Assessment of the likelihood of the introduction of foot-and-mouth disease through importation of live animals into the Malaysia-Thailand-Myanmar peninsula

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Objective—To assess the likelihood of an introduction of foot-and-mouth disease (FMD) into the Malaysia-Thailand-Myanmar (MTM) peninsula through terrestrial movement of livestock.

Animals—89,294 cattle and buffalo legally moved into the MTM peninsula.

Procedures—A quantitative risk assessment was conducted by use of a stochastic simulation. Patterns of livestock movement were ascertained through review of relevant governmental records and regulations and by interviewing farmers, traders, and local officers when the records did not exist. Parameters identified in the process were the probabilities of livestock having FMD and of FMD infection going undetected during import processes. The probability of an animal accepted for import having FMD was also assessed. Sensitivity analysis was performed to determine the effects that each parameter had on the model.

Results—The simulation yielded an average consignment prevalence of 10.95%. Typically, each animal in a quarantine facility had a 2.7% chance of having an inapparent form of FMD infection; hence, it was likely an animal would not be identified as infected. Findings revealed that the mean probability of an animal accepted for import having FMD was 2.9%, and the risk was as high as 11%.

Conclusions and Clinical Relevance—Results of the model allowed for the evaluation of movement regulations currently imposed in the MTM peninsula. Evidence from the study suggested that current practices in animal movement were far from efficient in preventing introduction of FMD-infected animals into the MTM region, and additional measures will be necessary. (*Am J Vet Res* 2008;69:252–260)

Foot-and-mouth disease is a highly contagious disease of cloven-hoofed animals. The disease has a tremendous impact on susceptible livestock in terms of production loss as well as economic disruptions as a result of trade restrictions. The FMD virus is easily transmitted directly (contact with infected animals or secretions) and indirectly (via living objects and fomites). The disease is characterized by vesicular eruptions of

ABBREVIATIONS

FMD	Foot-and-mouth disease
RCU	Regional Coordination Unit
OIE	World Organization for Animal Health
MTM	Malaysia-Thailand-Myanmar
DLD	Department of Livestock Development
NSP	Nonstructural protein
P_S	Probability of an infected animal having detectable clinical signs
P_A	Probability of an infected animal being accepted for import

the epithelium of the mouth and feet, hence the name. Vesicular eruptions can also be detected on the skin of the teats and udder.

Foot-and-mouth disease is endemic in most countries in Southeast Asia, except for Indonesia and parts of Malaysia and the Philippines. There have been continuing efforts to eradicate the disease from the region. A key ongoing effort has been coordinated by the RCU of the OIE through the Southeast Asia FMD Campaign. This campaign involves 8 countries in the region (Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, the Philippines, Thai-

land, and Vietnam). The OIE review on the Southeast Asia FMD Campaign in 1999 identified the importance of the establishment of a disease-free area to accelerate the eradication of FMD in the Southeast Asian region. To facilitate this recommendation, the 5-year program developed in 2001 included the Malaysia Peninsula and parts of Thailand and Myanmar and is known as the MTM Campaign for FMD Freedom. An area of the MTM peninsula was selected as a potential FMD-free area because of its natural advantages and FMD situation that currently favored control and eradication of FMD. The MTM countries have also developed a good tripartite example of international cooperation.

Various programs have been designed to help ensure that the MTM Campaign for FMD Freedom achieves its objectives. One of the more important programs is the prevention of the introduction of FMD while ongoing eradication efforts are being conducted in the MTM areas. The main purpose of the study reported here was to evaluate the risk of FMD introduction resulting from terrestrial movement of livestock from areas outside of MTM zones. A quantitative risk assessment model was developed to assist with the evaluation.

Materials and Methods

Zones for FMD—For the MTM Campaign for FMD Freedom, several clearly defined zones have been declared by legislative or administrative action of the respective countries to facilitate movement within zones and to enable control, eradication, and exclusion of FMD (**Figure 1**). Zones for the campaign include buffer zones, control zones, and eradication zones. Details on zone demarcations, definitions, and requirements for progression of zone status are explicitly documented in the Minimum Standard Definitions and Rules.[1]

Risk assessment—General processes for conducting a risk assessment have been clearly outlined.[2,3] In accordance with OIE guidelines,[2] a risk assessment was conducted that used a hazard identification step to briefly determine whether FMD was a potential threat to the MTM region. A release assessment was then conducted that focused on the assessment of the likelihood of FMD introduction. Risk scenario trees were developed and used as the study framework.

Hazard identification—A review of the existing literature and other information identified that the introduction of FMD via terrestrial movement of livestock was a hazard for the MTM region. Of 207 reported outbreaks of FMD in the MTM peninsula from January 2001 to February 2002, 120 (58%) were attributable to the movement (both legal and illegal) of livestock.[4] The MTM member countries were aware of the importance of animal movement and declared that movement would increase the risk of the spread of FMD. It has been recommended that MTM member countries adopt a policy of controlled legal movement to reduce the spread of disease.[5]

It was of interest to the RCU and MTM countries to determine whether swine would be a major concern for the MTM Campaign for FMD Freedom.[5,6] Analysis of scientific evidence suggested a minor role of swine as a direct cause of FMD outbreaks in the region.[7,8] Typical swine management practices in Thailand and Malaysia somewhat reduced the chance of pigs being exposed to FMD virus. Swine were not fed raw meat, offal, bone marrow, or unpasteurized milk and were commonly housed individually in pens and separated from other species of livestock. There were small numbers of swine moving to MTM areas as a result of a decrease in demand in Muslim communities. Although it was suggested in a report[6] that there were extensive numbers of grazing swine in Myanmar, there was only 1 report[4] of an FMD outbreak in a swine population during the period from 2000 to 2003. Pigs do not develop persistent infection with FMD virus; thus, it is less likely for swine to become carriers.[9,10] Because of the minor role of swine in the FMD outbreaks in this region, the term livestock in our study refers only to dairy cattle, beef cattle, and buffalo.

Risk scenario trees—Development of risk scenario trees was identified as a pertinent part of the risk assessment for disease introduction.[3,11] Import-export policies and procedures must be examined prior to development of scenario trees. Inquiries about import-export regulations were made to the appropriate institutions within the MTM countries. The information obtained was then used to construct a risk scenario diagram. In addition, local villagers and traders in the MTM zones were interviewed to identify other possible routes of livestock trafficking that may not necessarily have adhered to the aforementioned movement regulations.
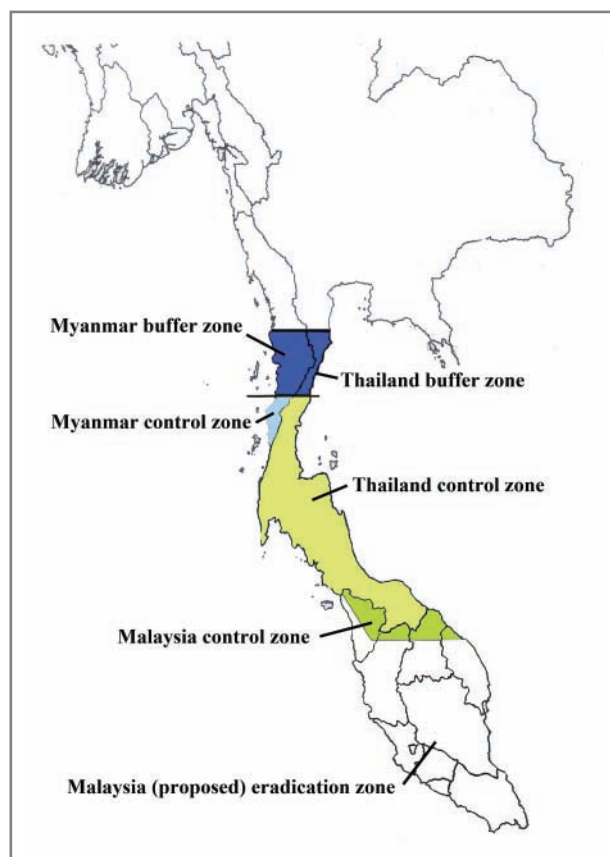

Figure 1—Zones defined in accordance with the Minimum Standard Definitions and Rules for control and eradication of FMD in the MTM peninsula.

The framework was determined for a complete risk assessment model (**Figure 2**). The model involved issuance of a movement permit and a subsequent period of quarantine. The framework mimicked movement of livestock from infected zones to MTM zones within Thailand. Application of this framework also extended to some transboundary movement of animals from Myanmar into Thailand, where inspection and quarantine were performed only when the animals reached the Thailand border.

Uncertainty and randomness within the model were stochastically described by use of computer software[a,b] to simplify the use of probability distributions. Each simulation consisted of 5,000 iterations performed by use of Latin hypercube sampling.

Model parameters—Parameters necessary for model computation included those pertaining to movement of livestock into the MTM areas and prevalence of FMD in transported livestock. Parameters were established through review of literature and official records and interviews of stakeholders and field experts.

Movement of livestock—Most of the movement of livestock in the MTM countries was unreported and driven largely by market prices of livestock in a particular region. The 3 countries in the MTM area share terrestrial boundaries, with Thailand as an intermediate country. Attempts were made to recognize patterns as well as determine the magnitude of livestock movement in the MTM areas. When records were not available, opinions of experts were used as the best estimates.

Myanmar

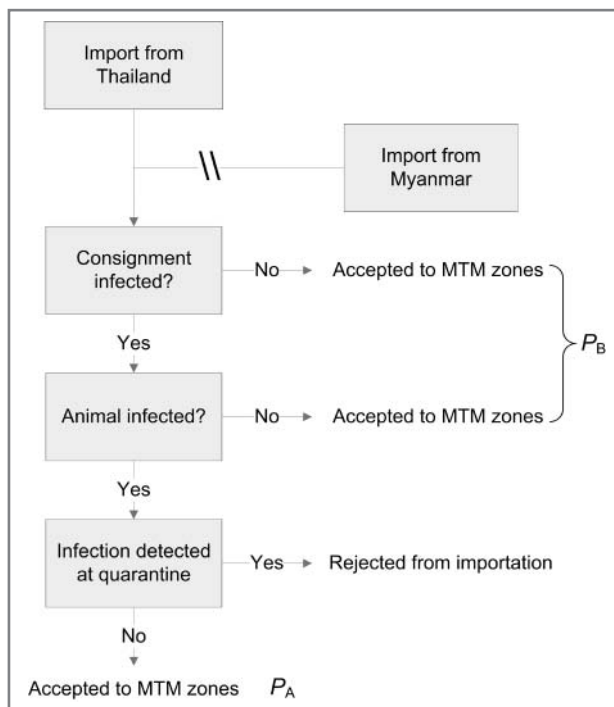No official records were kept for movement of livestock in Myanmar. Thus, information on livestock movement was based on expert opinions. To solicit expert opinions, a workshop was conducted in Yangon in January 2004. Participants included local veterinary officers of the Livestock Breeding and Veterinary Department as well as Deputy Directors from all 14 states or divisions. Participants drew maps and provided the direction of livestock movement for domestic and international animal traffic. Participants then provided the approximate numbers of livestock and the perceived amount of risk involved for each direction of movement.

Workshops were also conducted in the Tanintharyi division in the Myanmar MTM area. Several workshops were initiated in a number of areas in the Tanintharyi division, including 5 villages in the Myeik district and 1 village in the Kaw Thaung district. The workshop sessions, which were similar to those for the workshop held in Yangon, included participation of local villagers and livestock traders. Information was obtained for incoming and outgoing animals, including sources, destinations, numbers, and types of animals. Villagers also were questioned as to whether they had witnessed outbreaks of FMD before and when those outbreaks happened. Any participant who had witnessed an FMD outbreak would describe to the other participants the clinical signs and patterns of spread.

No movement of cattle or buffalo from divisions-states north of the MTM zones to the MTM zones in Myanmar was reported. There was movement of cattle and buffalo from small eastern islands to Myeik, but this was considered irrelevant to FMD control because the islands were free of FMD. It was estimated that 300 to 500 animals/mo were walked across the border into Thailand, primarily through Maw Htaung point in Tanintharyi Township. This movement usually involved local animals in Tanintharyi Township; however, there may have been some animals from Myeik Township or areas farther north when the number of animals in Tanintharyi Township was not sufficient. Reverse movement from Thailand to the Myanmar buffer zone was not reported. Because of geographic difficulties, only limited numbers of animals were moved south from the buffer zone to the control zone. All animal movement in the buffer zone was by land. It was estimated that 8,000 cattle and 7,000 buffalo from other townships were transported by land to Myeik Township annually.

Thailand

Movement of livestock in Thailand was managed by the Animal Quarantine Inspection Services Section under the supervision of the Bureau of Disease Control and Veterinary Services, DLD. There were 38 international and 16 domestic animal quarantine stations in the country. In addition to the governmental animal quarantine stations, there were approved private quarantine premises that were accredited and routinely inspected by veterinary officers. According to the regulations, animals destined for the proposed FMD control zones in Thailand must be accompanied by movement permits issued by the DLD provincial office from which the animals originate. Animals were housed for a period at a quarantine station and released when no signs of infectious diseases were detected. When a consign-

Figure 2—Schematic of the FMD risk assessment model for MTM zones resulting from terrestrial movement of livestock.

ment passes all of the quarantine requirements, it was then assigned a Movement Release Form. All Movement Release Forms were maintained at animal quarantine stations, with summary reports submitted monthly to the Animal Quarantine Inspection Services Section headquarters. However, information from Movement Release Forms was not reliable for providing knowledge of livestock movements because there were discrepancies between the records and the actual animals that passed through the animal quarantine stations. For example, consignments initially proposed to move to the southern regions may not have necessarily reached the intended destination. Similarly, some consignments destined for other regions may have ended up in the regions of concern because of appealing markets. Supposedly, all domestic livestock movement to the MTM zones in Thailand should have transited through Phetchaburi or further south at Prochuab Khiri Khan province. Thus, the copies of the movement permits issued by the DLD provincial offices in these 2 provinces were used instead of the Movement Release Forms.

MALAYSIA

The Division of Epidemiology and Veterinary Medicine, Department of Veterinary Services supervised movement of livestock in Malaysia. There were 7 animal quarantine stations and checkpoints located in Peninsula Malaysia, most of which dealt with international trade of livestock. Only animals destined for immediate slaughter were allowed to move south from the control zone into the (proposed) eradication zone (south of the Besut and Perak districts). However, there were common grazing areas that straddled the boundary between the 2 zones in several locations, and there was uncontrolled movement of livestock. There were no permanent checkpoints on the roads leading from the control to the eradication zones, but the Department of Veterinary Services used mobile units to patrol the roads; these units were supported by the police.

The local supply of fresh meat in Malaysia could not meet the demand for local consumption. As a result, Malaysia was a major importer of livestock and livestock products in the region. In 2001, analysis of records revealed that 5,279 cattle or buffalo were imported from Thailand and 3,558 cattle or buffalo from Myanmar. In 2002, total imports of cattle or buffalo from Thailand were slightly decreased to 4,353 animals, and import from Myanmar was halted because of an outbreak of FMD at one of the quarantine stations. In September 2003, Malaysia stopped the importation of cattle and buffalo from Thailand as a result of an FMD outbreak at the Padang Besar quarantine station. However, Department of Veterinary Services officers admitted that annually there were at least 20,000 livestock being traded illegally across the borders to satisfy the local demand for fresh meat.

Movement documents, including import licenses, health certificates, and other supplemental documents, were checked at arrival at a quarantine station. Veterinary officers conducted a series of physical inspections during the quarantine period to validate the health status of the animals. The records of animal movement were maintained at the quarantine station and subsequently were submitted to the Department of Veterinary Services.

Prevalence of FMD—A simple calculation of prevalence was derived from the number of affected and number of susceptible animals in a defined temporal partition. In Southeast Asia, several systems have been developed to recognize these vital elements in prevalence calculations. Some countries have developed a system for reporting outbreaks on a national scale, as is evident in Thailand, Malaysia, and the Philippines. However, because of limited resources, other countries in the region have only received reports regarding animals with virulent FMD. An outbreak reporting system has also been developed by the OIE-RCU, and member countries have agreed to submit monthly reports of outbreaks to the OIE-RCU database. However, the number of outbreaks does not reflect the number of animals infected with FMD virus. This is attributable to the high probability of inapparent and persistent infections,[10,12] especially in areas where FMD is endemic and vaccination is practiced.[13]

Estimation of prevalence from regional surveillance—An active seroprevalence surveillance was conducted in Thailand in early 2003 in an attempt to determine the amount of FMD infection in the country.[c] A total of 4,185 cattle from all 9 regions in Thailand were tested by use of an ELISA to detect NSP antibodies (**Appendix**). Findings for that surveillance provided valuable information for constructing an assessment model of FMD risk for the study reported here.

From the findings for the regional surveillance, the prevalence of the regions could be calculated. Sensitivity of the NSP antibody test used for the regional surveillance was approximately 88.89%, and specificity was approximately 1.[14] On the basis of that information, it is possible that a few infected livestock were not detected by the test. The number of false-negative results was estimated by use of the following equation:

$$m_{Ii} = RiskNegbin(s_{Ii} + 1, P_{NB})$$

where m_{Ii} is the number of animals with false-negative results, s_{Ii} is the number of animals with positive results for the NSP antibody test in region i, and P_{NB} is the sensitivity of the NSP antibody test. The true prevalence of FMD in region i was then estimated by use of the following equation:

$$P_{Ii} = Risk\beta([m_{Ii} + s_{Ii} + 1], [n_{Ii} - \{m_{Ii} + s_{Ii}\} + 1])$$

where P_{Ii} is the prevalence of FMD (ie, probability of disease) in the livestock population within region i (regions 1 to 7) in Thailand, and n_{Ii} is the number of livestock tested within region i.

This step yielded the FMD prevalence for each corresponding region. After the simulations were conducted, there were 7 prevalence estimates that could be combined to yield a distribution of within-consignment prevalence for all other infected consignments. A command (ie, RiskDiscrete[{weighing},{probabilities}]) generated a discrete distribution whereby the probability was weighted by the likelihood of it happening. In

the study reported here, the prevalences for regions 1 to 7 were weighted by the likelihood for the region of origin of a consignment. Therefore, the equation used to derive the overall regional prevalence was as follows:

$$\text{RiskDiscrete}([P_{I1}:P_{I7}], [\text{No. of consignments from region 1: region 7}])$$

where $P_{I1}:P_{I7}$ are the calculated prevalences of FMD for each of the 7 regions.

Estimation of prevalence from consignment surveillance—The DLD Thailand instigated consignment surveillance related to FMD in imported animals. For each consignment that entered international animal quarantine stations, a number of blood samples were collected for laboratory testing to detect evidence of FMD infections. Although the information may not have been representative of domestic movement of livestock, it could be used as an indirect estimation of the prevalence of FMD and for comparative purposes. There were 57 consignments tested for FMD infection by use of the NSP antibody test[d]; 28 consignments had at least 1 sample with positive results.

The distribution of the between-consignment prevalence was estimated by use of the following equation:

$$Pc = \text{Risk}\beta(s_C + 1, [n_C - s_C] + 1)$$

where Pc is the between-consignment prevalence, s_C is the number of consignments with at least 1 sample with an infected animal, and n_C is the total number of consignments.

In a study[14] conducted on the NSP antibody test, it was found that 152 of 180 (84.6%) sera from disease-positive cattle had positive test results, and 4 of 379 (1%) sera from disease-negative cattle had positive test results. Thus, a distribution was estimated for the test sensitivity as $\text{Risk}\beta(a + 1, c + 1)$, where a is the number of disease-positive animals with positive test results and c is the number of disease-positive animals with negative test results. Distribution for test specificity was estimated as $\text{Risk}\beta(d + 1, b + 1)$, where d is the number of disease-negative animals with negative test results and b is the number of disease-negative animals with positive test results.

A simulation similar to the one performed for the regional surveillance to estimate m_{Ii} and P_{Ii} was performed to determine the distributions of infected animals that had negative results for the NSP antibody test and within-consignment prevalence for each consignment that contained animals with positive test results. The combined within-consignment prevalence of all 28 infected consignments was calculated by use of the following equation:

$$P_V = \text{RiskDiscrete}([P_{V1}:P_{V28}], [n_{s1}:n_{s28}])$$

where P_V is the combined within-consignment prevalence of FMD, $P_{V1}:P_{V28}$ is the within-consignment prevalence of FMD for each of the 28 consignments with infected animals, and $n_{s1}:n_{s28}$ is the number of samples submitted from each of the 28 consignments with infected animals. The probability that an imported animal

would be infected with FMD virus was then simply calculated as $P_C \times P_V$.

Release assessment model—On the basis of interviews of local villagers and farmers in MTM zones in Myanmar, it was realized that movement from other areas into MTM zones in Myanmar was extremely limited because of difficulties in transporting animals. Most of the movement originated from adjacent areas that had no reports of FMD since the outbreak in 1990. Serologic surveys for antibodies against FMD conducted by use of the NSP antibody tests in Tanintharyi Division yielded no positive results since 2001.[e] Hence, movement of livestock into the MTM zones from the Myanmar side was not considered a major risk in the study reported here and was not included in the analysis. It was clear that the domestic movement of livestock in Thailand from areas outside MTM zones into the MTM zones was the primary concern.

Legal movement of livestock from Thailand and Myanmar into Malaysia has not been allowed since 2003. Although there may have been illicit movement of livestock from other MTM countries, the risk of FMD introduction into Malaysia would be perceived similar to the implementation of no additional prevention measures. The risk in this situation was similar to the risk of FMD introduction prior to the livestock being imported into Malaysia. Hence, for simplicity of the model, the probability of FMD introduction into Malaysia was excluded from the analysis.

According to the Thai DLD Animal Epidemic Act as written in 1956 and amended in 2003, livestock movement into MTM zones in Thailand required quarantine at the origin of at least 21 days.[15] Throughout the period of the quarantine, animals were inspected for any signs of livestock diseases, particularly FMD. When there was no observable evidence of diseases of concern, then the animals were released to the destination stated in the import permit, where an additional 3-day quarantine may have been required (Figure 2).

Probability of infection not detected during quarantine—Inapparent infection with FMD always poses tremendous concern regarding the spread of the disease. Multiple factors are involved in the development of clinical signs following infection.[9,10,16] Animals may be infected with FMD virus, yet clinical signs of FMD may not manifest or may be difficult to detect. Inapparent infection is especially detected when there is a moderate to high degree of immunity in a herd, such as when FMD is endemic or animals are vaccinated against FMD virus.[17,18] As a result, sensitivity of screening for infection in Thailand by only observation for clinical signs was far from perfect. Unfortunately, the effort to estimate the effectiveness of quarantine procedures was not successful because no data were available for the direct estimation.

Morbidity rates for FMD infection have been reported in Thailand and could also be calculated from outbreak reports acquired from the DLD. Morbidity rates for FMD outbreaks in northern Thailand were between 11% and 20%.[8,19] Outbreak reports from the DLD are in agreement with these calculations and yielded an approximate morbidity rate of 14% (11,939

cases/85,303 susceptible livestock). These estimates, however, were based on observations of clinical signs of the disease, and no reference was made as to the number of animals that were actually infected. Because such data were not available, opinions of experts were used as the best estimates to construct the distribution for the probability of livestock having detectable clinical signs following infection. Because quarantine will increase the likelihood of infected livestock having detectable clinical signs, estimates for the most likely, minimum, and maximum values were predicted by experts as 70%, 0%, and 100%, respectively. In other studies,[20,21] it was recommended to use the Pert distribution (rather than the Triangular distribution) when dealing with this type of data, where the minimum and maximum value were set at extremes. Thus, the probability of infected livestock having detectable clinical signs during quarantine was calculated by use of the following equation:

$$P_S = RiskPert(0, 0.7, 1)$$

where P_S is the probability of infected livestock having detectable signs during quarantine.

It is generally accepted that once the clinical signs of FMD appear, it is almost certain that the animal will be tentatively diagnosed as infected with FMD. Only animals with clinical signs will be excluded from shipments. The probability of an infected animal not having detectable signs was calculated as $1 - P_S$. The value for P_A (ie, the probability of an incoming animal having FMD and not being detected during quarantine) was the product of the likelihood of an infection in a consignment and the likelihood of the animal not having clinical signs (ie, P_A = FMD prevalence $\times$ [1 − P_S]).

Probability of incoming animals having FMD—The probability of animals accepted for movement or trade becoming infected with FMD (ie, P[infected|accepted]) could provide intuitive meaning to the MTM countries. The probability was determined by use of the following equation:

$$P(infected|accepted) = P_A/(P_A + P_B)$$

Table 1—Summary statistics for the prevalence of FMD that resulted from simulations performed by use of data from regional and consignment serologic surveillance and for the probability of inapparent infection of FMD during quarantine in livestock moving into the MTM zones.

Variable	Prevalence from regional serologic surveillance (%)	Prevalence from consignment serologic surveillance (%)	Probability of inapparent infection during quarantine (%)
Minimum	0.19	0.04	0.01
Maximum	14.91	58.47	10.65
Mean	7.37	10.95	2.74
SD	2.00	8.37	1.62
Variance	0.04	0.70	0.03
Median	7.51	8.03	2.50
Mode	6.83	4.96	2.07
5%	4.02	2.46	0.53
25%	6.20	4.72	1.50
75%	8.68	15.28	3.73
95%	10.39	28.28	5.75

where P_B is the probability of a healthy animal accepted for import. The value for P_B was calculated as 1 minus the prevalence of FMD in incoming animals (Figure 2).

Sensitivity analysis—In the model reported here, we used expert opinion to reflect the likelihood of infected livestock having clinical signs of FMD (P_S), and the most likely value was set at 70%. It could be argued that this may have been an inflated value because FMD was considered endemic in some regions in which there was extensive use of vaccine. More pessimistic estimations may have been suggested, thereby resulting in higher chances for accepted livestock to be infected with FMD. We investigated the effects of this assumption on the value for inapparent infection associated with the risk of importing FMD-infected livestock. The model was run with P_S values that ranged from 5% to 95% in increments of 5%. The minimum and maximum values were set constant at 0% and 100%, respectively, for all values of P_S.

Results

Calculation of prevalence—The estimated prevalence of FMD was summarized (**Table 1**). The simulation yielded similar outputs for the most likely prevalences at 7.37% and 10.95% for the regional surveillance and consignment surveillance, respectively. However,
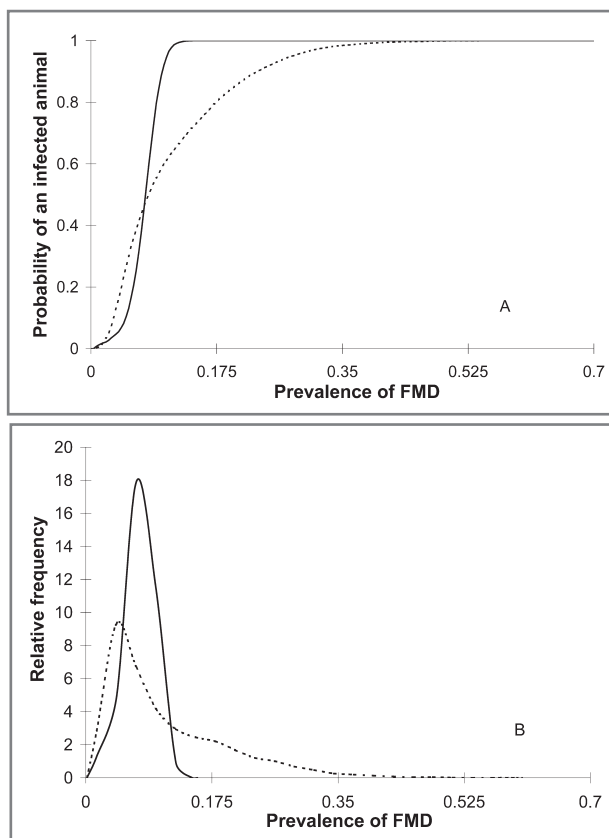

Figure 3—Cumulative probability distribution (A) and frequency distribution (B) for FMD prevalence in livestock intended to move into MTM zones, as estimated from regional (solid line) and consignment (dashed line) serologic surveillance.

the SD calculated for the consignment surveillance data was approximately 4 times as large as the SD calculated for the regional surveillance data. Testing for equality of variances revealed that the variance calculated from the regional surveillance was significantly ($P < 0.001$) lower than that derived from the consignment surveillance. This more expansive result for the consignment surveillance reflected uncertainty in the data and may have been attributable to the smaller number of samples collected for the consignment surveillance, compared with the number collected for the regional surveillance (**Figure 3**). Hence, for the sake of brevity, the decision was made to conduct the remainder of the analyses with the prevalence calculated for the regional surveillance.

Distribution for P_A—The distribution was calculated for P_A (**Figure 4**). For each animal that entered a quarantine station, there was an approximate mean probability of 2.74% that the quarantined animal would have an inapparent form of FMD infection. The simulation yielded a distribution with similar values for the 3 measures of central tendency (Table 1).

Probability of imported animals being infected with FMD—For animals that met all the requirements for importation into the MTM zones in Thailand, it was pertinent to understand the degree of risk that the animals may have carried FMD. Mean probability of animals accepted for importation being infected with FMD, as estimated from the simulation, was 2.86%. The risk was as high as 11%, and 95% of the iterations yielded a probability of 6% or less. Summary statistics for the probability of infection given that an animal

was accepted for importation into the MTM zones were calculated (**Table 2**). The distribution resulting from a simulation of 5,000 iterations was plotted (**Figure 5**).

Sensitivity analysis—The value for P_S had an effect on the degree of risk for introduction of FMD into the MTM zones (**Figure 6**). Not surprisingly, as the assumed amount of animals with clinical signs of FMD increased, the probability of the introduction of FMD into the MTM zones decreased. For example, the risk was reduced by almost 70% when P_S increased from 10% to 90%.

Figure 5—Ascending cumulative probability distribution (A) and frequency distribution (B) for the probability that animals accepted for import into the MTM zones would have FMD.
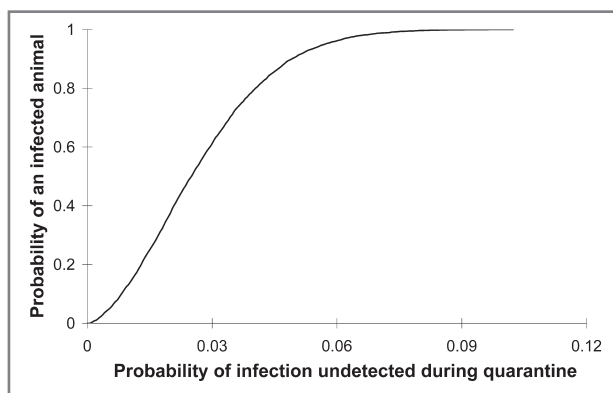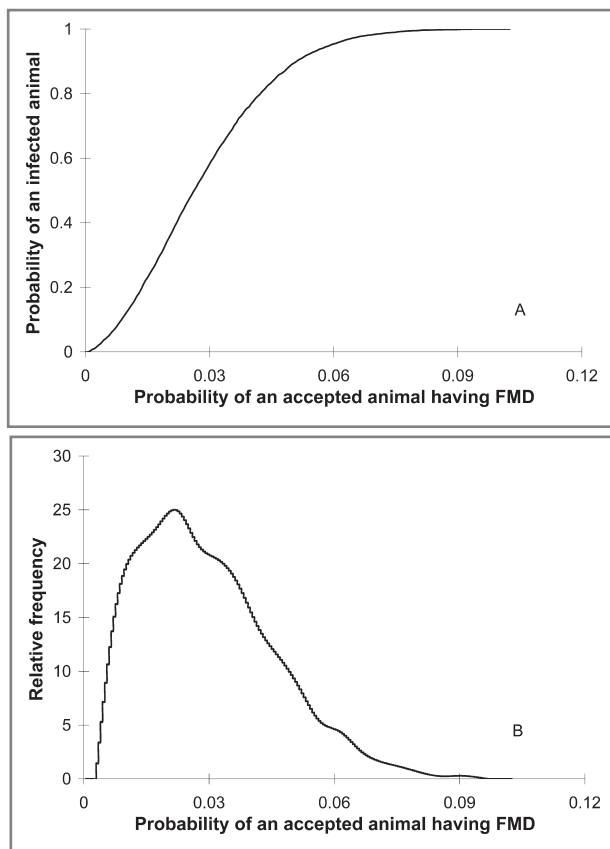
Figure 4—Cumulative probability distribution that infected livestock being moved into MTM zones would have the inapparent form of FMD during quarantine.

Table 2—Summary statistics of the probability of infection, given that animals have been accepted for trade.

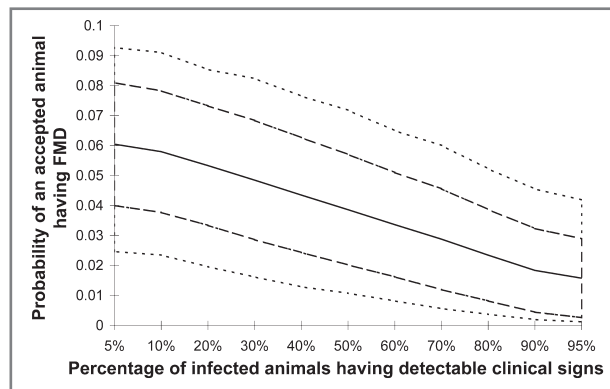| Variable	P(infected|accepted) (%)
Minimum	0.01
Maximum	10.98
Mean	2.86
SD	1.67
Median	2.64
Mode	3.06
5%	0.55
25%	1.58
75%	3.90
95%	5.95

Figure 6—Mean (solid line), SD (dashed lines), and 90% confidence intervals (dotted lines) for sensitivity analysis of the probability of FMD infection in an imported animal, as influenced by the probability that FMD would be detected on the basis of observable clinical signs during quarantine.

Discussion

The estimated probability of the introduction of FMD involving terrestrial movement of livestock into MTM zones in Thailand may appear to be small. However, concerns about the risk of importing FMD-infected livestock are heightened when the number of livestock moved south in the MTM each year is considered. According to government records, movement of cattle and buffalo into the MTM area was estimated at 89,294 animals/y. Thus, there is almost a 100% chance that there will be at least 1 infected animal accepted for importation into the MTM zones in any given year. An approach to manage the risk is to alter movement procedures or regulations. Currently, the only action taken to protect MTM zones against FMD relies on the efficiency of the observation of classical signs of the disease.

Results of the study reported here revealed that such a process reduced the probability of FMD introduction by > 60% of the risk when no action was taken. However, it was strongly suggested that additional measures be used to increase the ability to detect the disease and thereby further reduce the risk of FMD introduction. This would certainly require practical judgment from decision makers because no such changes could be made without consequences. For example, implementing more stringent measures may make traders less likely to comply with the regulations. Applying more rigorous processes would also result in higher management costs; this has always been a primary constraining factor in developing countries. Increased regulatory measures would eventually encourage more illicit movement of livestock. Consequently, any changes in movement regulations will have to be devised by use of the best available resources and knowledge.

The models described in the study reported here can be used as tools for weighing the available options because they are inherently flexible. The risk of FMD introduction may be reduced by decreasing the risk at the source (ie, encouraging importation of livestock from sources where the prevalence of FMD is low). This is always easier said than done. In Southeast Asia, the rule of supply and demand dictates the price of livestock and thus determines the pattern of livestock movement. It is not practical at this point to designate movement patterns on basis of the risks.

It should be kept in mind that this study only described the risk involved with legal movement of livestock for those adhering to existing regulations. The methods for this study may be used to assess the risk of FMD introduction attributable to illicit movement when certain assumptions are satisfied. First, it is assumed that the distribution of FMD prevalence in consignments intended to move without permits or reporting is the same as the distribution for animals with permits and that were reported. Second, during illegal movements, no movement management is practiced that would alter the existence of FMD distribution in the consignment. Third, distribution of the origins of incoming livestock moved legally is the same as for livestock moved illegally. When all the assumptions are met, calculation of the risk of FMD for incoming livestock transported illegally can be relatively simple. The probability of livestock entering illicitly that have FMD would be the same as the FMD prevalence.

It is also important to mention that the analysis completed was designed only for quantification of the risk of FMD introduction (namely, release assessment). It does not guarantee that each introduction will result in an outbreak at the location where the animals are received. Another process must be considered to assess the probability of an outbreak from such introduction (ie, exposure assessment).

To our knowledge, this is the first study in which investigators have attempted a quantitative assessment of the risk of FMD introduction in the MTM region. Analysis of the results revealed that currently implemented movement regulations were not sufficient to protect MTM areas from FMD introduction, and additional measures should be encouraged. Applications of this assessment have proven valuable for the accomplishments of the MTM campaign and can possibly extend to other similar campaigns in the region. The purpose of the study reported here was to provide recommendations based on the best available data to officials who make decisions pertaining to control and eradication of FMD in the MTM areas. It is up to the decision makers to exercise the options to achieve the goal of the campaign in a practical and feasible manner.

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Appendix

Geographic distribution of the apparent prevalence of FMD infection in livestock in each of 9 regions in Thailand.

Region	No. of animals tested	Positive results for the NSP antibody test	
		No.	%
1	480	12	2.5
2	476	3	0.6
3	480	39	8.1
4	477	23	4.8
5	480	32	6.7
6	360	23	6.4
7	479	35	7.3
8	478	0	0
9	475	10	2.1
Total	**4,185**	**177**	**4.2**

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