detailed models in the future analysis taking into account other factors as well as all the factors considered in the present model.

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