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Laboratory Diagnosis and Quality Control Technologies in Assessing Livestock Diseases

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Abstract

Enzyme-linked immunosorbant assay (ELISA) technology was employed as the primary diagnostic tool during Australian Centre for International Agricultural Research Project Number 9204 based at Hang Chat, northern Thailand. ELISAs were implemented for the assessment of foot-and-mouth disease virus and infectious bursal disease virus antigen and antibody, as well as antigen detection for classical swine fever virus and Newcastle disease virus antigen. Internal quality control was implemented from the ELISAs using Shewhart-CUSUM (cumulative summation) control charts facilitated and simplified by the use of the QCEL (quality control for ELISA) computer program. This paper describes the ELISA and quality control methodologies and the results obtained during the 23-month laboratory component of the project.

Introduction

Laboratory diagnostic techniques such as the enzyme-linked immunosorbent assay, more commonly known as ELISA, have become a mainstay in veterinary diagnostics over the past decade. Such techniques are robust in the hands of an experienced operator and can lend themselves to local reagent production should suitable equipment be available. In Thailand, previous Australian Centre for International Agricultural Research (ACIAR) projects have established and validated ELISAs for the detection of foot-and-mouth disease (FMD) antigen and antibody at the Northern Veterinary Research and Diagnostic Center (NVRDC), Hang Chat and the Foot-and-Mouth Disease Vaccine Center, Pak Chong (Westbury et al. 1988; Blacksell et al. 1994a,b).

During the 23-month laboratory component of ACIAR Project Number 9204 a further four ELISAs for the detection of antigen and antibody for infectious bursal disease (IBD) and antigen detection only for classical swine fever (CSF) and Newcastle disease (ND) were established at the NVRDC. In addition, the aforementioned and previously established FMD ELISAs provided the basis for FMD antigen and antibody investigations. This paper describes the methodologies, overall results and internal quality control (QC) procedures for the diagnostic technologies employed during ACIAR Project 9204.

Materials and Methods

Foot-and-Mouth disease

Foot-and-mouth disease antigen typing ELISA

The detection of FMD antigen in epithelial samples from FMD-suspect animals and the determination of serotype identity in the case of positive samples was accomplished by the FMD antigen typing ELISA (FMD AT-ELISA).

Immunological reagents used in the FMD AT-ELISA were produced at the FMD Center, Pak Chong, Nakornratchasima province, using the following methodology. Baby hamster kidney (BHK) cell monolayers were infected with an FMD serotype representative of local strains and incubated for 24 hours at 37°C. The virus supernatant was collected and the viral proteins precipitated by the addition of 7% (w/v) polyethylene glycol 6 000 followed by centrifugation at 5 000 rpm for 30 minutes. The pellet was collected and resuspended in 25 volumes of PBSA (phosphate buffered saline without calcium and magnesium ions added) and centrifuged at 10 000 rpm for 30 min, the supernatant collected and further centrifuged at 30 000 rpm for 2 hours and the resultant pellet resuspended in 2 ml of PBSA. The resuspended pellet was centrifuged at 10 000 rpm for 30 minutes and the pellet resuspended in a 1% sodium dodecyl sulfate (SDS) solution in PBS. The preparation was loaded onto a 15–45% sucrose gradient and centrifuged at 27 000 rpm for 3 hours and the purified virus fraction collected.

Rabbits and guinea pigs were inoculated via the intra-muscular route with 20 µg of the purified virus emulsified in Freund's complete adjuvant. At 30 days post-inoculation the rabbits were boosted with 20 µg of the purified virus emulsified in Freund's incomplete adjuvant and the guinea pigs euthanized and bled out and the serum collected. The rabbits were euthanized and bled out at day 45 post-inoculation and the serum collected. The sera were assessed for their suitability as FMD AT-ELISA reagents and the most appropriate sera pooled for use as rabbit or guinea pig anti-FMD polyclonal IgG.

The FMD AT-ELISA employs an indirect sandwich format using the method of Roeder and Le Blanc Smith (1987) with local modifications as described by Blacksell et al. (1994b). Briefly, the assay methodology employed rabbit anti-FMD polyclonal IgG, specific for serotypes O, A and Asia 1, to 'trap' the FMD antigen in the sample which is detected by guinea pig anti-FMD polyclonal IgG, also specific for serotypes O, A and Asia 1. The presence of the guinea pig anti-FMD antibodies is indicated by an anti-guinea pig IgG immunoglobulins conjugated to the enzyme, horse radish peroxidase (HRP), which subsequently produces colour development in the presence of a soluble substrate, 3', 3' tetramethylbenzidene (TMB). The reaction was stopped by the addition of 1M H_2SO_4 and the optical density read at 450 nm. The sample optical density was corrected for background noise. Samples with optical densities greater than 0.10 in more than one test were considered positive for FMD antigen.

Foot-and-mouth disease liquid phase blocking ELISA

The assessment of serum for the determination of FMD antibodies was achieved by the FMD liquid phase blocking ELISA (FMD LPB-ELISA). The FMD LPB-ELISA was employed using the methodological principles described by Hamblin et al. (1986) and immunological reagents as described for the FMD AT-ELISA.

Briefly, the assay methodology required FMD antigen of a specified serotype to be incubated with test serum which was transferred to an ELISA plate coated with rabbit anti-FMD polyclonal IgG, specific for the serotype under assessment to 'trap' any unbound antigen. The bound FMD antigen in the sample was detected by guinea pig anti-FMD polyclonal IgG, followed by the addition of an anti-guinea pig IgG-HRP conjugate and the substrate, TMB. The reaction was stopped by the addition of 1M H_2SO_4 and the optical density read at 450 nm. The result for each serum was calculated in the following manner to determine the percentage inhibition (PI) of FMD antigen binding by the sample,

$$PI = 100 - \left(\left(\frac{Test\ sample\ OD}{Negative\ control\ OD} \right) \times 100 \right)$$

Samples with a PI greater than 50% were considered positive for FMD antibody.

Classical swine fever

Classical swine fever antigen trapping ELISA

The classical swine fever antigen trapping ELISA (CSF AT-ELISA) is an indirect double sandwich antigen capture ELISA employing a polyclonal antigen trapping antibody and three monoclonal antibodies, a pestivirus group, BVDV-specific (bovine viral diarrhoea virus-specific) and negative, to specifically detect the presence of CSF antigen or otherwise by inference in tissue homogenates and leucocytes from CSF suspected cases (Shannon et al. 1993).

The CSF AT-ELISA methodology and reagents used at the NVRDC were essentially the same as those described by Shannon et al. (1993). Briefly, samples were prepared using the following methods. In the case of assessing leucocytes, blood was collected into heparinised vaccutainers and centrifuged, and the buffy coat cells harvested from the interface of the plasma and the packed red blood cells. The harvested buffy coat cells were transferred to a new tube and treated with cold 0.17M NH_4Cl to lyse the red blood cells. The treated cells were washed twice in PBSA and the leucocyte pellet treated with a 1% Nonidet P40 (NP40) (v/v) solution, centrifuged and the supernatant harvested for assay. Spleen and lymph node tissues were processed into a 20% w/v homogenate in a 1% NP40 (v/v) in PBSA. The sample was incubated, centrifuged and supernatant used undiluted in the test.

The ELISA method required the use of a 96-well U-bottom polypropylene microtitre plate which was used as a liquid phase incubation plate (LP plate) and a 96-well flat-bottom polystyrene microtitre plate used for the ELISA procedure (ELISA plate). The LP plate was blocked for potential immunoglobulin binding and the ELISA plate was coated with goat anti-CSFV IgG and both plates incubated overnight at 4°C. The following day, the ELISA plate was washed and blocked to prevent any potential adverse immunoglobulin binding. The LP plate was washed and the test sample, QC control, and CSF positive and negative control samples added to three appropriate wells. Pestivirus group-reactive, BVDV-reactive and negative monoclonal antibodies were added to the appropriate wells and incubated with the test sample. Following the completion of the incubations, the ELISA plate was washed and sample/monoclonal antibody mixtures transferred from LP plate to the ELISA plate in the appropriate format wells and incubated. The LP plate was discarded at the completion of this transfer step. At the completion of the incubation the ELISA plate was washed and biotinylated goat anti-mouse IgG conjugate added and incubated, followed by the addition of biotin-streptavidin-HRP. Following washing, TMB substrate was added and the reaction stopped with 1M H_2SO_4 and read at 450 nm. The results were interpreted by first calculating a signal to noise ratio (S/N) for each sample thus,

$$S/N = \frac{\text{Mean OD with Positive Mab}}{\text{Mean OD with Negative Mab}}$$

As recommended by Shannon et al. (1993) the following interpretation was made for each sample: an S/N ratio > 2.00 is CSF antigen-positive, 1.50–1.99 is equivocal and the test repeated, and < 1.50 is CSF antigen-negative.

Infectious bursal disease

Infectious bursal disease virus antigen detection ELISA

The detection of IBD antigen was accomplished by the use of a proprietary antigen capture ELISA employing a indirect sandwich capture format produced by TROPBIO (JCU Tropical Biotechnology Pty Ltd, Australia). Briefly described, the method used a 10% (w/v) homogenate of bursa which was diluted in a proprietary dilution buffer and added to a antibody-precoated ELISA plate. Appropriate controls supplied with the test kit were diluted and included at this stage. The presence of bound antigen was detected by the addition of a high-titre chicken anti-IBD virus antibody followed by an anti-chicken–HRP conjugate and ABTS [2,2'-azinobis (3-ethylbenzthiazoline-sulfonic acid)] substrate read at 414 nm. Test results were calculated thus,

$$\text{Mean nett OD} = (\text{Mean sample OD}) - (\text{Mean negative control OD})$$

with a mean nett optical density of 0.20 considered positive for the presence of IBD virus antigen.

Infectious bursal disease virus antibody detection ELISA

Antibodies against IBD were detected in an indirect ELISA format. Briefly, rabbit anti-IBD virus antibodies were coated onto an ELISA plate followed by addition of semi-purified IBD virus. Test serum was reacted with the bound reagents in the ELISA plate and the presence of antibodies detected by an anti-chicken–HRP conjugate and TMB substrate with the reaction stopped with 1M H_2SO_4 and read at 450 nm. Test results were calculated thus,

$$S/P = \frac{Mean\ sample\ OD - Mean\ negative\ control\ OD}{Mean\ sample\ OD - Mean\ positive\ control\ OD}$$

with the following interpretation, sample/positive (S/P) ratio of > 0.20 was positive, 0.15–0.199 was equivocal, and < 0.15 was negative.

Newcastle disease

Newcastle disease virus antigen detection ELISA

The detection of Newcastle disease antigen was carried out using proprietary antigen capture ELISA produced by TROPBIO. Briefly described, the antigen was detected in spleen homogenate diluted in a proprietary dilution buffer that was reacted with a ND virus group-specific monoclonal antibody and added to a antibody-precoated ELISA plate. Appropriate controls supplied with the test kit were diluted and included at this stage. The presence of bound antigen was detected by the addition of anti-mouse–HRP conjugate and ABTS substrate read at 414 nm. Samples with a resultant optical density of > 0.50 were considered ND virus positive, 0.20–0.49 were equivocal and should be passaged in eggs and re-evaluated, and < 0.20 were considered ND virus negative.

Internal Quality Control of ELISAs

FMD ELISA QC variables

In the case of the FMD AT-ELISA, the QC reagent was a buffered standard control antigen (SCA) prepared for serotypes O, A and Asia 1. On the occasion of each test, the SCAs were serially diluted and a mean standard antigen result calculated and employed as the QC variable. Detailed methodologies have been described previously (Blacksell et al. 1994a, 1996). The QC reagent for the FMD LPB-ELISA was a bovine serum positive for serotypes O, A and

Asia 1. The QC reagent was serially diluted in the ELISA and the log_2 transformed dilution at which the 50% positive end-point calculated was used as the QC variable (Blacksell et al. 1996).

CSF ELISA QC variables

The QC reagent for the CSF AT-ELISA was a standardised dilution of a CSF-positive spleen homogenate (Blacksell et al. 1996). To minimise potential variation in the QC variable, the spleen homogenate was aliquoted and stored at –80°C. Results were expressed as a signal-to-noise ratio (Shannon et al. 1993) as described in a previous section.

IBD ELISA QC variables

The QC reagent used for the IBD virus antibody detection ELISA was a IBD-positive chicken serum. The QC reagent was serially diluted in the ELISA and the log_2 transformed dilution at which the positive end-point was reached was used as the QC variable. In the case of the IBD virus antigen detection ELISA, the result of the positive control included with the TROPBIO kit was used as the QC variable which unfortunately did not lend itself to QC assessment.

ND ELISA QC variables

In the case of the ND virus antigen detection ELISA, the result of the positive control included with the TROPBIO kit was used as the QC variable which did not lend itself to QC assessment.

Shewhart-CUSUM control charts

Shewhart-CUSUM (cumulative summation) control chart methodology was based on that described by Westgard et al. (1977) as an internal QC procedure using a single variable to detect systematic and random assay variation and adapted for the FMD AT-ELISA by Blacksell et al. (1994a). Briefly, the performance characteristics of an ELISA were determined by performing the assay on at least 10 separate occasions and the mean and standard deviation(s) results calculated. These results were then used to calculate 'decision limits' for the assay which are used as the performance parameters for future QC assessment. The decision limits calculated for Shewhart-CUSUM analysis were target mean (t), warning limit (k) which was set at 1 standard deviation and the out-of-control limit (h) set at 2.7 standard deviations (see Figure 1).

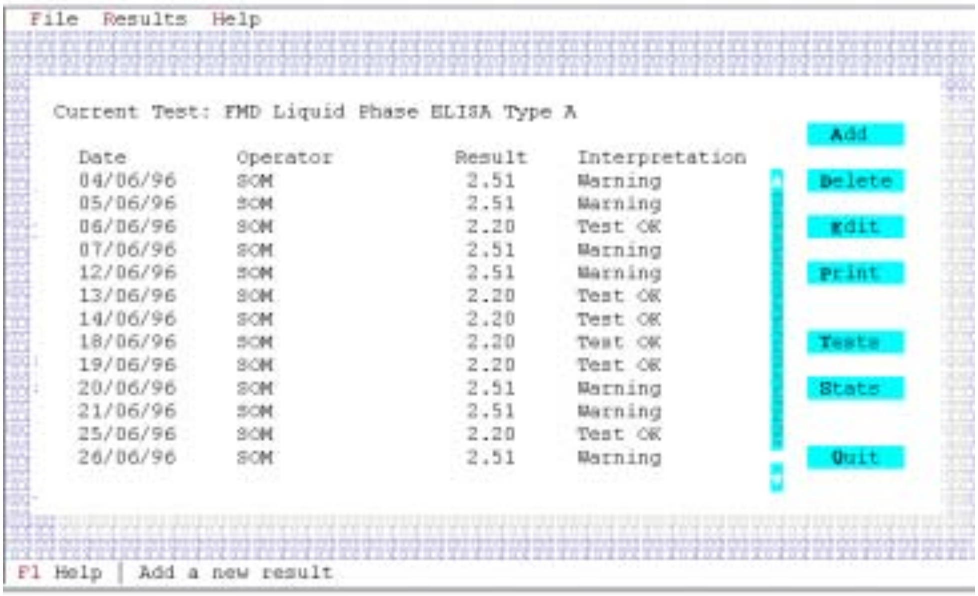

Figure 1. Data input and quality control variable interpretation screen for the QCEL (quality conrol for enzyme-linked immunosorbent assay—ELISA) program.

QCEL program

The QCEL (quality control for ELISA) program as described by Blacksell et al. (1996) is a DOS-based computer program which facilitates the input and output of QC data, requisite calculations, Shewhart-CUSUM charts and interpretation of QC variable results.

At the main entry screen of the QCEL program the operator is prompted for date, their name and the QC variable result (Figure 1). From this information the QCEL program provides an interpretation of the test performance based on the predetermined ‘decision limit’ parameters. The QCEL program provides an interpretation (Figure 1) of the QC variable results in the following manner.

Test OK	This interpretation indicates that no action is required. Accept test results.
Warning	This interpretation indicates that there is a possible problem with the assay. Investigate the results for potential systematic data trends. Accept test results.
Out-of-Control	This interpretation indicates that there is a definite problem with the assay. Investigate and resolve problem. Reject test results.

The QCEL program also has the capability to view QC data in graphical form (Figures 2 to 5), automatically update ‘decision limit’ parameters to reflect current assay performance, assess operator performance and automatically calculate assay performance statistics.

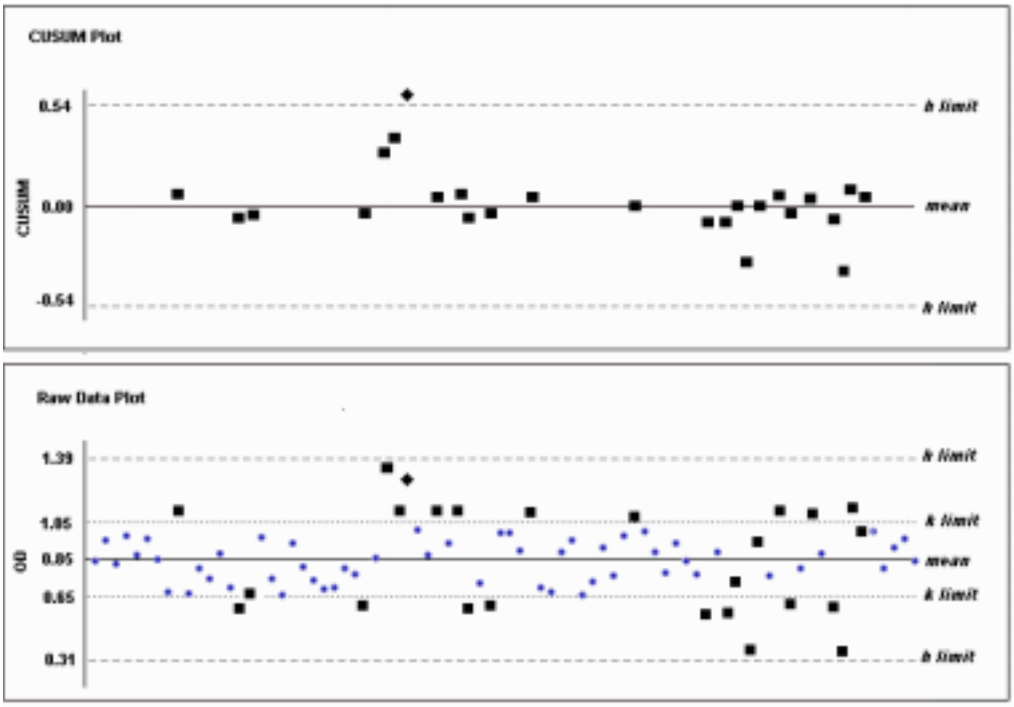

Figure 2. Shewhart-CUSUM (cumulative summation) control chart from the QCEL (quality conrol for enzyme-linked immunosorbent assay—ELISA) program for a portion of the foot-and-mouth disease antigen typing ELISA type A results. Where: OD = optical density; * = acceptable result; ■ = warning (k) result; ◆ = out-of-control (h) result.

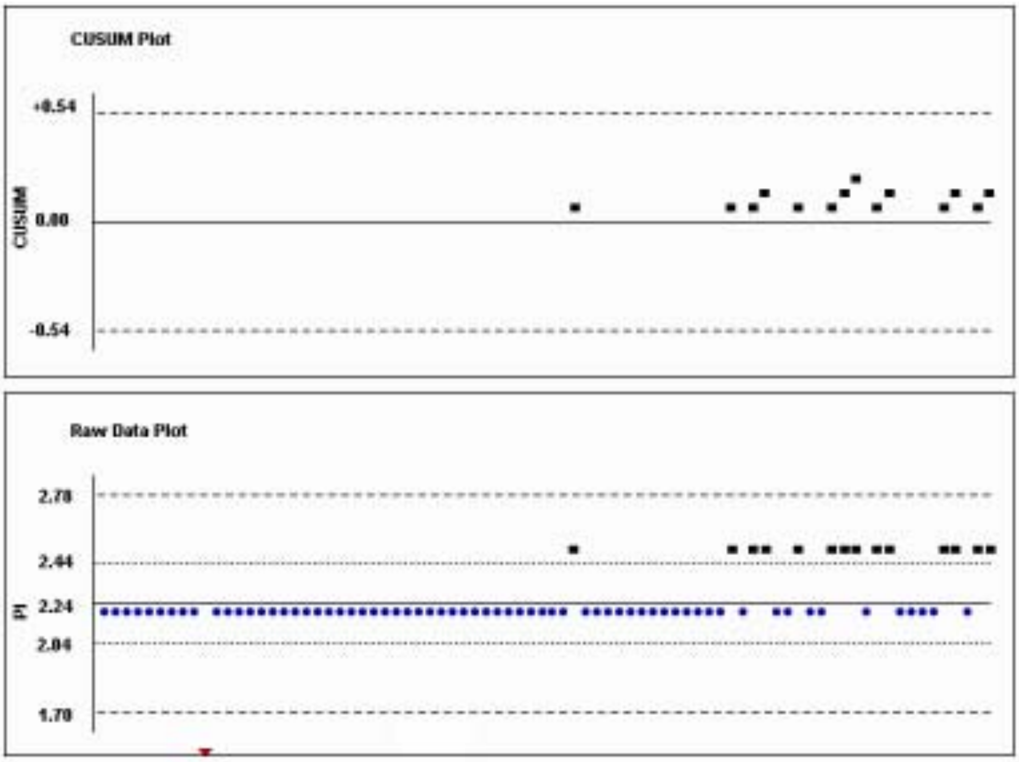

Figure 3. Shewhart-CUSUM (cumulative summation) control chart from the QCEL (quality conrol for enzyme-linked immunosorbent assay—ELISA) program for a portion of the foot-and-mouth disease liquid phase blocking ELISA type A results. Where: PI = percentage inhibition; • = acceptable result; ■ = warning result. The Out-of Control result on this graph was outside the graph limits and signified by the following symbol (◆).

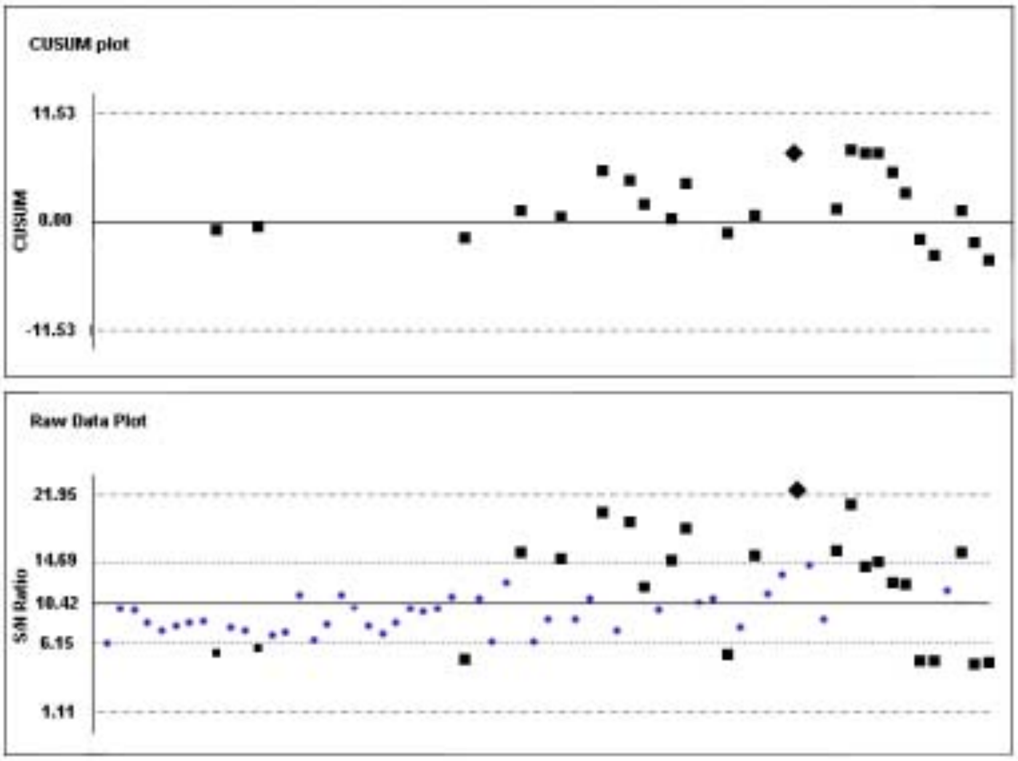

Figure 4. Shewhart-CUSUM (cumulative summation) control chart from the QCEL (quality conrol for enzyme-linked immunosorbent assay—ELISA) program for all classical swine fever antigen trapping ELISA type A results. Where: S/N ratio = signal to noise ratio; * = acceptable result; ■ = warning result; ◆= out-of-control result.

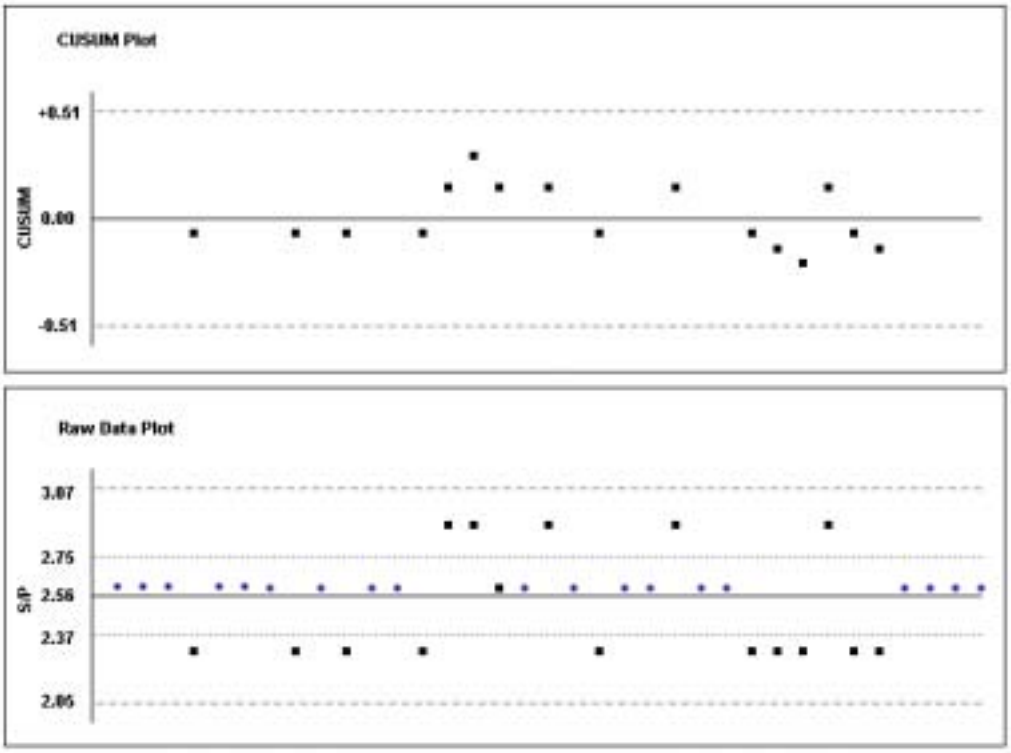

Figure 5. Shewhart-CUSUM (<u>cu</u>mulative <u>sum</u>mation) control chart from the QCEL (quality control for enzyme-linked immunosorbent assay—ELISA) program for all infectious bursal disease antibody ELISA results. Where: S/P = sample/ positive ratio; * = acceptable result; ■ = warning result.

Results and Discussion

Foot-and-Mouth disease

During the 23-month laboratory component of the project, 149 samples were submitted from 119 outbreaks for the FMD AT-ELISA. Of the samples submitted, 109 outbreaks were deemed positive for FMD virus of which 42 were positive for type Asia 1 virus and 67 positive for type O virus. The QC results for each of the FMD AT-ELISA serotype systems indicated reproducibility of the QC variables, thereby providing confidence in the assay (Table 1). Variation of the QC variable was within acceptable limits with the co-efficient of variation (cv) for serotypes O, A and Asia 1 being 22.95%, 23.50% and 27.47%, respectively. The percentage of out-of-control (OOC) events was low with the highest percentage being the type A system with 2%.

A representative QC plot for serotype A is presented in Figure 2 with an OOC event indicated following a trend of abnormally high results. Following the OOC event the assay system was re-evaluated to rectify the problem. Overall the FMD AT-ELISA is a highly robust assay which has been adapted well to routine diagnosis.

Table 1. Summary of quality control results for all enzyme-linked immunosorbent assay (ELISA) tests.

	FMD AT-ELISA Type O	FMD AT-ELISA Type A	FMD AT-ELISA Type Asia 1	FMD LPB-ELISA Type O	FMD LPB-ELISA Type A	FMD LPB-ELISA Type Asia 1	CSF AT-ELISA	IBD Antibody ELISA
Mean	1.22	0.85	0.91	2.35	2.24	2.60	10.42	2.56
s	0.28	0.20	0.25	0.16	0.20	0.15	4.27	0.19
cv	22.95	23.50	27.47	6.81	8.93	5.77	40.97	7.42
% OK	60.40	62.00	57.84	100.00	82.58	69.49	63.08	54.29
% Warning	38.61	36.00	41.18	0.00	16.85	28.81	35.38	45.71
% OOC	0.99	2.00	0.98	0.00	0.56	0.00	1.54	0.00
n	102	102	102	178	178	178	65	35

Where: FMD AT-ELISA = foot-and-mouth disease antigen typing ELISA; FMD LPB-ELISA = foot-and-mouth disease liquid phase blocking ELISA; CSF AT-ELISA = classical swine fever antigen trapping ELISA; IBD = infectious bursal disease; s = standard deviation; cv = co-efficient of variation; % OK = percentage of results giving an 'Acceptable' result; % Warning - Percentage of results giving a 'Warning' result; %OOC = percentage of results giving an 'Out-of-Control' result; n = number of tests

A total of 20 818 sera were tested in the FMD LPB-ELISA during the project against serotypes O, A and Asia 1 for a total of 62 454 tests. Epidemiological analysis of the results is presented elsewhere in this monograph. The QC results for the FMD LPB-ELISA systems, presented in Table 1, indicate a high level of reproducibility in the assay system. Overall cv results are low although some of the lack of variation may be attributable to the choice of QC variable. Nevertheless, the assay is robust and stable in the hands of an experienced operator. A representative QC plot for serotype A is presented in Figure 3 where an OOC event was observed indicating a very low level of assay sensitivity which was attributed to a dilution error.

Classical swine fever

The CSF AT-ELISA was used for the assessment of 211 samples with 38 samples being positive. The majority of the samples submitted were spleen tissue taken following post-mortem examination of CSF-suspected cases, although a smaller number of leucocyte samples were processed for CSF-carrier assessment. The QC results (Table 1) reflect the somewhat complex nature of the assay with a high cv recorded (i.e. 40.97%) relative to other assays. Nevertheless, the assay performed within the reasonable limits according to %OK, %Warning and %OOC values. One OOC event was recorded following a series of unacceptably high results (Figure 4) which was remedied following a modification to the operator's technique.

Infectious bursal disease

One hundred and seventy three bursas from IBD-suspected chickens were submitted for assessment of which 69 were positive in the IBD virus antigen detection ELISA. QC assessment was performed as prescribed in the test methodology included with the kit. All tests recorded acceptable QC results according to the manufacturer's guidelines (results not shown).

A total of 1 601 chicken sera were assessed in the IBD virus antibody detection ELISA during the course of the project of which 1 290 (80.57%) were positive for IBD antibody. The QC results for this assay indicated a low degree of variability (cv = 7.42%) with good reproducibility. No OOC events were recorded for this assay. The QC plot for this assay is presented in Figure 5.

Newcastle disease

Two hundred and eighteen spleen, trachea or lung from ND-suspected chickens were submitted for assessment of which seventeen were positive in the ND virus antigen detection ELISA. All tests recorded acceptable QC results according to the manufacturer's guidelines (results not shown).

Conclusion

The results presented in this chapter describe the successful implementation and application of ELISAs at the NVRDC, a regional laboratory in northern Thailand, to enable the elucidation of the epidemiology for the target diseases prescribed for ACIAR project 9204. The ELISA methodologies described are robust and give reproducible results in the hands of an experienced operator thereby enabling ELISA technology transfer to a regional laboratory. Furthermore, should the necessity arise, ELISA reagents may be produced under local conditions or alternatively—where only limited testing is required or propriety technology employed—may be purchased in commercial kit form. The inherently complex nature of the ELISA may result in random or systematic test variation and therefore some form of QC assessment to monitor assay performance is desirable. The Shewhart-CUSUM control chart methodology as described in this paper and facilitated by the QCEL computer program has simplified the application, performance and maintenance of internal ELISA QC at the NVRDC that could be easily transferred to other regional laboratories.

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Sampling Considerations for Active Surveillance of Livestock Diseases in Developing Countries

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Abstract

Theory and applications of sampling for estimating protection levels of livestock against disease in developing countries are examined. Often, the budget for sampling is strictly limited and it is difficult to obtain a sampling frame. Hence there is a crucial need for statistical efficiency. Random coordinate sampling is found to be effective where no list of villages from which to sample is available. The classic two-stage {30,7} sampling design is found to be highly robust under a variety of circumstances, although choice of sample size at each stage may be simplified in the presence of cost discontinuities.

Introduction

Programs for the control or eradication of major epidemic livestock diseases are either under way or planned in almost all of the countries of Southeast Asia (OIE 1996). This regional and worldwide concern is a result of the clinical impact of many diseases, as well as their ramifications for international trade. The potential benefits of achieving national or sub-national disease-free zones are generally perceived to warrant the expenditure of a significant proportion of national animal health budgets on control and eradication programs. However, in order to maintain funding for expensive control programs, animal health authorities must be able to demonstrate the continuing effectiveness of such programs. Also, it is imperative that reliable information be obtained upon which to base these programs and that cost-effective information collection procedures be devised.

One of the most important diseases present in Southeast Asia is foot-and-mouth disease (FMD). Using FMD as an example, this paper examines surveillance measures used to establish the level and distribution of important diseases, and to monitor vaccination program effectiveness (or perhaps more importantly, to identify weaknesses in vaccination programs so they can be addressed). Surveillance programs have a number of requirements:

- Measures of the current FMD situation should be quantifiable, objective and of known precision.
- FMD incidence over time should be measured regularly. The shorter the period between assessments, the sooner problems will be identified and corrected. However, relatively small changes between periods close together in time may be difficult or expensive to identify.
- The information should be gathered for relatively small geographical units so that local problems or geographic patterns can be identified. Single assessments of the FMD situation for an entire country only represent the average of all the states, provinces or districts.
- Estimates of the FMD situation should be unbiased; otherwise they may result in either unwarranted concern or dangerous complacency.

The only practical way to achieve reliable incidence estimates is to use properly designed surveys based on probability sampling. The preceding requirements dictate that such surveys need to be carried out frequently and cover each area of a country in some detail. All this adds up to a significant expense which may be overwhelming for developing countries. Often almost all the FMD control budget is spent on vaccine. With this in mind, the following discussion is directed towards obtaining required information for as low a cost as possible.

Many measures of the 'FMD situation' are available, but some are more useful than others. One measure of vaccination program effectiveness commonly used by veterinary services is the number of doses of vaccine used. There are unfortunately many hurdles a dose of vaccine must cross before it is able to contribute to the control or eradication of FMD, and this measure gives no indication of how well vaccination distribution and use is managed.

The most practical measure of vaccination program effectiveness bypasses the vagaries of vaccine storage, administration technique, timing of administration and so on, and simply measures the effect of the vaccine on target animals—the FMD antibody titre is measured for instance by enzyme-linked immunosorbent assay (ELISA). If a cut-off point is used to define the antibody titre at which an animal is deemed to be protected against infection, serological surveys can be used to estimate the prevalence of animals protected against the disease. When the proportion of protected animals reaches a critical level (probably around 80% for FMD) then herd immunity is achieved and new introductions of virus will not result in an outbreak of disease (Anderson and May 1985; Cleland et al. 1994). Analysis of data from serological surveys is naturally broken down by the relevant virus types in the area.

While the immediate aim of a vaccination program is to increase the proportion of protected animals in the population, the ultimate aim is to decrease the amount of disease in a population. Laboratory procedures commonly available are not able to distinguish reliably between natural immunity and titres resulting from vaccination (Ahl and Wittmann 1987; Chamnanpood et al. 1994). Hence a high prevalence of protected animals may be due to a high level of disease in the population rather than effective vaccination. To truly understand if a vaccination program is achieving its ultimate aim, measures of disease incidence are also needed.

The Australian Centre for International Agricultural Research (ACIAR) Project 9204 has been concerned with development of an information system for animal health in Thailand. A trial in active surveillance was conducted over three provinces in north western Thailand, namely Lampang, Lamphun and Chiang Mai. A two-stage sampling procedure was adopted, with villages being selected with *probability proportional to size* in the first stage and a constant number of livestock in selected villages being selected randomly in the second stage. Antibody titres for FMD above a critical level (positive diagnoses) were taken to indicate animals being protected from the disease, due to exposure to the disease, vaccination or both.

This paper reviews statistical and practical considerations in multistage sampling designs for active surveillance of livestock diseases, with particular emphasis on FMD in Thailand. Issues addressed include statistical efficiency, estimator formulae for proportion of protected animals, and sampling design and cost considerations. A simulated sampling approach to comparing sampling designs with respect to their precision and cost is presented. Practical considerations in serological surveys are examined, including application of a random coordinate sampling design, capture/recapture methods and retrospective village outbreak analysis.

Seroprevalence Surveys

A seroprevalence survey to demonstrate FMD vaccination program effectiveness should involve the collection and analysis of blood samples from a random selection of animals from the reference population. The unit of interest is therefore the individual animal, and the main question to be answered is: '*What is the prevalence of animals with protective antibody titres against each of the significant FMD virus types in this area?*'

Survey designs

Simple random sampling from a population consisting of tens of thousands of animals is virtually impossible, due to both the difficulty of developing a sampling frame and the expense of visiting many widely separated sites to bleed just one animal from each. Stratified and multistage sampling designs offer potential for more cost-effective monitoring of animal health. Stratification by region, province or district could be important in assessing the spatial nature of protection levels. Relative to simple random sampling, multistage sampling leads to some loss in statistical efficiency for a given sample size, but can greatly reduce cost where sampling frames are difficult to obtain and travel costs are high.

For large-scale livestock surveys, multistage sampling becomes essential. Two-stage sampling involves (i) selecting groups of animals or owners, and then (ii) selecting individual animals from each selected group. In the Southeast Asian context, the first stage usually involves the random selection of a number of villages. At the second stage, animals are randomly chosen from each of the selected villages. A variety of methods for selection at each stage is available, depending on the individual circumstances. However, sampling strategies in which each animal in the population has the same probability of selection, known as self-weighting samples, are generally the easiest to analyse (Cochran 1977; Kish 1995).

A two-stage design, involving approximately 30 villages and 15 livestock from each, and six-monthly visits, has been trialled for FMD monitoring in the three Thai provinces. Villages have been selected with probability proportional to village cattle numbers. The fixed number of livestock per village is efficient in terms of the time that field team members need to spend in a village to collect blood specimens. That is, probability proportional to size (PPS) sampling has advantages with respect to cost per sample member, and hence to the precision for a given survey budget. Also, in general it leads to greater statistical efficiency than placing an equal probability of selection on each village.

Efficiency of PPS sampling

Developing multistage sampling designs requires an appreciation of the concepts of *statistical efficiency* and *cost of sampling*. Sampling designs can be compared on the basis of their expected precision of estimators for a given sample size. Combined with cost-effectiveness of the sample design, this provides the basis for choosing between alternative sampling designs. An estimator is efficient if it has a low variance, i.e. if the *sampling distribution* of that estimator is narrow and peaked. Efficiency is a relative concept by which alternative sampling designs can be compared. Two efficiency estimators frequently used are the sample mean $\overline{x}$ (an estimator of the population mean $\propto$) and the sample proportion *p* (an estimator of the population proportion $\neq$).

The measures of efficiency for estimators can be expressed in terms of variances of sampling distributions, e.g. $V(\overline{X})$ and $V(P)$, where $\overline{X}$ and *P* are random variables representing the sampling distributions of the mean and proportion respectively, from repeated samples of fixed size from a given population. These measures may be defined in terms of the population parameters, given the sampling design. They are theoretical measures, in the sense that population parameters (means, variances) normally are not known, hence estimates must be made on the basis of sample statistics. If variances of the sampling distributions are small, reflected in small sample standard errors, confidence intervals (e.g. for proportion of protected animals) will be narrow, so estimates will have a high information content. Formulae for variance of the sampling distribution of means for multistage sampling are quite complex. Fortunately, they are considerably simplified for PPS sampling.

By way of notation, consider a livestock population which can be divided into *M* villages or primary sampling units (PSUs). Each PSU has N_i members, for a total population of *N* members (N = □ N_i). Further, *m* of the PSUs are to be selected with probability proportional to size, i.e. the probability of selecting each is $p_i = N_i / N$. A constant number $(\bar{n})$ of animals or secondary sampling units (SSUs) will be drawn from each selected PSU. The objective is to estimate ≠, the *proportion* in the population having the particular characteristic, e.g. high blood titre against FMD.

Sampling theory is normally developed with respect to the mean. Hence efficiency formulae will be considered first for the sample mean and then for the sample proportion. Greek symbols will be used for population *parameters* (mean ∝, proportion ≠ and variance □^{2}); upper case letters will be used for *population numbers* and lower case for *sample numbers* (e.g. N_i and n_i). A single subscript will be used for PSU *totals* (x_i).

Suppose two-stage sampling is carried out, with PSUs *selected with replacement* and SSUs *selected without replacement*[1]. The variance of the sampling distribution of sample means (Yamane 1967, p. 254; Levy and Lemeshow 1991, p. 267) is

$$V(\hat{\mu}) = \frac{1}{mN}\sum_i^M N_i\left(\mu_i - \mu\right)^2 + \frac{1}{mN}\sum_i^M \frac{N_i - \bar{n}}{N_i - 1}\sum_j^{N_i}\frac{\left(x_{ij} - \mu_i\right)^2}{\bar{n}} \qquad (1)$$

The first of these terms represents variance of the sampling distribution of means between PSUs, and the second represents variance within PSUs.

1. Development of variance formulae is simpler if sampling is conducted with replacement, because probability of selection does not vary as sampling proceeds. However, sampling without replacement tends to be more practical in that it is usually undesirable to have individual population members repeated in a sample. In two-stage sampling, the favoured practice would appear to be to select the PSUs with replacement (WR) and the SSUs without replacement (WOR), and this is the basis on which formulae are developed here.

The sample proportion may be viewed as a special case of the mean, i.e. the mean of a binary or 0–1 variable. Hence, efficiency formulae for a proportion may be developed from those for the mean. The population variance for the *proportion* under two-stage sampling (from Yamane 1967, p. 278) is

$$V(\hat{P}) = \frac{M-m}{M(M-1)\overline{N}^2} - \frac{\sum_i^M \left(N_i\pi_i - \overline{N}\pi\right)^2}{m} + \frac{M}{mN^2}\sum_i^M \frac{N_i^2(N_i-n_i)}{N_i-1}\frac{\pi_i(1-\pi_i)}{n_i} \quad (2)$$

where $\overline{N}$ is the average PSU size, n_i is the sample size from the *ith* PSU, $\neq_i$ and (1 – $\neq_i$) are the proportions of protected and non-protected members in the *ith* PSU, and *P* is the overall proportion protected.

The *efficiency* of two-stage sampling and simple random sampling may be compared using the expression (Yamane 1967, p. 227; Murthy 1967, p. 327)

$$V(\overline{X}) = V(\overline{X}_{srs})\left[1+(\overline{n}-1)\rho\right] = \frac{\sigma^2}{m\overline{n}}\left[1+(\overline{n}-1)\rho\right] \quad (3)$$

where $V(\overline{X}_{srs})$ is the efficiency measure for simple random sampling, and $m\overline{n}$ is the total sample size. Here □ is the *intracluster correlation coefficient*, or measure of homogeneity within PSUs relative to the population mean. Members within a PSU tend to be more uniform or homogeneous than members of the overall population. That is, diseases tend to form pockets, and as well vaccination coverage tends to be more complete in some areas than in others. Where such homogeneity within PSUs exists, □ will tend to be positive and the sampling error can be expected to be greater than that which would be obtained under simple random sampling. The *design effect* approach uses the term in square brackets as an inflation factor to increase the sample size relative to that which would be needed with a simple random sample.

Statistical estimator formulae and precision estimates

While efficiency formulae are needed in considerations of sample design and size, once a survey has been conducted the task becomes one of estimating population parameters based on sample data. Both point estimates (especially the mean and proportion) and confidence intervals may be derived. The unbiased estimator of the population mean under two-stage sampling (Yamane 1967, p. 218) is

$$\hat{\mu} = \frac{1}{N}\frac{M}{m}\sum_{i}^{m} \frac{N_i}{n_i}\sum_{j}^{n_i} x_{ij} \tag{4}$$

Provided each population member has an equal probability of selection in the sample, the *sample mean* is an unbiased estimate of the population mean. This is the case under PPS sampling, which is a *self-weighting* design in that the fixed number of SSUs compensates for the unequal probabilities attached to the PSU, so:

$$\hat{\mu}_{pps} = \frac{1}{m\bar{n}}\sum^{m}\sum^{\bar{n}} x_{ij} \quad \text{(Yamane 1967, p255)} \tag{5}$$

The estimate of the *variance* of the sampling distribution of means may be obtained by substituting sample estimates into the above efficiency formula, and summing over the sample numbers. However, a simpler formula (Yamane 1967, p. 255; Cochran 1977, p. 309; Levy and Lemeshow,1991, p. 268), is

$$\hat{V}\left(\bar{X}_{pps}\right) = \frac{1}{m} \quad \frac{1}{m-1}\sum^{m}\left(\bar{x}_i - \bar{x}_{pps}\right)^2, \quad \bar{x}_i = x_i / \bar{n} \tag{6}$$

An interesting feature of this formula is that "*the estimator depends only on the variation between ultimate clusters and not on the variation within an ultimate cluster*" (Yamane 1967, p. 255). The size of the samples from within PSUs does not enter directly into the formula, although the distribution of PSU means about the overall population mean will depend on *n*.

Under two-stage sampling, in which $\bar{n}$ items are selected at random from each of *m* PSUs, the *unbiased estimator of the population proportion* ≠ is

$$\hat{\pi} = \frac{M}{Nm}\sum^{m} N_i\, p_i, \text{ where } p_i = \sum^{n_i} x_{ij} / n_i \quad \text{(Yamane 1967, p274)} \tag{7}$$

Here p_i is the sample proportion with the characteristic in the *ith* PSU, $N_i p_i$ is an estimate of the population number in the *ith* PSU, and these are summed to obtain an estimate of the number in the *m* selected PSUs. The factor *M/m* inflates this to an estimate of the total number in the *M* population PSUs, and dividing by *N* converts this to an estimate of the average (i.e. the proportion with the characteristic). Under PPS sampling, this formula simplifies to

$$\hat{\pi} = \frac{1}{m\bar{n}}\sum^{m}\sum^{\bar{n}} x_{ij} = \frac{1}{m}\sum p_i \qquad (8)$$

where x_{ij} (the value for the *jth* animal in the *ith* selected village) takes a value of 1 (protected) or 0 (unprotected).

The estimated variance for the population proportion under two-stage sampling is

$$V(\hat{\pi}) = \frac{1}{N^2}\left[M^2 \frac{M-m}{M}\frac{1}{m}\frac{1}{m-1}\sum_{i}^{m}\left(N_i p_i - \frac{1}{m}\sum_{i}^{m} N_i p_i\right)^2 \right. \qquad (9)$$

$$\left. + \frac{\mathrm{M}}{\mathrm{m}}\sum_{i}^{m} N_i^2 \frac{N_i - n_i}{N_i}\frac{1}{n_i}\frac{1}{n_i - 1} n_i p_i q_i \right]$$

Yamane 1967, p281

where p_i and q_i are sample proportions.

Under two-stage PPS sampling, a constant number of elementary sampling units $(\bar{n})$ is selected from each PSU. Under certain assumptions, the variance may be estimated by the simplified formula:

$$\hat{V}\left(P_{pps}\right) = \frac{1}{m}\frac{1}{m-1}\sum^{m}\left(p_i - \hat{\pi}\right)^2 \qquad (10)$$

Yamane 1967, p288

An interesting feature of this formula is that variance depends only on the variation between PSUs, and not on the variation within them.

A standard design employed in World Health Organisation surveys of immunisation coverage involves selection of 30 villages and seven people from within each village (Henderson and Sundaresan 1982; Lemeshow and Robinson 1985; Fredrichs 1989). The logic underlying this design is that a target precision in estimation of a population proportion of plus or minus 10% is sought. Under simple random sampling, and assuming the worst case in terms of sample size (where ≠ = 0.5), the half-width of the 95% confidence interval would be

$$
\begin{aligned}
&z_{0.025}\, s_P \leq 0.1 \\
&\text{i.e. } 1.96\sqrt{\pi(1-\pi)} / n \leq 0.1 \\
&\text{or } n \geq (1.96/0.1)(0.5) = 98
\end{aligned}
\qquad (11)
$$

Using a *design factor* of 2.0 (i.e. assuming that two-stage sampling is half as efficient as simple random sampling), a sample size of at least about 200 is indicated. The standard design of $m\bar{n}$ = (30)(7) = 210 meets this requirement, and hence provides a 'ballpark' figure for sample size.

Although this design has been widely used, Lemeshow and Robinson (1985) note that "*30 clusters is based more on tradition and intuition than on statistical theory*" and caution against its mechanical application without regard to the specific population. They note that much larger samples are needed to obtain reliable estimates with respect to rare diseases (where ≠ < < 0.5). In practice, there is often some loss of randomness in the second stage of sampling because of difficulties in selecting households and individuals in developing countries, and this too could dictate need of a larger sample.

Where information is needed on protection levels over a number of regions, samples within each of those regions would need to be sufficiently large to achieve a target precision level, e.g. not less than about 200 beasts per region. Also, where the objective is to detect changes over time in protection levels, the relevant sampling distribution is that of differences between sample proportions, and the improvement between years may be modest, again suggesting a larger sample could be needed to achieve accuracy requirements.

Optimal sample design and size

A number of approaches may be employed to determine a recommended sampling design. These will be discussed in terms of two-stage sampling of livestock for protection against FMD, where the first stage is PPS sampling with replacement, and second stage sampling is without replacement. These approaches include:

- determining the sampling design which will provide the most precise information for a given budget;

- obtaining information with a target precision level at minimum cost. The precision level with respect to a proportion, for example, can be defined according to a number of criteria, e.g. half width of the confidence interval, or standard deviation of an estimator as a percentage of the point estimate;

- maximising the expected net gain from sampling in a static context, or maximising the present value of benefits less costs over time from sampling.

A widely used *cost function* for two-stage sampling is the following formula (Yamane 1967, p. 264; Snedecor and Cochran 1989, p. 449; Levy and Lemeshow 1991, p. 262) is

$$C = c_0 + c_1 m + c_2 m\bar{n} \quad (12)$$

where c_0 are overhead costs, c_1 are costs per PSU, and c_2 are costs per SSU.

This is a linear function in that the cost per PSU is assumed constant over all PSUs, and the cost per SSU is assumed constant for all SSUs within each PSU. For practical purposes, overhead costs are sometimes omitted in sample size calculations, since they do not depend on m and $\bar{n}$.

In setting up an active surveillance program, costs would be incurred for:

- laboratory facilities to test blood specimens;
- training of technicians in laboratory testing;
- purchasing or hiring vehicles;
- acquiring equipment such as chillers, specimen bottles, syringes, ropes and protective clothing;
- obtaining sampling frames and drawing samples; and
- reporting of survey results.

For each village included in the sample, there would be costs involved in: vehicle expenses incurred in travelling to and from villages; wages, accommodation and meals for the field team; and payments or gratuities to villagers assisting with the survey. It is probable that other activities would be carried out at the same time as the survey, such as vaccination for FMD or other diseases. This would affect the time required in each village. No allowance is made here for the cost of veterinary activities associated with the active surveillance program. For each animal from which a blood specimen is drawn, there would be costs comprising mostly staff wages and laboratory testing costs (materials and technician time).

Decisions have to be made concerning the extent to which costs are allocated to the sampling program as distinct from normal activities of veterinary staff and facilities. An example of the kind of question which arises is whether any of the overhead costs of vehicles should be costed against sampling. Purchase of vehicles could be regarded as a sunk cost independent of the sampling activities. However, additional use would increase vehicle depreciation, other routine activities involving use of vehicles may be carried out in conjunction with the survey, and active surveillance may become part of the regular activities of the veterinary agency. Similar issues arise with respect to placing a cost on the time devoted to surveys by regular staff, as distinct from staff employed specifically for surveys. From an opportunity cost viewpoint, vehicles and staff not engaged on the sampling program could be allocated to other desirable activities by the agency, or hired out to the private sector. The view is taken here that these resources should be charged to the sampling program at their full cost. Using the linear cost function and estimates of the population variance parameters, the sampling design in terms of m and $\bar{n}$ can be found such that the sampling efficiency is maximised for a fixed budget C, using the Lagrangean multiplier technique (Harrison 1997).

Use of simulation to compare designs

An alternative to deriving formulae for an 'optimal' sampling design is to simulate sampling from populations with specified parameters, using random number generation procedures on a computer. This simulation approach may be regarded as a fallback method when an analytical approach to determining the sample size cannot be obtained, but in practice it will often prove more flexible and easy to apply than an analytical approach even when the latter is available.

For any nominated sampling design (equivalent to a treatment in a simulation experiment), a large number of synthetic samples (replicates) can be generated and the sampling efficiency determined in terms of the estimated variance of the overall sample proportion of protected animals. A sampling cost function can be included to indicate total cost of any sampling design. Once the simulation method has been set up, and programmed to a computer, this approach allows a large number of alternative sampling designs to be evaluated in terms of efficiency and cost. As well, the parameters relating to the livestock population and sampling cost can be varied readily, to allow a comprehensive sensitivity analysis.

This simulation approach has been used in relation to sampling designs for active surveillance of protection levels against FMD in beef cattle and buffalo in Thailand. A computer program in the Q-BASIC language has been developed to carry out simulated sampling. Default parameters for this program are indicated in Table 1. These estimates are based on information gained in the Thai–Australia Animal Health project. An overhead cost of sampling has been included, and the data collection cost per village includes an allowance for vehicle and labour costs. For convenience, it has been assumed that the proportion of protected animals across villages follows a normal distribution.

Table 1. Default parameter values for simulated sampling.

Population proportion with positive titres		0.5
Between-village variance of proportion		0.06
Average number of livestock per village		200 head
Overhead cost of active surveillance sampling, c_0		100 000 bt
Vehicle cost per village sampled	700 bt	
Labour cost per village sampled	600 bt	
Cost of accommodation etc per village sampled	500 bt	
Data collection cost per village or PSU, c_1		1 800 bt
Data collection cost per blood specimen	20 bt	
Laboratory analysis cost per blood specimen	50 bt	
Data collection cost per SSU, c_2		70 bt

Note: one Thai baht (bt) is equivalent to about $A0.04.

Levels of the two sample size factors are varied in defining treatments for the simulation experiment. The number of villages is varied between 10 and 40 in steps of 10, and the number of livestock per selected village is varied between five and 30 in steps of five. The proportion of protected animals by village is assumed to follow a normal distribution with parameters as in Table 1. Each treatment is replicated 1 000 times. When drawing samples for each village, sampling without replacement is achieved by reducing the total number of protected or unprotected animals after each sample observation. An example of simulation output is provided as Table 2.

Table 2. Sampling efficiency and cost for various two-stage probability proportional to size (PPS) designs, as obtained from a simulation experiment.

Sampling design		Sampling efficiency		Total cost
m	n-bar	Est. Var (P)	1.96 SE	(000 bt)
10	5	0.0098	0.1941	122
10	10	0.0082	0.1774	125
10	15	0.0069	0.1627	129
10	20	0.0061	0.1533	132
10	25	0.0056	0.1465	136
20	5	0.0046	0.1332	143
20	10	0.0038	0.1203	150
20	15	0.0032	0.1115	157
20	20	0.0034	0.1144	164
20	25	0.0027	0.1017	171
30	5	0.0031	0.1085	165
30	10	0.0027	0.1012	175
30	15	0.0023	0.0936	186
30	20	0.0024	0.0968	196
30	25	0.002	0.0885	207
40	5	0.0026	0.1002	186
40	10	0.0017	0.0805	200
40	15	0.0015	0.0770	214
40	20	0.0017	0.0806	228
40	25	0.0016	0.0785	242

Suppose the accuracy requirement for active surveillance is that the error in estimation of the proportion of protected animals in the population be not more than 0.10 or 10%. Table 2 indicates that a sampling design which includes a PPS first-stage sample of 30 villages (with replacement) and a constant second-stage sample size of 10 to 15 animals (without replacement) per selected village would on average yield meet this accuracy requirement.

This table further indicates that:

- provided the number of villages is sufficiently large (20 to 30 or more), increasing the number of animals per selected village is unlikely to have much impact on sampling error;

- while accuracy of estimation improves strongly as the number of villages included in the sample is increased from 10 to 20, increasing the number of villages beyond 20 to 30 yields only small increases in sampling accuracy;

- within the range of sampling designs of interest, the overall survey cost depends primarily on the number of villages included in the sample; and

- if the estimate is to be made to within 10 percentage points, the classic {30,7} design would go close to achieving this accuracy target.

The simulation model may be used to carry out sensitivity analysis with respect to a number of parameters. Some examples are illustrated below.

If there is *high variability between villages* with respect to proportion of protected animals, then there is increased likelihood of obtaining extreme villages in the sample, and accuracy of estimation is reduced accordingly. This is illustrated in Table 3, for which the between-village variance has been doubled relative to that in Table 2, i.e. set at 0.12. It is apparent from this table that a larger sample—of about 40 villages and 10 animals per village—would be required to achieve a 10% accuracy requirement.

In terms of *population protection level*, the worst case situation with respect to sampling error arises when 50% are protected, as assumed in Tables 2 and 3. If the proportion is substantially higher, the sample size required to achieve a target level of precision will be reduced accordingly. This is illustrated in Table 4, which has been derived for a population protection level of 80%. In this case, a sample as small as 20 villages and 15 animals in each (or 30 villages and five animals in each) would meet the 10% error target.

Table 3. **Sampling error for a range of two-stage probability proportional to size (PPS) designs when between-village variance is doubled.**

Sampling design		Sampling efficiency		Total cost
m	n-bar	Est. Var (P)	1.96 SE	(000 bt)
10	5	0.0125	0.2189	122
10	10	0.0113	0.2084	125
10	15	0.0107	0.2031	129
10	20	0.0095	0.1908	132
10	25	0.0082	0.1770	136
20	5	0.0063	0.1552	143
20	10	0.0052	0.1417	150
20	15	0.0049	0.1373	157
20	20	0.0049	0.1378	164
20	25	0.0042	0.1276	171
30	5	0.0039	0.1218	165
30	10	0.0036	0.1183	175
30	15	0.0033	0.1123	186
30	20	0.0037	0.1195	196
30	25	0.0031	0.1089	207
40	5	0.0033	0.1132	186
40	10	0.0023	0.0941	200
40	15	0.0023	0.0937	214
40	20	0.0026	0.0990	228
40	25	0.0025	0.0984	242

Table 4. **Sampling error for a range of two-stage probability proportional to size (PPS) designs when overall protection level is 80%.**

Sampling design		Sampling efficiency		Total cost
m	**n-bar**	**Est. Var (P)**	**1.96 SE**	**(000 bt)**
10	5	0.0066	0.1588	122
10	10	0.0062	0.1539	125
10	15	0.0055	0.1453	129
10	20	0.0048	0.1355	132
10	25	0.0044	0.1307	136
20	5	0.0038	0.1207	143
20	10	0.0027	0.1013	150
20	15	0.0026	0.0997	157
20	20	0.0024	0.0968	164
20	25	0.0020	0.0887	171
30	5	0.0023	0.0940	165
30	10	0.0019	0.0851	175
30	15	0.0017	0.0802	186
30	20	0.0017	0.0813	196
30	25	0.0015	0.0769	207
40	5	0.0017	0.0797	186
40	10	0.0013	0.0707	200
40	15	0.0011	0.0662	214
40	20	0.0012	0.0689	228
40	25	0.0011	0.0642	242

In general, for a fixed total sample size, the sampling cost will be lowest if the number of villages is small and the number of livestock sampled per village is large. However, the cost savings from reducing m and increasing $(\overline{n})$ will be reduced if the sampling cost per village is a decreasing function with respect to number of villages, or an increasing function with respect to size of village samples. The first of these situations has been noted by Murthy (1967, p. 334), who divides the cost per PSU into two components, one a constant and the other depending on the number of SSUs in a selected PSU. The latter is made a function of the square root of m rather than of m itself, on the grounds that the more PSUs selected the less travelling between them will be needed.

The cost per village assumed here is an average cost; villages which are more remote or have poorer road access may involve greater travel time and expense. For second-stage (village) samples of up to about 20 beasts, it would normally be possible in northern Thailand to obtain blood specimens from two villages per day. As village sample size increases, an increasing proportion of villages will require a full day for the veterinary team, leading to increased wage, accommodation, meals and transport costs per village. The increased time would arise not only because of the additional animals which must be bled, but also because negotiations with additional livestock owners and additional mustering would be involved.

The effect of an increasing the cost per village as the number of animals is increased would be to favour a greater number of villages (PSUs) and a smaller number of animals per village. It would appear that for village samples larger than about size 20, it becomes difficult to complete all villages at the rate of two per day. It is probable that for samples of more than about 50 animals, normally only one village could be sampled per day. This information can be represented in the following village cost function:

$$c_2 = \begin{cases} 1800, \bar{n} \leq 20 \\ 1800 + 1800\,(\bar{n} - 20) / 50,\ 20 < \bar{n} \leq 50 \end{cases} \qquad (13)$$

Should a higher precision level than 10% be required, this discontinuity in the cost function would affect the sampling design, favouring a greater number of villages relative to the number of animals selected within each.

‘Snapshot’ versus comparative estimates of protection level

If a survey is designed to estimate the level of protection at a given point in time, this level can be derived as a point or interval estimate. The interval estimate is obtained as $p \pm z\, s_P$, where z is the estimated standard normal variate (asymptotic to 1.96 as sample size increases) and s_P is the standard error as estimated from the sample (s_P″ 0.05 in the classic {30,7} design). As distinct from this ‘snapshot’ case, the interest may be in monitoring the progress of vaccination in terms of changes in the protection level over time. The change in proportion protected between two successive time periods may be derived as a point or interval estimate, of $\neq_1 - \neq_2$, given by $p_1 - p_2 \pm z\, S_{P_1 - P_2}$, where $S_{P_1 - P_2}$ is the estimated standard error as estimated from the two samples. If independent samples of villages are drawn each year, the variance of the difference between sample proportions is the sum of the variances for the individual samples:

$$Var(P_1 - P_2) = Var(P_1) + Var(P_2) \qquad (14)$$

The standard error which is the square root of this sum, will also be increased relative to the snapshot estimate for a single village. That is, a larger sample will be required to estimate the difference in protection level between years than is required to estimate the protection level in a given year, when both are to be estimated at the same level of precision. If the *same villages* are selected in each year, then this will increase precision with which the change in protection level is estimated, and partially eliminate the need for a larger sample.

Other approaches to choice of sampling design

Another approach which has been suggested for monitoring population attributes with respect to target levels (e.g. effective protection against FMD) is *acceptance sampling* (Harrison and Tamaschke 1993, Ch. 18). This technique would approach vaccination effectiveness from an hypothesis testing rather than confidence interval viewpoint. Once a sample of blood specimens is collected and tested in the laboratory, the number or proportion of non-protected specimens (*defectives*) would be compared against an *operating characteristics curve* for a given protection level in the population or *lot*. A statistical decision would then be made as to whether the population was of an acceptable quality level. Acceptance sampling provides an alternative way of examining sample data, which is useful when the objective is to determine whether a required minimum level of protection in a population has been attained.

Bayesian decision theory provides a mechanism to combine existing, and perhaps subjective, knowledge about disease incidence with information obtained from active surveillance. Also, it provides a mechanism for combining statistical and economic information to derive more meaningful criteria for assisting decision-makers in choosing sampling designs. The Bayesian approach (Harrison and Tamaschke 1984) allows *prior* information about the values of estimators (e.g. mean and proportion) to be combined with *sample* information derived from active surveillance sampling) to obtain *posterior* probabilities for random variables. This technique is used for revision of probabilities in the light of new information, and could be applied to estimates obtained in previous surveys or derived subjectively. By comparing the expected value of sample information with the cost of sampling, this technique could indicate the expected net gain from sampling for various sample sizes, and hence shed light on the optimal sample size.

The major limitation of the Bayesian approach is the difficulty in obtaining estimates of the expected value of sample information which are needed to estimate the expected net gain from sampling. The analysis goes beyond statistical considerations into economic estimation. Returns from information will depend on how the information is used, the consequent improvement in animal health, and the improved trade access and changes in producer, consumer and trader economic surpluses.

The Bayesian approach outlined above has been considered in a static or one-period context. An extension would be to estimate the costs and returns from an information system such as active surveillance in a multiperiod framework. Discounted cash flow analysis could then be used to derive performance criteria such as net present value and internal rate of return from alternative sampling designs.

Practical Considerations in Selection of Villages and Livestock

First stage sampling

The way in which villages are selected at the *first stage* of multistage sampling depends on what prior information is available. In the ideal situation, complete and up-to-date lists of villages will be available, along with accurate estimates of the number of relevant livestock in each village (cattle, buffalo and pigs). The veterinary field services of many countries collect this information on an annual basis. If these data are available, and are deemed to be reliable, the most efficient form of sampling is to select villages with *probability proportional to size* (PPS) as described above.

In many cases, data on livestock in villages are incomplete, out of date or not accessible. If a comprehensive village sampling frame exists (maintained by the veterinary services, statistics office or other government departments), villages can be chosen by *simple random sampling* . In this case, random numbers between one and the total number of villages in the area are used to select sample villages. Naturally, no account is taken of the village size. In order to achieve a self-weighting sample, a fixed proportion of the livestock population in each village must be sampled, e.g. 5% (Kish 1995). This means that the final sample size is somewhat unpredictable.

A more difficult situation arises when no reliable village sampling frame exists. Fortunately, even amongst the least developed countries in Southeast Asia, the village is almost always an important lower level division in the administrative hierarchy, and lists of villages are therefore usually readily available. However, these lists are sometimes unreliable. One requirement of two-stage sampling is that the elements on the sampling frame at the first stage (villages) contain each and every element of interest (animals). That is to say that each animal in the target population 'belongs' to one (and only one) of the villages on the sampling frame. Areas of new or scattered settlement, shifting agriculture, or rugged inaccessible terrain may contain many livestock which are not associated with an official, government-recognised village. These 'unofficial' livestock could have an atypical disease situation, perhaps because they do not have access to the government veterinary services. When there is any doubt about the completeness of the village sampling frame, it may be necessary to assume that it is inadequate, and use sampling techniques which are able to provide an objective measure of the quality of village lists.

Random geographic coordinate sampling offers a technique for the selection of a random sample without the need for a sampling frame. Various versions of this technique exist (Clark and Gordon 1980; OIE 1990) but a newly developed form validated in Lao People's Democratic Republic (PDR) (Cameron 1998–this thesis is available on the companion CD-ROM) promises to produce unbiased estimates more efficiently and at a lower cost than previously advocated techniques. In random geographic coordinate sampling, pairs of random numbers are generated, which are interpreted as the x and y coordinate of a geographic point. All villages within a specified fixed radius of this point are identified by a field team, and one of these villages is chosen, again at random, to be sampled. When analysing data from this form of sampling, village results must be weighted proportional to the number of villages located around that random point. Otherwise, the analysis is similar to that used with simple random sampling, and likewise, a fixed proportion of animals needs to be sampled from each village to achieve a self-weighting sample. Simulation studies have shown that this technique is unbiased and produces estimates with virtually the same precision as simple random sampling from a complete sampling frame (Cameron 1998).

Random geographic coordinate sampling suffers from a number of drawbacks, foremost amongst which are: many randomly selected points will contain no villages in the specified radius, so new points need to be selected; locating and enumerating the villages requires much more travel than traditional surveys, so field costs are significantly higher; and identification of the random point, and the boundary of the encompassing radius, may be difficult in the field. These problems can be partially overcome using a hand-held global positioning system (GPS) receiver to identify position in the field, and the use of satellite or aerial photos to pre-scan selected points and eliminate those with no sign of habitation within the radius. Both these approaches were used in the Lao work. Despite the improvements offered, surveys using this technique are more arduous than traditional surveys. However, in the absence of a reliable sampling frame, there is little option.

No matter which of the preceding three approaches to first-stage sampling is adopted, stratification of the sample will usually improve the precision of the estimates. In practice, stratification is often only possible by geographic area, such as district or province.

Second stage sampling

Once a number of villages have been selected for the survey by whatever technique, the *second stage* of sampling involves selection of animals for blood sampling from those villages. Random sampling of individual animals at the village level is probably one of the most difficult aspects of seroprevalence surveys. Failure to select a truly random sample is likely to introduce bias, and to undermine all the effort in selecting villages properly. Most sampling at the village level is based on convenience, often guided by village authorities, leading to selection of the animals of cooperative owners. Those most willing to have animals bled are also those most likely to have their animals vaccinated, i.e. a biased group. Other strategies have been used, such as a village walk in a randomly chosen direction, as adopted by the World Health Organisation's Enhanced Program for Immunisation to sample children (Lemeshow and Robinson 1985). Simulation studies have demonstrated that this is usually a reasonable approximation to random sampling (Harris and Lemeshow 1991). Turner et al. (1996) proposed a variation involving division of a village into a number of smaller blocks. This, in effect, introduces another level of selection and degrades statistical efficiency.

An approach developed for livestock surveys in Southeast Asia, and also trialled in Lao PDR, involves the use of a notebook computer to assist in the random selection of animals from a village sampling frame. A village meeting, for which as many of the livestock owners in the village as possible are encouraged to attend, can be used to gather a range of relevant data. Each livestock owner is asked their name and the number of animals of each relevant species that they own. A simple list is compiled on paper with numbered lines. After all those present have been added to the list, villagers are asked to list those livestock owners not present, and the number of animals owned by each, which are also recorded. When the list is complete, the number of animals owned by each villager is entered into a computer. Names are not entered, as villagers are identified by the number of the line on which their name appears on the written list. In this way, data entry for a village of 100 livestock owners can be achieved in 2 or 3 minutes. The computer then randomly selects the required number of animals from this list, and reports selected animals along with identification numbers of owners. For example a sample of six animals might be listed as:

owner 7 animals 3 and 13,

owner 15 animal 7,

owner 45 animals 2, 8 and 16.

The three livestock owners can be identified by their line number on the written list, and invited to submit their animals for sampling. Individual animals to be sampled are also derived from the list. During blood collection animals are ordered in some way (even if just by counting the group from a distance) and those animals corresponding to the computer selected numbers are sampled. These operational techniques—village meetings for creating the sampling frame and use of a simple computer program for sample selection—make the sometimes daunting task of selecting a random sample at the village level somewhat more feasible. In the absence of a notebook computer, random number tables can be used to achieve the same result manually.

Incidence surveys

FMD vaccination programs can only be considered effective if they ultimately result in a reduction in the number or severity of outbreaks of FMD. In the wake of a massive outbreak, a seroprevalence survey will indicate a rapid increase in proportion of animals protected against the disease. This should not be interpreted as a success for the vaccination program. Only when accompanied by decreasing incidence of outbreaks should increasing prevalence of protected animals be seen as an indication that a vaccination program is achieving its aims.

Estimating disease incidence in livestock populations is much more difficult than measuring seroprevalence. Estimation is made simpler by considering only the incidence of village FMD outbreaks, rather than the individual animal incidence. Traditionally, incidence measures are based on reports of outbreaks which may or may not be accompanied by diagnostic samples. In many countries in which the disease is endemic, only a small proportion of FMD outbreaks are reported to central government animal health authorities. Under-reporting occurs for a number of reasons (Ogundipe et al. 1989), such as poor communications or transport infrastructure, lack of villager awareness, or because, in some countries, FMD is not a notifiable disease. Use of disease outbreak notifications to estimate FMD incidence results in a significantly biased estimate. Notification patterns are subject to so many external (non-disease) factors that they may not even reflect the real patterns of disease, i.e. estimates are biased, and the bias is unlikely to be consistent.

To gather more reliable information on disease incidence, active surveillance techniques are required. Such surveys require either regular careful observation in a large number of villages, or observation of a smaller number over an extended period of time, neither of which may be feasible in the Southeast Asian context. Two approaches which produce somewhat less precise estimates of disease occurrence, but at a small fraction of the cost and time required than traditional surveys, are now examined.

Capture/recapture methodology

A technique used for wildlife population estimates can be applied to the problem of estimating disease incidence in domestic animals. If one needs to estimate the total number of fish in a lake, it is possible to use a combination of the results of two surveys. Firstly, a number of fish are caught, tagged and released. Then a second group of fish are caught. The total number of fish caught in the first and second rounds, and the number of fish caught in both (i.e. tagged fish caught in the second round) can be used to estimate the total number of fish in the lake. In the same way, the results of two independent disease surveys can be combined to yield an estimate of the total number of outbreaks in a given period of time.

Passive FMD outbreak reporting systems provide the first source of information. To be useful, these records must clearly identify the village in which the outbreak occurred, and the time at which it occurred. The second source of information is a special-purpose survey, perhaps using a village meeting as discussed above. Details can be obtained on the number of outbreaks of FMD in the village over the previous one or two years. These records are compared to those contained in the passive FMD reporting system, and village outbreaks which appear on both lists are identified and counted. An estimate of the total number of outbreaks in the designated time period is given by $N = n_1 n_2 / n_{12}$, where N is the total number of outbreaks over the period, n_1 is the total number of outbreaks identified in the first source (outbreak reports), n_2 is the number from the second source (the survey) and n_{12} is the number of matching outbreaks appearing in both sources. If the total number of villages in the area is known, the estimated outbreak total can be used to calculate a crude incidence rate in the form *outbreaks per hundred villages per year*.

There are many limitations to this approach. Unless the number of outbreaks appearing on both lists, n_{12}, is relatively high, the estimate is imprecise—see Seber (1970) for confidence interval calculation. This means that both the number of reported outbreaks and the number of outbreaks identified through the survey should be relatively high. In addition, the estimate may be biased because of the way in which outbreaks are reported. This bias will usually result in an underestimate of the total number of outbreaks, and may be adjusted for by more sophisticated techniques (Sekar and Deming 1949) or the use of more than two lists (Yip et al. 1995). Despite these drawbacks, the estimate of disease incidence produced will be much more accurate than that derived from passive reports.

Retrospective village outbreak analysis

A second approach to measuring disease outbreak occurrence[2] involves the use of a simple retrospective village survey. This can be combined with village interviews held as part of seroprevalence surveys. During a group interview of livestock owners, villagers are asked to recall, as accurately as possible, the time of the most recent outbreak of FMD. If no outbreak can be recalled, the earliest date since which villagers are sure there has been no outbreak is recorded.

Collection of outbreak occurrence data based on the memory of villagers, and potentially stretching back over many years, presents some problems and naturally introduces inaccuracies. Group interview techniques are available to aid memory recall, such as the development of village histories and calendars to help recall timing of an event, and participation of many livestock owners so that the 'group memory' of the village can be tapped. Use of this approach for FMD is particularly appropriate, because the disease has a dramatic and memorable clinical manifestation, and occurs in distinct outbreaks in a cyclic pattern.

The disease experience of the villages surveyed can be summarised in the form of a Kaplan-Meier *survival curve* (Lee 1992). The data cannot reliably be converted into the more familiar incidence rate but reflect the same information. They can reveal changes in disease occurrence over time or differences between areas. The log-rank test (Tibshirani 1982; Lee 1992) can

2. 'Occurrence' encapsulates both incidence and prevalence. While the objective is to measure incidence, the result of survival analysis is neither a true incidence nor a prevalence measure, but can be used as an alternative to incidence.

be used to determine whether survival curves differ. Differences can be quantified using the *hazard ratio*, which is analogous to the risk ratio (Armitage and Berry 1994).

The characteristics of this technique which may potentially be criticised by purist epidemiologists are, in fact, its strengths for use in Southeast Asia and other developing parts of the world. The data are gathered by group interviews and depend on people's memories; this makes the survey rapid and inexpensive to conduct, requiring no laboratory support, and able to produce usable measures of disease occurrence in a period of weeks. When no other data exist, or existing data sources (e.g. passive outbreak reports) are severely biased, and funds are limited, rapid inexpensive surveys able to provide quantitative measures of disease occurrence are badly needed. Provided potential inaccuracies are recognised and minimised through interview technique, use of retrospective outbreak surveys can fill an important gap in our disease knowledge.

Conclusion

Sample surveys are an expensive but potentially powerful means of obtaining up-to-date information about animal health status. Statistical theory for multistage designs is highly complex. If estimates of population parameters concerning protection levels and of sampling cost components are available, it is possible to estimate sample sizes required to achieve accuracy targets. Further, simulated sampling provides a rapid and effective method to compare the statistical efficiency and cost of a range of sampling designs, and to carry out sensitivity analysis with respect to parameters for which values are uncertain.

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9

Evaluating Information Systems in Developing Countries— Issues and Lessons Learnt from a GIS Project

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Abstract

Recently it has become apparent that information systems are not succeeding to the extent that has been envisaged. This paper sets out to explore the reasons for success or failure of information systems being used in developing countries through use of a case study into the geographical information system (GIS) set up as part of an animal health system in Thailand. Whereas technical failure is an obvious factor, this paper identifies lack of management involvement and/or user resistance as critical to the success of such information systems. In addition, successful information systems need to introduce real changes into existing or manual processes rather than merely automating them.

Introduction

> *An information system provides a societal capability based on the use of information that encompasses its full context of people, institutions, policies, processes, incentives, data, information technology, and infrastructure ... Failures and horror stories litter the history of information industry. Even success stories ... reveal formidable social and technical complexities. Developing and deploying information systems ... is socially and technically complex, even in the face of technical advances and obvious potential benefits. (TheWorld Bank. 1998. pp. 9–11.)*

It is commonplace to argue that if decision-makers had better information they would make better decisions. The next step is to argue that we need an information system to provide the required information. Yet, as the World Bank (see above) and many others have observed, the history of the information industry is littered with failures. Indeed, very pointedly, there is a journal dedicated to this issue—*Failure and Lessons Learned in Information Technology Management: An International Journal.* More recently authors of a review of information systems expressed their findings in the title of a resulting publication*: What Went Wrong ? Unsuccessful Information Technology Projects (KPMG 1998).*

The question is: why do these systems fail? The literature is not short on failure measurement. While it is relatively common to concentrate on technical factors, more reflective studies regard the implementation of an information system as a change process and treat failure as a combination of factors and events that are organisational and social as well as technical in nature. The core constraining factors or elements which contribute to failure appear to lie in limited human and organisational capabilities.

Developing and deploying information systems is socially and technically complex despite technical advances and potential benefits. It is necessary to take a broader, non-technical view which treats the situation less as a 'technical' failure of project management and more as a failure of change management. As such we can draw upon experience of technology transfer and also from experiences in process re-engineering. It can be argued that even 'successful' information systems projects can be regarded as failures if they merely automate existing processes or manual processes rather than introduce real changes in these processes. In geographical information system (GIS) analysis, e.g. the new systems may be limited to recording the current situation in order to simply produce maps and improve the speed and accuracy of managing what are often day-to-day operational activities rather than manipulating data to provide new information.

While the traditional tools of systems analysis and systems design can still be used, we have to ask the question: what is the real purpose of the system? What are the real requirements or the real user-needs? Once these are identified clearly it is relatively easy to come up with a system design and also to come up with project management. Studies indicate that this process can be helped by posing a set of questions which might be asked in retrospect:

- Did the users resist the system?
- Were the users satisfied with the system's scope?
- Was the system designed to meet users' needs?
- Was the quality of the information system acceptable?
- Was the information produced by the system of acceptable quality?
- Was the information used?
- Did the information influence management decisions?
- Did the information affect organisational performance?

These questions—especially the last three—raise several related issues, specifically:

- How does one recognise the need for change?
- How does one introduce change?
- How is the change managed?
- How do we measure the successful outcomes or the beneficial impacts of change?

These issues can be elaborated by examining features of successful and unsuccessful systems.

Features of Successful Systems

Success of change or innovation, according to the evidence available, depends on why, by whom and how it is introduced. Studies indicate that when the change involves a new or different way of doing whatever is an essential process for the organisation success is likely. Similarly, studies indicate that strong and sustained top management involvement and support is essential. Apart from providing the official imprimatur to the project, top management support means that adequate resources (e.g. financial support, staff allocation and training etc.) are more likely to be made available for the project. It also means that the project is more likely to be driven by an understanding of the interaction between the technology and the underlying business processes within the organisational context.

Once these ingredients exist then the more technical project management issues come into play. These include: a disciplined approach; a thorough feasibility study; having restricted objectives which have achievable goals; and opting for proven software packages rather than in-house software development. Success in the context of these factors is a project management issue—i.e. the project is well conceived; it is essential for the organisation's business; it has high-level support; and it is executed competently.

Features of Failed Information Systems

It is interesting that despite expectations there are many studies which have documented failed systems. Information systems according to one study can fail at three points in time: during development; at the stage of introduction to the users' organisation (implementation); or at some point during their operation. A recent review of information systems failures indicated that around 35% of projects were terminated during development. While this classification indicates *when information systems fail it does not indicate why systems fail.*

Why do information systems fail? Their failure is the result of a combination of events and factors that are organisational and social as well as technical in nature. Of these, the technical elements are easiest to identify, perhaps because they tend to be most 'visible'. Available evidence indicates that the factors include:

- the use of new or unproven technology;
- the use of technology that doesn't work or is unreliable;

- the introduction of technology that is difficult to use and is part of a system which is complex overall;
- the technology doesn't meet needs;
- late equipment delivery;
- inadequate hardware environment (lack of air conditioning, unreliable electricity etc);
- no local supplies of consumables;
- data incompatibility;
- data conversion problems;
- insufficient training;
- high turnover of key personnel; and
- personnel who lack motivation.

Other factors which are both technical and organisational in nature include:

- manual and automated systems running together;
- multiple types of systems in terms of hardware, software and operating procedures;
- poor project planning—inadequate risk management, little or no user participation in design;
- key users resisting change; and
- unrealistically high expectations of what the new system can do.

However, the key problems appear to stem from organisational and institutional sources. Thus if senior management places little value on information and does not have a systematic approach to information management, the project is likely to be seen as an information technology project and not vital to the critical mission of the organisation. As such the project is unlikely to have top management involvement and support and is unlikely to be institutionally sustainable in the long run; indeed it may not survive its first major 'crisis'. Also, in this environment it is very likely that the initiative for change may come from outside and may be saddled with unrealistic scope and expectations both on the part of the innovators as well as on the part of the users.

As one writer (Cobb 1998) has observed: “We know why projects fail, we know how to prevent their failure—so why do they still fail?” The problem, it appears, is being caused by the fact that the ideal situation in which the ‘right things’ can be done rarely exists. ‘Negative’ factors which interact to bring about this situation include: people resist change; the problem is ‘too big’; pragmatic decisions are popular; there is a learning process involved; change is incremental; and there may be budgetary constraints. To top it all usually change is being introduced in a context which itself is changing.

The Case Study

The rest of this paper describes an information systems project from a developing country. It describes a GIS that was set up as part of an animal health information system in Thailand and then discusses some of the lessons learnt from that experience. The project was a component of a larger project between the Australian Centre of International Agricultural Research (ACIAR) and Thailand’s Department of Livestock Development (DLD). The project had as its main objective the improvement of animal health in Thailand. It sought to achieve this by improving diagnostic techniques and by improving data collection, management and analysis techniques by introduction of IT. The project established that these objectives could be achieved by using active surveillance for data collection and by using GIS for data management and analysis. The discussion that follows is restricted to GIS only.

The GIS as constructed

A GIS is an integrated system of management of geographically-linked data. The system consists of data collection, input, storage, manipulation and analysis, and output.

Software

The GIS software chosen to build the system consists of personal computer (PC) *ARC/INFO* and *ArcView2*[1]. PC *ARC/INFO* is a collection of powerful, fully functional modules for data entry (digitising), editing, error correction, projection, transformation, merging, and various other manipulations, as

1. PC ARC/INFO“ 3.4.2 and ArcView“ version 2.0, 1994 Environmental Systems Research Institute Inc., 380 New York Street, Redlands, CA 92373 USA.

well as spatial analysis, presentation and cartographic design. The PC version is a close relative of the original *ARC/INFO* designed for UNIX systems and, as a result, is a large, unwieldy command-line driven program. *ArcView2* is a MS Windows-based program designed to simplify the task of data querying and map presentation. During the later stages of system development, *ArcView GIS* version 3 became available. This program extends the capabilities of *ArcView2* to include virtually all the key functions of PC *ARC/INFO,* including digitising, editing and spatial analysis. Its capabilities and user-friendly Windows interface means that it has largely superseded PC *ARC/INFO.*

Software for the entry and manipulation of geographically-linked, tabular (or 'attribute') data is also required. *dBASE* version 5 for Windows was used as it enables the handling of very large data files together with the rapid construction of efficient Windows-based data entry screens and complex multi-database queries.

Hardware

The system (acquired in late 1994) is based on two IBM-compatible Pentium 90 computers. One computer is used primarily for map-related activities and is equipped with a 17" high-resolution monitor and a 500 megabyte hard disk. The other is used primarily for database management activities, and is equipped with a 724 megabyte hard disk, CD-ROM drive and internal fax/modem. Both machines run MS DOS 6.22 and MS Windows for Workgroups 3.11 in the Thai versions, enabling the display of the Thai character set.[2]

An A1 digitising table (GTCO Super L II) is connected to the computer running PC ARC/INFO. This allows for the digitising of maps up to 60 cm by 84 cm. A Hewlett-Packard“ PaintJet XL300 A3 colour inkjet printer is used allowing full colour A3 pages of complex graphics to be printed.

Mapping Data Requirements

In establishing a GIS it is first necessary to determine what the purpose of the system is, what data is required to meet these needs, what sources of data are available, and which of the potential sources most closely meets these requirements.

2. The ability to use Thai script within the system is of critical importance. The tonal nature of the Thai language means that many words (including place names) cannot be effectively transliterated into roman script and Thai must be used to clearly identify them. A similar problem could be faced with GIS development in other developing countries which use their own non-roman script. Lao People's Democratic Republic and Cambodia each have their own unique script; however, no special edition of MS Windows has been produced. This problem is overcome by the use of local-script TrueType Fonts using a standard coding format.

The existing animal health information system in Thailand generally records information on livestock populations, disease events, vaccination etc. down to the village level. In developing the GIS it was decided to use the village as the smallest unit of concern or the basic record. Factors which influenced this decision included: *administrative* (the current Thai animal health information system is essentially a village-based system with a large amount of useful data already collected); *technical* (the data entry and storage requirements of maintaining a national georeferenced database at a greater than village-level detail was considered not necessary at this stage); *epidemiological* (with intermingling of livestock, a village could be treated as a single herd); and *cartographic* (even at province level there would at least 500 mapping points).

Once the decision had been made to treat the village as the basic unit, two other considerations remained. These were the other resolutions or levels of aggregation at which the database was to be created, and the issue of mapping scale. In Thailand both these issues were resolved relatively easily.

Thailand has a highly centralised system of government, based in Bangkok. The country is divided into 76 provinces (*changwat*) each with a provincial capital. Provinces are divided into an average of 11 districts (*amphur*) ranging from three to 25. Each district has a district capital in which is located a district office, housing a variety of government officials and departments. Amongst these is the District Livestock Officer from the DLD. Districts are subdivided into an average of nine subdistricts (*tambon*) ranging from two to 24, and subdistricts are in turn made up of an average of nine villages (*mubaan*). The study area comprised three provinces, 42 districts, 331 subdistricts and 2 969 villages.

Each village has defined administrative boundaries, although in practical terms these are rather vague. Each house in a village is numbered and has associated with it a 'house-license' (*tabien baan*), an important administrative document listing all the residents of that house. The local government system is based upon the village and subdistrict levels. Each village has an elected head (*phu yai baan*). The *phu yai baan* jointly elect a subdistrict head (*kamnan*). The *phu yai baan* and the *kamnan* are are jointly responsible for the maintenance of records and statistics at the village and subdistrict levels.

The scale at which base maps are digitised is one of the most critical questions in the establishment of a GIS. Some of the issues that guide the decision include: largest scale of anticipated output (presentation of a map at a scale larger than the original is misleading, as it implies a level of detail and accuracy that is not present); nature of data used (it was considered essential that a scale chosen had to allow clear differentiation between neighbouring villages); data storage and computing resources available (to avoid unnecessary storage requirements and slower processing, the scale of the base maps should not be too much greater than the largest dictated by the system requirements); digitising resources available (the time taken to digitise maps will increase with the scale—digitising at a scale that is greater than that required could be a time consuming and expensive proposition); uniformity (if maps displaying data from different sources using different scales are to be produced, the source data with the smallest scale determines the maximum sensible scale of the final map); and aconservative approach (it is generally advisable to use maps of a slightly larger scale than that needed to cater for future extension of the system).

However, despite these important considerations, the final deciding factor, which usually outweighs all others, is the base maps that are available for digitising.

Data and required capabilities of the system

An informal user-needs analysis was conducted through discussions with staff at various levels. The basic user requirements were for a system which was able to:

- store livestock disease information (disease events identified by village, disease or antibody prevalences for a defined area);
- store livestock demographic data (total number of livestock by village and species—primarily cattle, buffalo, pigs and chickens);
- produce livestock population distribution maps (maps of the total number of animals and of population density for a variety of species at (i) the national level—broken down by province or district, and (ii) the provincial level—broken down by district or subdistrict);
- produce disease distribution maps (point maps of the location of villages experiencing disease outbreaks, national or provincial maps showing disease incidence, or relative risk by district or subdistrict); and
- assist in the calculation of disease occurrence measures (combine disease occurrence data and population demographics to calculate prevalence and incidence estimates either nationally, by province or by district).

Desired system capabilities included the ability to:

- assist in the epidemiological investigation of disease patterns (produce a range of disease and risk factor maps which may suggest causal hypotheses or possible control measures);
- help monitor major disease control programs (produce maps of vaccine coverage and seroprevalence, as well as maps illustrating changes in disease incidence); and
- assist in the control of disease outbreaks (provide information for the field management of animal disease emergencies).

This analysis produced a definition of the minimum required dataset—the most basic geographical data required to achieve a functioning system. The primary focus was to produce a pilot GIS in a study area comprising three provinces in northern Thailand, namely Chiang Mai, Lamphun and Lampang. The GIS was constructed to act as a model for a future nationwide GIS, using the same maps, scale, software and data gathering techniques. In addition to the study area GIS, a separate system was established covering all of Thailand at a lower level of detail, to begin the study of problems arising from this national approach.

The minimum required dataset to achieve a working system consists of the following geographical features:

Feature	**Feature type**	**Geographic coverage**
Village locations	points	Study area only
Subdistrict boundaries	polygons	Study area only
District boundaries	polygons	Study area + national-level maps
Province boundaries	polygons	Study area + national-level maps
Livestock Development regions	polygons	National-level maps

The minimum dataset is a static list of requirements. However, the desired dataset is much wider, and the list is likely to change as more becomes known about the disease situation and risk factors. Elements within the desired dataset are those geographical features which are suspected causal factors or proxies for suspected causal factors in the diseases (or problems) under investigation. Examples include map coverages of roads, waterways (rivers and lakes), elevation, land use, soil type, and climate (temperature, rainfall, winds).

A scale of 1:50 000 was chosen as the appropriate scale of base maps for the GIS. This scale provided the required level of detail to distinguish clearly between neighbouring villages, and maps showing the required data (villages and subdistrict boundaries) were available at this scale. Dyeline copies of the National Statistics Office (NSO) Mapping Division's 1:50 000 district maps were made, and these copies were used for digitising administrative boundaries for Lampang and Lamphun Provinces. Subdistrict, district and province boundaries from the administrative boundary coverage of the Chiang Mai University Multiple Cropping Centre were used for Chiang Mai Province. The NSO district maps were used to digitise village locations for all three provinces. Road maps at 1:250 000 from the Office of Accelerated Rural Development were used to digitise road locations.

On the national level, the NSO's national district map was digitised, and a copy of a Thai national land use map was obtained from the United Nations Environment Programs Global Resource Information Database.

Attribute data—geographically linked animal health data

As noted earlier, the first step in creating a GIS database is to identify features of interest and then create a map base which would be the foundation of mapping and spatial analysis operations. This map base is essentially the portrayal of the minimum attribute of a geographic feature—its position. While the attributes of a feature are virtually unlimited, data collection and management considerations restrict the list to a much smaller set. In the present study—an animal health information system application—it was decided to identify (i) a minimum set and (ii) a desirable set.

The minimum attribute dataset required for epidemiological investigations varies for the disease, species and question under consideration. However, in general terms, to determine estimates of disease occurrence (incidence and prevalence) both the numerator (the number of cases—incident or prevalent) and the denominator (the number of animals or animal-time at risk from which the cases arose(need to be estimated. To investigate disease-effect measures (e.g. incidence rate ratios), further data are required on the exposure of cases and non-cases to the risk factor in question.

The ideal disease data for an animal health information system includes complete counts of the number of animals affected at every disease event, for those diseases of interest—for instance a complete count of the number of outbreaks of foot-and-mouth disease, and the number of animals affected. As discussed earlier, reliable data of this nature is not available, and active surveillance techniques must be used to make unbiased estimates. The minimum dataset for livestock disease data is therefore the best disease data that is available and which most accurately reflects the disease situation in the population.

In order to calculate rates, it is necessary to know how many animals are 'at risk'. In a village-based information system, this means that village-level livestock populations, broken down by species, are necessary. The desired dataset would include age and sex breakdowns for each species, and perhaps further information on the production system and management.

The basic user requirements identified disease-mapping as the key capability of the system. The minimum dataset therefore included no data on potential disease-risk factors. However, as one of the desired functions of the system was to assist in the epidemiological analysis of disease distribution, relevant potential risk factor data formed part of the desired dataset.

A combination of routine laboratory submissions and data from the active surveillance surveys was used for disease occurrence estimates. The village censuses from the NSO and Thammasat University, both conducted in 1992, together were used to provide two independent estimates of the source populations at risk. The other data contained in these censuses provided information which could be used as proxies for disease-risk factors. The NSO and Thammasat University (TU) data were used in combination to provide a sampling frame of villages for random village surveys. Other data that has been incorporated into the GIS from the desired dataset group includes the livestock movement data and weather data.

Available data sources

A wide range of maps produced by different organisations exists in Thailand. The value of these maps for a GIS for animal health depends on several factors. They must: contain the spatial information required; be of an appropriate scale; be able to be accurately georeferenced; contain complete, up-to-date, information; and be available for use. Table 1 and the notes which follow describe the maps that could be used as a source of geographic data in a GIS for animal health in Thailand. Unlike geographic data, the range of attribute data relating to animal health is somewhat more limited. Possible data sources for disease occurrence data, livestock demographics, and disease risk factors are listed in Table 2.

Table 1. Possible geographic data sources for a geographical information system (GIS) for animal health in Thailand.

Source	Content	Scale	Date	Projection	Geo-referenced?	Format	Coverage
National Statistics Office[a]	District (amphur), subdistrict (tambon) boundaries, village locations	1:50 000	Constantly updated[b]	Universal Transverse Mercator (UTM)	Yes	Paper	National (one sheet per district)
Chiang Mai University[a]	District, subdistrict boundaries, land use, rivers	1:50 000	1992	UTM	Yes	Digital	Chiang Mai province
National Statistics Office	Province, district boundaries	1:1 500 000	Not known	Not known	Yes	Paper	National (single sheet)
Royal Thai Survey Department	Province, district boundaries, village locations, roads, rivers	1:50 000	Variable[c] (from 1960s)	UTM	Yes	Paper	National
Highway Office	Highways, main roads	1:1 000 000	Not known	Not known	Yes	Paper	National (four sheets)
Office of Accelerated Rural Development	Roads	1:250 000	1983	Not known	No	Paper	National? Kept at provincial level.

[a] Based on Royal Thai Survey Department 1:50 000 topographical maps, Universal Transverse Mercator (UTM) projection, zone 47 with Everest spheroid. The original topographical maps are marked with a 1 km UTM grid and a 5 minute latitude and longitude grid. They contain the location (and sometimes name) of settlements, subdistrict, district, provincial and national boundaries, roads, railways, rivers, 20 m elevation contours, and an indication of predominant vegetation types.

[b] The office is notified of all changes that take place (creation of a new village, splitting subdistricts, districts or provinces into two, and merging of regions or villages) with written descriptions, and these changes are recorded on the district sheets. Descriptions of new villages follow a rigid bureaucratic formula, identifying by means of UTM grid references, lines bounding the northern, eastern, southern and western extent of the village area. This information is not directly transcribed, but instead cross-referenced with the original topographic sheets and the village is then marked as a point location on the Mylar maps at the estimated centre of the described village area. As a result of this constant updating of information, most of the data contained in these maps is very up-to-date. This includes those features of interest (village locations and administrative boundaries) but road data, for instance, is almost 30 years out of date. In 1995 the office commenced a project to convert all paper, district-level maps to digital format.

Table 1. (cont'd) Possible geographic data sources for a geographical information system (GIS) for animal health in Thailand.

Source	Content	Scale	Date	Projection	Geo-referenced?	Format	Coverage
Department of Town and Country Planning	District, subdistrict and village boundaries, buildings, 20 m contours, rivers etc	1:15 000	Variable (most < 7 years old)	Not known	No	Paper	National
Royal Thai Army[d]	Village, subdistrict, district boundaries etc.	1:50 000	Variable (from 1995)	UTM	Yes	Digital	Five provinces in central region (progressing to national)
National Land Titling Project	Cadastre (land plots)	Variable	Under development	Not known	Yes	Digital	Bangkok, provincial centres (progressing to national)
Chiang Mai University[e]	Province, subdistrict boundaries, transport, rivers	1:250 000	1970, 1979	UTM	Yes	Digital	17 Provinces in northern Thailand

[c] The Royal Thai Survey Department is in the process of producing new 1:50 000 topographical maps, which will be available for sale. These maps will have the same data as the original topographical maps used by the National Statistics Office in the production of the district maps excepting that UTM grids will be omitted.

[d] The Royal Thai Army has commenced a project which aims to create a digital map of the whole country, based on new orthocorrected aerial photographs. Accurate maps at 1:50 000 are being produced with the Intergraph GIS program. Coverages being developed include village boundaries (field staff are being used to confirm the boundaries based on land ownership and village of residence), roads, buildings, and rivers. As of August 1995, about five provinces in central Thailand had been digitised. The army's aim is to complete the project within five years. It is unlikely that these maps will be made generally available.

[e] Chiang Mai University Department of Computer Science produced the maps in 1995, based on maps from the Royal Thai Army Department of Mapping. These maps were placed on the Internet FTP server at Chiang Mai University and are freely available. The subdistrict coverage contains some demographic attribute data, but no data directly applicable to animal health. Village locations are not available.

Table 2. Possible data sources for disease occurrence data, livestock demographics, and disease risk factors for a geographical information system (GIS) for animal health in Thailand.

Data Source	Update Frequency	Format	Completeness	Coverage
Disease Occurrence				
Diagnostic laboratory submission database[a]	Continuous	Digital	Poor (high level of under-reporting)	National (five laboratories)
Active surveillance	Intermittent	Digital	Good	Three provinces in study area
Livestock Demographics				
National Statistics Office village-level survey[b]	Annual	Digital	Fair	National
Thammasat University village-level survey[b]	Annual	Digital	Fair	National
Department of Livestock Development Livestock Inventory[b]	Annual	Paper	Good (depending on district staff)	National
Pig and poultry farms [c]	One-off (1992)	Not known	Not known	National
Disease Risk Factors				
Weather	Monthly	Digital	Good	National
Livestock movement [d]	Continuous	Paper	Fair (some missing data)	National (>20 check points)

[a] The usual means by which samples are submitted to the laboratory is via the District Livestock Officer. In the case of a disease outbreak, the officer visits the village, usually takes samples, and administers some treatment. These samples are submitted, along with a submission form, to the regional laboratory. All data from the submission form are entered into a laboratory submission database which includes the owner's address, information about the clinical signs, number affected and number dead, suspected diagnosis, samples received, tests performed, and test results and diagnosis. The submission form and structure of the submissions database is uniform across the five laboratories servicing the whole country.

[b] The three village livestock data sources record the number of families in the village and the total number of animals of different species kept. The National Statistics Office and Thammasat University village-level surveys collect a great deal of other information as well. The information is usually collected by the village head-man or volunteer.

[c] There is no formal system of central registration of piggeries or poultry farms in Thailand. The establishment of a list of farm locations involves the use of agricultural census data, producer organisation data, commercial company records etc. This is a very expensive and time-consuming process. In the case of pig farms, such a list was compiled in 1992, giving a total number of pig farms in Thailand of around 10,000. Information includes piggery location and the number of sows kept. Unfortunately, this list was compiled by a private company and the information, which could be used as a relatively complete sampling frame, is not readily accessible.

[d] Animals moving from one province to another are required to be vaccinated against foot-and-mouth disease at least 10 days before movement. Certificates are issued by the District Livestock Officers and must be presented at Livestock Inspection Stations distributed on major highways around the country. A record of each vehicle inspected is kept, recording (amongst other things) the source and destination of the animals. These data are only collected at a limited number of inspection stations on major highways and are submitted to the provincial and regional offices each month.

Stages in construction

Both geographical data and attribute data required processing and manipulation for integration into the GIS. Investigations revealed the range of geographical and attribute data available. Hardware and software were purchased, installed and set up.

The process of creating the GIS database—especially the map base—is an unavoidably complex process. It includes several key steps. These are:

Map collecting, and updating where necessary

Before they could be digitised, the NSO *amphur* (district) maps had to be updated, copied and coded to ensure the most recent boundary and village location information. (This meant that the data contained on the maps was accurate as of January 1995.)

Digitising

Digitising is the process of converting a map into a digital form and storing it in the computer where it can be manipulated by GIS software. For GIS software to be able to undertake these processes it has to be able to (i) treat the digital map base as real geographic space, and (ii) link geographic features with whatever attribute data is available.

A 'tic file' is a file required by PC *ARC/INFO* to associate digitised map data with real-world locations. It consists of a series of points identifiable on the map, and of known geographical location in the real world, each identified with a unique code. The most commonly used system for the creation of a tic file is to digitise it directly from the map. While this is a straightforward technique it means that a separate tic file, and therefore map coverage, is created for each separate map sheet. This means that if multiple map sheets cover an area, the resulting coverages must be combined after digitising to form a single coverage. Apart from being a tedious and time-consuming procedure, this has the added disadvantage of requiring the double-digitising of external boundaries on each map sheet which then need to be eliminated. A further problem with this approach is that irregularly spaced tic points (due to map sheet distortion) will result in distortion of the final coverage.

To overcome all these problems, a different approach was used. A master tic file was created covering the entire study area, using 5 minute latitude/ longitude intersections as the tic locations. The total number of tic points in a rectangle bounding the study area is 962, so a spreadsheet was used to generate the coordinates, convert to decimal degrees, and assign tic identifications (IDs). Because of the large number of tic ID codes used, a system of coding was used that allowed immediate checking of codes and obviated any need for reference to other sources. The code used was derived from the longitude and latitude of each tic point in degrees and minutes. The last digit of the degrees of longitude, followed by the two digits of the minutes of longitude were appended to the last digit of the degrees of latitude and the two digits of minutes of latitude (e.g. the point E101°35' N19°45' would be coded as 135945).

Map projections refer to the way in which features on the surface of the earth are 'projected' on to a flat piece of paper, the map. A wide variety of projections exist, appropriate for particular situations. Latitude and longitude measurements, as used to define the tic coverage, refer to angles at the centre of the earth. However, the district maps were in the Universal Transverse Mercator (UTM) projection. Before digitising map features on to the blank tic coverage, the coverage had to be converted to the same UTM projection as the maps.

To link a geographic feature with its attribute data, PC *ARC/INFO* identifies all features by means of a numeric code. To the final user, this coding may be transparent and all features can be referred to by name or interactively through a graphical interface but during the construction of the GIS the use and maintenance of these codes is very important. During the GIS development, three main coding systems were employed: *map codes*, as used by the Statistics Office Mapping Division [MAP]; *National Statistics Office codes*, as used in the NSO's village survey [NSO]; and *Thammasat codes* as used in TU's village survey [TU]. The codes for all features were based on the hierarchical system of administrative divisions, using a nine-digit code.

Creating the digital map base

The subdistrict boundaries were digitised first for Lampang and Lamphun provinces. For Chiang Mai province the required coverage was obtained from the Multiple Cropping Centre of Chiang Mai University. After the subdistrict coverage was completed the village point locations were digitised. During digitising, the subdistrict coverage was displayed on the screen to visually confirm correct positioning. Each village was entered by entering its code and then pressing a key to indicate its position. The IDAUTOINCRMENT feature of the PC *ARC/INFO* program greatly facilitated the entering of village codes.

The resulting three subdistrict files were merged to form a single coverage. The use of the same tic file for the two newly digitised sections meant that despite being digitised in different locations, the parts of the map fitted together extremely well. The Chiang Mai section of the coverage was modified as necessary to make it consistent with the data for the other two provinces.

Digitising error correction was performed during the process of digitising the various map sheets and extensively again after all the coverages were merged. As an additional check, the number of subdistricts per sheet was recorded and a cumulative total kept to compare the number of polygons reported by PC *ARC/INFO* to the number of subdistricts present on map sheets already digitised. Tallies of the number of villages per subdistrict and the number per map sheet, as well as cumulative totals, were maintained and these were monitored for discrepancies during digitising. After digitising, considerable effort was put into detecting and correcting any village code errors—some of these procedures are routinely implemented in the later version of GIS software.

Making source data consistent

National Statistics Office village census

The study area data from the NSO consisted of three files, one for each province. The data in each file was completely numeric, in *ASCII* format, but arranged in an unusual way[3]. In order to convert this data into a useable format a program was written in Pascal which created a file still in *ASCII* format, containing one record per line and starting with a single copy of the village identification data. This file was then imported (via several different formats) into dBASE 5 for Windows.

Thammasat University village census

The entire national village database was provided. This consisted of 75 self-extracting compressed files, one for each province (excluding Bangkok). Each compressed file contained four separate files, one data file, and coding files for village, subdistrict and district listing the identification code and name in Thai. All files were in *dBASE* format, with the coding files containing a text

3. The data had originally been stored in seven separate files representing different parts of the questionnaire, but these had been compiled into a single file with the data for record 1 from file 1 on the first line, the data for record 1 from file 2 on the second line, and so on down to the seventh line. The next seven lines contained the seven parts of the data for record 2, continuing on with seven lines per record. The first 21 characters of each line contained village identification data (including the nine digit village code). The 22nd character was a file identifier, running from one to seven for each line of the record. The data itself started at character 23, and occupied a variable amount of space according to which file it came from. The actual data in each line was in fixed length, or SDF format where each field occupies fixed columns but there are no field delimiters or spaces between fields.

field with the name, and numeric fields for the codes. The data file consisted solely of text fields containing only *ASCII* numerals. Each field contained the responses to each major question. Many questions had several parts, and in this case all the answers were entered into the same field in fixed length format. The combination of text fields with multiple numeric responses meant that all data had to be converted into numeric fields with one field per response before the file could be used.[4]

Northern Regional Veterinary and Diagnostic Laboratory submission database

The submission database is a *dBASE* format file and can therefore be used in PC *ARC/INFO* and *ArcView* with no conversion. However, it was necessary to link the source of each submission to its place of origin. The address of the owner was used as the source of the submission, and this was used to insert a code into the database corresponding to the owner's village.

Once the three data sources were converted to a reasonably similar file structure it was necessary to make the record identification system consistent. The three main data sources (MAP, NSO and TU) used a similar coding system based on two digits for each administrative level, resulting in eight digits for village identification (or nine if a one-digit region code was included). However, while the principle behind the coding systems for each system was similar, the actual codes used were not the same. This meant that a district referred to as number 6 in one data source could be called number 8 in another. Automatic data linking was therefore not possible. To overcome this problem, a series of translation tables were developed, consisting of the name of the feature and the codes from the three primary data sources. A separate table was developed for each level of administration (province, district, subdistrict and village). These tables were created sequentially, starting from the largest division and moving to the smallest. This meant that the tables could be linked and codes from high

4. The conversion involved first extracting the 75 compressed files and merging the resultant 75 sets of four files into four separate files, one containing the data (occupying just under 100 megabytes) and one each for district, subdistrict and village codes. This process was automated by the use of a dBASE program. No province code file was provided, so one was created by using the district code file. The large multi-record fields of the data file were then broken down into their component fields. This was done by creating a conversion file with reference to the data dictionary provided, listing the original file field names and the starting position and length of each separate data item in the fields, and assigning a new field name for the data item. This file was used to create an empty dBASE file of the correct structure. A dBASE program then linked the original and destination files, transferred the data as a substring of each original field, converted it into numeric data, and copied it into the appropriate field in the destination file.

administrative divisions could automatically be entered, usually requiring data entry of only the digits needed for the current level[5].

The final stage in data integration was to link the various data sources. This took place within the *ArcView* program. A geographical feature is selected to be mapped, for instance subdistricts. The *ARC/INFO* MAP codes are contained within the polygon attribute file (PAT) describing this feature. These *MAP* codes are used to link the PAT to the same field in the translation database for the same level of data, in this example subdistricts. Finally, the NSO or TU code fields in the now linked translation table are used to link in turn the NSO database or the TU database. This having been done, any of the 551 fields from TU or 194 fields from NSO are available for graphical display or analysis. The submission code database can be linked directly to the PAT because its codes are the same as the MAP codes and do not require translation.

Building an application

ArcView can be used for the ad hoc linking and display of any of the geographical and attribute data, and the creation of maps. More complex attributes can be derived by linking multiple files, for instance with dBASE, and calculating new values from existing data. An example of this includes the creation of animal density maps, using area data from PAT files, and animal population data from the NSO or TU databases. ArcView's programming language Avenue also offers the ability to develop automated procedures to carry out routine tasks quickly and simply. Chapter 10 of this monograph (by A.R. Cameron and P. Sharma) describes a disease-outbreak response management system developed with Avenue. Even more complex programs can be developed to create a customised user-interface and automate a wide range of routine tasks.

Lessons Learnt and Success Evaluation: a Discussion

The main aim of the project was to improve the animal health program by improving animal health data collection, management and analysis

5. A table containing feature name, TU code, and blank columns for NSO code and MAP code was generated from the TU code file. The NSO and MAP codes were then manually entered for all the named features by cross reference to the maps and code books that accompanied these data sources. Finally, features not appearing in the TU codes but present in the NSO and MAP codes were added and the codes entered. Recent changes in administrative boundaries caused some mismatches between the data sources. For instance, a subdistrict which was located in a particular district in one source had been moved to another district in a different source. Solution of these coding conflicts was a very time-consuming process.

capabilities. It sought to achieve this aim by a pilot project in which active surveillance techniques and GIS were to play the major role. This paper has already discussed how the GIS was set up and discussed the various technical problems that were encountered and solved successfully. However, there is a need to consider the achievements of the project in terms of the success/ failure criteria identified at the start of this paper. This discussion will commence with the narrow technical issues (which are easier to identify) and finish with some of the more difficult organisational issues.

Equipment and physical site issues

The life of this project (1994–1997) has seen one of the most rapid improvements in the availability, performance and the cost of GIS-related computing hardware. These changes, together with the standardisation brought about by the widespread adoption of the Windows operating system, has meant that a single personal computer is now powerful enough and has enough storage capacity to run a GIS-based animal health information system in Thailand (and in the vast majority of developing countries). The evidence of this technology revolution is clear: an A3 6-pen plotter in 1994 cost A$2 500—by 1997 the same amount of money would have purchased a high-speed A2 multi-colour inkjet printer; typical hard disk size in 1994 was around 0.5 GB—in 1997 it was nearer 4 GBs with the price remaining the same; and RAM had increased from 4-8 megabytes to 32 megabytes as standard. While software (and data) demands on the hardware increased during this period it is abundantly clear that hardware improvements more than compensated for these increased requirements.

With the improvement in hardware the overall demands on physical site have become less important. While it is true that most electronic equipment works best in an air-conditioned environment and 'clean' power supply, the prevailing view is that 'if the operators can stand it, so can the equipment'. Electricity supplies, in general, have improved over the past decade in most developing countries; also relevant, is the domestic development and production of various kinds of line filters, voltage regulators and uninterruptible power supply units. As part of this site improvement we must also note the widespread availability of high capacity data backup devices such as magnetic tapes and compact disc writers. In summary, as a single central computer is now adequate to develop, operate and maintain an animal health information system, the hardware and software costs of a system should be within the capabilities of government veterinary services in most developing countries.

The pattern of favourable trends in hardware development have been reflected in software development as well. The project was started with the DOS-based PC *ARC/INFO* as the GIS software package. While this package is very powerful with regard to its GIS features it is relatively difficult to master especially in the critical area of hard-copy map output. By the end of the project the scene had changed completely as a full-featured version of *ArcView* (Version 3.0), essentially the Windows-based successor to *ARC/INFO*, was available. This package has a user friendly interface and one of its strong features is the ease with which hard-copy maps can be produced.

The choice of both the hardware and software was influenced in part by local availability and support. All equipment was acquired locally and could be serviced in the study area. Similarly, the GIS software chosen was a mainstream product for which training could be provided from various sources ranging from the vendor to various training providers.

Data issues

In contrast to typical database applications, GIS applications cannot be developed until the critical map database has been created. The traditional and very time consuming approach has been to digitise existing paper maps of appropriate scale. In Thailand, the NSO 1:50 000 district maps proved to be an appropriate source of base geographical data to meet the requirements of the system. However, in Thailand (and elsewhere), in order to digitise a complete national coverage, digitising equipment and skilled operators may be required for many months. During the development of the pilot GIS in Thailand a number of veterinary and technical staff were trained to digitise. The staff had enough time amongst their other duties to do the necessary work, and so no additional staff costs were incurred. This approach (which may be possible in many developing countries which maintain relatively large government services, the members of which are often underemployed) may enable large areas to be digitised relatively quickly at very low cost. The advent of on-screen or 'head-up' digitising also has the potential to impact dramatically on the time-consuming digitising process. In this approach, maps are scanned and then digitised on the computer screen—the process is claimed to be between three to 10 times quicker than manual digitising. (The scanned maps are also available for other uses.)

A better alternative to digitising data during system development is the use of maps which are already in a digital form. In Thailand, no digital coverages with the required data at the appropriate scale for the study area existed at the time this research commenced. However, GIS is a rapidly growing area and much work is currently being undertaken by the NSO and the Royal Thai

Survey Corps to produce digital coverages of different parts of the country. It is likely that good quality national coverages will be available in the near future. If these are prepared by government departments it is in the interests of national development that they be made available to other branches of the government at low cost.

Recent developments in global positioning systems (GPSs) mean that introduction of GIS is now possible even in those situations where paper maps do not exist. These satellite-based units permit field mapping by personnel with relatively basic surveying training. With simple differential correction techniques, positioning accuracy of better than 10 metres can be achieved routinely; also, the use of GPS units connected to notebook computers (or similar data-logging devices) is now commonplace. These developments mean that in some situations the laborious process of digitising may not be necessary as maps can be created directly from GPS-acquired data.

The two most important types of data relating to animal health are disease occurrence and livestock demographic data. Improvement in the quality of disease occurrence data is dependent either on an improvement in the operation of the passive disease reporting system, or the widespread implementation of active surveillance techniques to measure the occurrence of specific diseases. In the present study, the NSO and TU village-level surveys did not provide information that was reliable enough to use for probability proportional to size sampling; it is also of inadequate quality for use at the village level in the calculation of disease rates. However, it may be adequate for rate estimates and for demographic mapping when aggregated to the subdistrict or district levels. The most reliable source of demographic data is probably that collected by district DLD officers, but this is not yet compiled centrally as village-level data. (This is an excellent example where a simple computer-based application would extract information from data is collected routinely but not processed effectively; the current manual procedure extracts district summaries only and the village-level data is effectively discarded.)

The main problem encountered in integrating village-level livestock populations and disease outbreaks data into the GIS was geocoding. Two changes in administrative procedures could remove this task, making coding automatic. The first is in the annual collection of livestock population data by district veterinary officers. Pre-printed forms based on the village codes in the GIS, listing the relevant identification information in addition to the map code for each village, and blank spaces for livestock numbers, could be distributed to district officers for completion. Coding at data entry would then be automatic, and the data could be directly linked to the GIS. This approach has been adopted in an animal health information system being developed in Lao People's Democratic Republic (PDR). A similar solution has been applied to outbreak data—in the laboratory submissions database, during data entry the operator selects the province, district, subdistrict and village from drop-down lists, and the resulting code is automatically recorded. This development will remove the need for time-consuming and error-prone manual coding and contribute to the seamless integration of the data into the GIS.

The discussion of available data sources has been limited to Thailand, where the pilot GIS was established. The trend towards the increasing availability of high quality digital maps is occurring in other less developed countries as well. The governments of Cambodia and Lao PDR, two of the least developed countries in Southeast Asia, have recently completed national digital coverages, based on maps at 1:50,000, showing administrative subdivisions, village locations, roads and rivers. It is likely that similar progress is occurring in other developing countries. The increasingly widespread availability of such map base data (supplemented by the use of GPS) means that the establishment of a GIS for animal health in a variety of developing countries is unlikely to be limited by lack of geographic data. The existence of appropriate digital coverages would make the establishment of such a system much faster than was the case with the pilot system developed in Thailand.

The project and the wider context

At the start of this paper we noted that the success of an information technology project depends on a wide range of factors. Clearly, the technical issues have to be solved to make the system work—this can be regarded as the minimum requirement. However, studies show that the organisational and institutional issues are critical to the success of an information system with strong top-level management support a major success element.

The project reported in this paper was a collaborative research effort between agencies in Australia and Thailand. In Thailand, the national agency involved was the DLD which has as part of its mission, the management and betterment of animal health in Thailand. It maintains a large veterinary services infrastructure including a system of high quality regional diagnostic laboratories. There is considerable support within the organisation for improving the information services which support its various programs. However, there is some basis for the perception that the organisation is not strategically driven by information technology. While the reasons for this are not fully known, it is clear that some of it based on the feeling that (better) information could be used against it or against Thailand's interests generally.

To evaluate the success or otherwise of the project we need to know what are the strategic objectives of the top management of DLD and then to see whether the project outputs provide the information to support these objectives. No overall analysis of the information needs of the DLD was conducted as the project was a pilot, the main objective of which was to develop a working system to develop the specifications of a national system. As the exercise was funded as a research project the usual on-going organisational issues were a low priority. These matters will be the major hurdles to overcome before full implementation can be considered.

The pilot project was highly successful from a technical point of view. It developed procedures which are relatively easy to implement nationally. However, it is not clear whether the project was seen in terms of its wider application, i.e. the development of a new way of doing things in which information technology would play an important part. Its ultimate success will be judged by whether or not a national system is instituted through allocation of critical (and scarce) resources for its expansion and maintenance.

Conclusion

This paper has demonstrated how a GIS can be created for animal health in a developing country such as Thailand. The development of the pilot system in three provinces has shown that it is relatively easy to solve the technical problems involved. Extension of the system to the national level will pose further challenges—these are likely to be organisational rather than technical in nature. While the task is well within the capabilities of the Thai government's veterinary services, the ultimate success of the information technology project discussed here is whether the system is implemented on a national basis.

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10

Using GIS as a Decision Support Tool: a Simple Outbreak Response Management System

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Abstract

The eventual aim of any information system is to function as a decision-support system for its users. This chapter describes a simple, computerised information system (the Outbreak Response Management System) specifically developed as a tool in the management of outbreaks of foot-and-mouth disease for use in implementing ring buffer vaccination in northern Thailand. Using this system, relevant information for response planning can be obtained in seconds, compared to several days to a week using traditional methods. In addition, it can utilise more data sources and is capable of generating alternative solutions. Potential improvements to and adaptations of the system are also discussed.

Introduction

The ultimate objective of any information system is to act as a decision-support system (DSS) for its users. The core characteristics of DSSs include:

- powerful and easy-to-use user interfaces;
- the ability to flexibly combine analytical models with data;
- the ability to explore the solution space by building alternatives ('what-if' scenarios); and
- allowing interactive and recursive problem solving (Densham 1992).

It is recognised that for spatial DSSs additional capabilities are required to address spatial components of a problem. These additional characteristics include:

- the provision of mechanisms for the input of spatial data;
- the ability to allow representation of the spatial relations and structures;
- inclusion of analytical techniques of spatial and geographical analysis; and
- the ability to provide output in a variety of spatial forms, including maps (Densham 1992).

The creation of a DSS software package and applying it to a problem is a relatively complex task. In general the complexity of the system varies with the degree of structuring of the problem and, more importantly, the extent the problem lends itself to straightforward solutions. Thus, most complexity would be exhibited when problems are ill-structured and multiple solutions (or combination of actions) are possible. While research and development of DSSs is guided by many objectives, one may argue that in many situations a 'push button' solution (the user pushes a button and the system gives a decision) is unnecessary and indeed may not work, such as in many developing countries. In these situations, applications can be developed which subscribe to the spirit of the quest (for the development of DSSs) but deliver a simpler and more robust system to users. These systems essentially provide the critical information on which users can base their decisions—even in their simplest form they can permit input of various kinds of data and permit users to develop various alternatives. This paper describes one such system which was developed in Thailand.

The management of the response to disease outbreaks is a challenge to all animal health planners and administrators. For both exotic diseases and diseases which are the targets of control or eradication programs the effectiveness of this response is critically important. Ineffective outbreak control may result in rapid spread of the disease to previously unaffected areas. This in turn may dramatically increase the task of eradication and seriously delay the final goal of freedom from disease. In addition, the economic losses incurred during an outbreak are multiplied if the outbreak spreads or lasts for an extended time.

In Thailand, the national foot-and-mouth disease (FMD) eradication plan outlines a staged approach to rid Thailand of the disease. The principles of the plan are similar to those used in many other countries. The plan is being implemented progressively from the south to the north. In the initial stages, mass vaccination is used to lower the incidence of disease outbreaks. As the incidence decreases, individual outbreaks are suppressed by the use of ring vaccination of all susceptible animals in a buffer zone surrounding the site of the outbreak. Once freedom from the disease has been achieved in an area, mass vaccination will cease. Outbreaks will then be addressed by use of ring vaccination, or 'stamping out'[1]. Finally all vaccination will cease and any outbreaks will be controlled by stamping out alone.

During the intermediate stages, ring vaccination around the site of the outbreak is an important tool for control of the disease. As the eradication program continues, more and more areas of the country will be using this approach. The requirements for the successful use of ring vaccination to control a disease outbreak are:

- Vaccination must be implemented very rapidly after the onset of the outbreak. Animals at risk in surrounding areas must be protected before they are exposed to the virus and this protection may take over a week to develop after vaccination.
- Livestock movement must be controlled. No animals should move from the buffer zone and no unvaccinated animals should enter it.

1. Stamping out involves the slaughter and disposal of both animals with the disease and all in-contact or at-risk animals. For instance, stamping out procedures in Thailand would involve the slaughter of the entire cattle and buffalo population of villages suffering an outbreak, and possibly the population of nearby villages or those recently receiving animals from the infected village.

- A very high proportion of susceptible animals within the buffer zone should be vaccinated and achieve adequate titres to protect them from infection.

- The vaccination buffer zone must be large enough to control the spread of the disease.

In order to achieve a high level of vaccination coverage over a relatively large area and in a very short period of time, relevant and reliable information must be readily available to the planners of the outbreak response so that they can mobilise the labour force and materials required quickly. Providing this information is one of the key management roles of an animal health information system. This section examines whether the geographical information system (GIS) developed in Thailand is able to play this management role.

A typical sequence of tasks required of outbreak response managers before any action can commence may include the following.

- When a sample from a suspected outbreak is submitted to the diagnostic laboratory, it must be analysed and typed as quickly as possible, and the results passed to the response manager.

- The village of origin of the sample must then be identified, and all villages that fall within a predetermined radius (the vaccination buffer zone) determined.

- The total livestock population in these villages needs to be estimated and enough vaccine to protect these animals obtained.

- The staff responsible for carrying out the vaccination need to be notified of the villages requiring vaccination and the number of animals to be vaccinated in each village. Extra staff from nearby areas may need to be coopted into the work.

- A work schedule needs to be drawn up with estimates of how much time will be required to vaccinate each village. Some villages at remote locations may take significantly longer to access than nearby villages.

- Road check points to control livestock movement in and out of the vaccination buffer zone need to be established, usually with the assistance of other authorities such as the police. The locations and staffing requirements of all such checkpoints need to be established.

The systems previously used in Thailand to gather this information on an ad hoc basis may have taken several days to a week. This would mainly have been done by contacting district staff and sending out teams from the laboratory epidemiology sections. While the existing system is still in use, this paper describes a simple, computerised outbreak response management system which was developed specifically for use in implementing ring vaccination in northern Thailand. This system is able to provide in seconds the key information required for response planning. The system, using a variety of linked data sources, is based on the low- cost GIS described in the previous chapters. Thus it is superior to the existing system in that it provides a quicker response, can use more data sources and output more information and, most importantly, it is capable of generating alternative solutions.

Program Overview

The Outbreak Response Management System is implemented in the *ArcView* program, using the in-built *Avenue* programming language. It draws on a range of geographical data sources and attribute data. The program has a simple interactive graphical interface in which the user is required to select the village in which the outbreak has occurred and specify the radius of the ring vaccination buffer zone. Both a graphic representation of the buffer zone and a text report are produced with the key planning information required as well as a table listing the details of all villages in the buffer zone. The program requires no knowledge of GIS systems and can be used by any user familiar with the *Windows* operating system.

Data Requirements

As localising the outbreak is key to its management, there are four key elements of geographical data required for full operation of the system. These are village locations, district boundaries, roads, and the location of district veterinary offices. Other spatial data, such as waterways, may be added to aid with interpretation. (Aerial photographs, if available, would be useful for visualising the landscape.)

Each of the four geographical elements identified above is stored as a coverage (or map layer) in the GIS and is linked with one or more attribute data files. The village locations are linked to files containing village, subdistrict, district and province names, and to a database containing village-level livestock figures. The source of this data was the National Statistics Office (NSO) village-level census from 1992. The district boundary coverage is linked to files giving district and province names. The road coverage contains data on the type and number of each road. Roads are divided into four classes: highways, main roads, secondary roads and minor roads. District veterinary office locations are linked to a database containing the name and contact details of the responsoble officers in each district.

System Outputs

Examples of screen displays are shown in Figures 1 and 2. When the outbreak village has been selected (by clicking with a mouse) and the radius of the vaccination buffer zone specified, the program marks the outbreak village, draws a circle representing the vaccination buffer zone, and highlights all villages falling within the circle. It then carries out a number of calculations and lists the results in a report window, an example of which is shown in Figure 3.

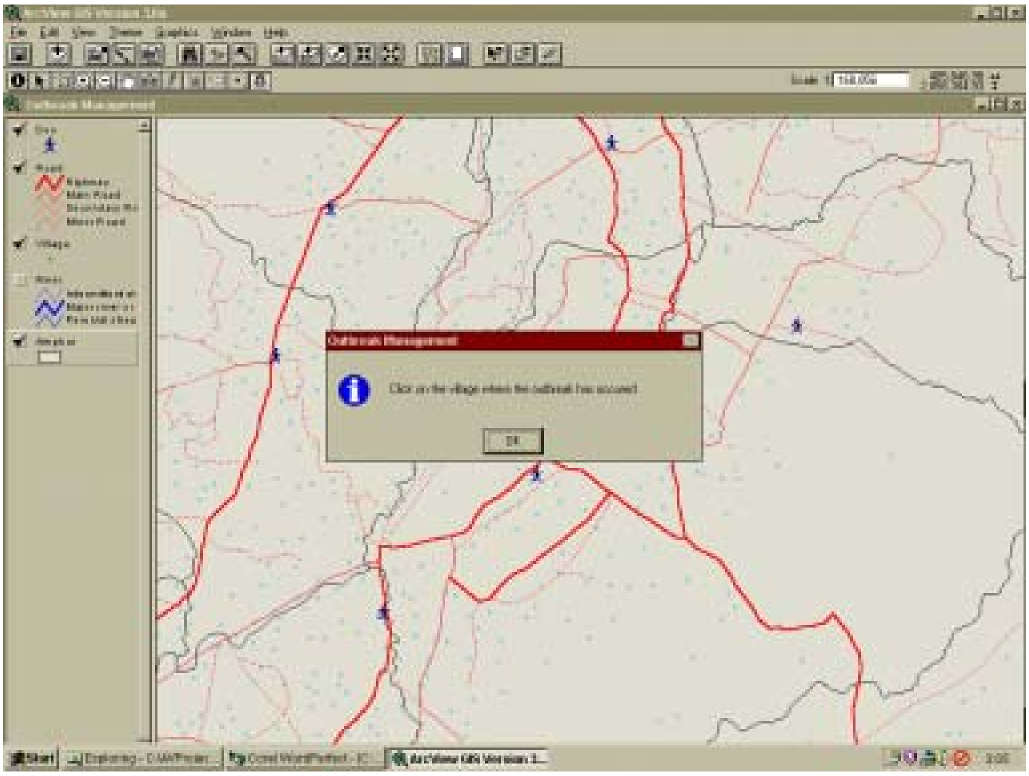

Figure 1. Computer screen display encountered using the Outbreak Response Management System—locating the outbreak village.

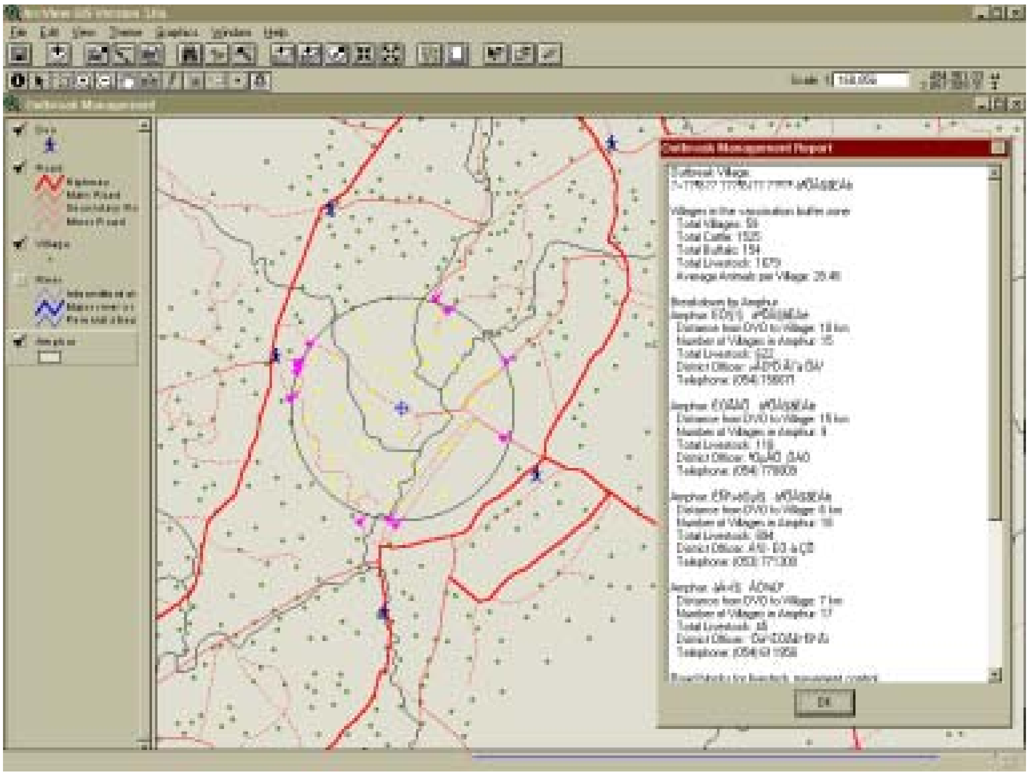

Figure 2. Computer screen display encountered using the Outbreak Response Management System—outbreak management area and report.

Figure 3. Example of a report generated by the Outbreak Response Management System.

Outbreak Village:	
Ban Luk, Pa Sak, Amphur Muang, Lamphun	Breakdown by Amphur
Villages in the vaccination buffer zone	Amphur: Muang Lamphun
Total Villages: 58	Distance from DVO to village: 5 km
Total Cattle: 2232	Number of villages in Amphur: 58
Total Buffalo: 539	Total Livestock: 2771
Total Livestock: 2771	District Officer:Jin Sarajant
Average animals per village: 47.78	Telephone: (054) 611958

Figure 3. (cont'd) Example of a report generated by the Outbreak Response Management System.

Road blocks for livestock movement control	1. 508982 2055497 (Major Road)
Up to 11 road blocks will be necessary	2. 506575 2057239 (Highway)
UTM Map Reference	3. 501849 2057150 (Minor Road)
	4. 499614 2055768 (Major Road)
	5. 497449 2051394 (Highway)
	6. 497255 2051016 (Major Road)
	7. 497268 2049919 (Major Road)
	8. 497275 2049385 (Highway)
	9. 498144 2047122 (Minor Road)
	10. 510817 2047828 (Highway)
	11. 502364 2057243 (Highway)
There are 4 villages further than 2 km from a road.	

The report contains the following sections:

- *Outbreak village.* The name, subdistrict, district and province of the village with the outbreak.

- *Villages in the vaccination buffer zone*. The total number of villages, the total number of cattle, the total number of buffalo, the combined total of cattle and buffalo, and the average number of cattle and buffalo in each of the villages. These summary figures represent an estimate of the total number of doses of vaccine that will be required for the ring vaccination.

- *Breakdown by district*. As local planning and field operations take place at the district level, for each district that contains villages in the vaccination buffer zone specific totals are calculated as follows.

    - Distance from the district veterinary office to the outbreak village. Some districts are large, and the veterinary office may be located a long way from the outbreak. In such cases it may be more appropriate to use district veterinary officers from other districts who are located closer to the problem area.

    - Number of villages in district. The total number of villages that require vaccination which are located in the district. This indicates the work for which the district officer is responsible.

- Total livestock. The total number of cattle and buffalo in the vaccination buffer villages in the district. This allows an estimate to be made of the number of doses of vaccine that will be required by particular veterinary officers.

- Name and telephone number of District Officer. Contact details mean that the responsible officers can be contacted quickly and told of the villages for which they are responsible.

- *Road blocks for livestock movement control*. The program calculates the total number and exact location of road blocks that may be required to prevent movement of animals into or out of the vaccination buffer zone. This is calculated as the intersection of the circle outlining the buffer zone with any roads. For each potential road block, its exact location in Universal Transverse Mercator (UTM) coordinates is displayed, as well as the type of road. This information can be transmitted to the police, who can use standard topographical maps to pinpoint the location of the required road blocks. The number of people required to staff each road block can be estimated by the road type. A more efficient location for road blocks may be found by moving to nearby road intersections. This can be determined by examining the map display.

- *Village access*. The number of villages which lie further than two kilometres from a road is shown. These villages are either accessed by roads not displayed on the map, or in some cases may have no road access. These villages will take more time to access than other villages.

In addition to the report, the program creates and displays a database (in *dBASE* format), listing each village along with its subdistrict, district and province, number of families, human population and numbers of cattle, buffalo, pigs and chickens, as well as whether the village has an electricity supply.

After generation and display of the results, the map display remains visible and is available for any of the wide range of further analysis options available in ArcView. This may involve interactively querying any feature by clicking on it to display all the currently linked attribute data associated with that feature. This could be used to examine the livestock population of villages that fall just inside or outside the boundary of the buffer zone and to consider inclusion or exclusion from the group of villages to be vaccinated. The map can be panned or zoomed and different layers of information (e.g. rivers) can be displayed. More complex spatial or database queries can be performed, to examine a subset of the buffer zone villages (e.g. those with large pig populations) or to add further villages to the vaccination buffer (e.g. villages along a major livestock transport route which passes through the outbreak village). All maps and reports can be exported for import into other documents or printed. *ArcView*'s *Layout* feature allows maps for particular purposes to be printed with enhanced formatting.

Potential Enhancements

The information provided by the system utilises all the relevant data which are currently available. While already providing most of the key information required for outbreak response management, there are a number of other data sources which may become available in the future and which could further enhance the system.

The first and most important of these is a more up-to-date and reliable source of village livestock numbers. The NSO annual, village-level surveys become available less than a year after the survey is conducted but have a relatively large proportion of missing data. Village-level data on animal populations are currently collected by district veterinary officers on an annual basis, and efforts are being made to routinely compile these data into a central database rather than aggregating it at each level of processing (district to province to region). Any data that are collected on an annual basis will clearly become out of date relatively quickly, and the numbers of livestock reported by the system must therefore only be used as estimates rather than interpreted as exact figures. (As the system improves it will be less risky to use estimated averages for villages where data are missing.)

Another potentially valuable enhancement would be to link the village database with a centrally collected database of vaccination records. This database would contain the village identifier, the date of vaccination, the number of animals vaccinated, and the type of vaccine used. This information could be incorporated into the system to estimate the number of animals that may already be protected against the particular virus type responsible for the outbreak, and thus decrease the number of animals requiring vaccination. This assumes that either vaccinated animals could be individually identified (perhaps through owner recall) or that the proportion of animals vaccinated during a village vaccination round is high enough to be able to consider the entire village as 'protected' for a given time after the vaccination. In any event, despite limitations, the link to the central vaccinations database would assist with the estimation of vaccine requirements for an outbreak.

In a similar light, district level administrative data on the routine vaccination program could be linked to the district veterinary office database to provide an indication of the vaccine stocks available at each district office. For emergency buffer vaccination, the adequacy of existing stocks could be assessed and the location of nearby excess stocks determined.

Finally, data on livestock movement patterns are available. This information has the potential to predict likely stock movements from the area of the outbreak. Authorities in those provinces which are probable destinations for such movements could be alerted to danger. Unfortunately, livestock data are only available at the province level, and are incomplete as many local movements are unrecorded due to the distribution of livestock movement checkpoints. The practical use of this information in the system is therefore probably limited.

Discussion

This implementation of a simple, outbreak response management system demonstrates how a basic, low-cost GIS can be used with multiple linked data sources to provide fast, effective disease control program management information. As the user is completely shielded from GIS operations and commands, the system demonstrates how a relatively simple program, written in the Avenue language, allows users with little knowledge of GIS and data-linking to access a range of important information instantly. It also shows that while a GIS may not be developed for this or any particular veterinary operation, such applications are relatively easy to develop once the GIS has been established. (It also highlights the difficulties involved in estimating the benefits of establishing a GIS—for, despite systems design procedures, often applications are not identified by users until the 'system' has been developed.)

EpiMan from Massey University (Palmerston North, New Zealand) is a very powerful specialist GIS for animal health, designed particularly for exotic disease outbreak response (Sanson et al. 1993). EpiMan maintains geographic and livestock population data down to the individual herd and property (farm) level. It incorporates modelling features (e.g. climatic models to predict windborne spread) and decision tools (to prioritise and assist with the task of tracing possible dangerous contacts and livestock movements). It also generates action plans and tracks the status of all herds.

The system described in this paper is capable of a small part of the functionality of more comprehensive systems such as *EpiMan*. There are two main differences between the two systems: firstly, the current system is relatively very inexpensive, implemented on one or two personal computers, and set up by a small team in a short period of time; secondly, the current system uses a relatively small number of data sources. For both these reasons, its outputs are very modest compared to those of its more comprehensive relatives. However, these same two factors make the system appropriate for use in developing countries where disease control and eradication schemes are much more urgently needed. Government animal health services in these countries are unable to invest the funds in high-end specialist information systems, and the data required to feed these systems (e.g. a digital cadastre for the region or country) are simply not available.

This application was developed specifically for the management of outbreaks of FMD in Thailand by use of ring buffer vaccination. Modification of the system for use in other countries and with slightly different data sources is a simple procedure. The program may also be modified for use with other diseases that occur in outbreak form and for which ring vaccination is a practical control method. It could also be adapted to a situation where destocking is required for outbreak control, and could be enhanced to help produce schedules for monitoring nearby villages for disease. Finally, virus dispersion models, which form a feature of the high-end systems, could be implemented in a very simple form, based on currently available data on prevailing winds, humidity and temperature. However, long distance airborne spread of FMD virus currently does not appear to be significant in Thailand or Lao People's Democratic Republic. The value of such complex models, where livestock movements, direct contact or fomites are the main modes of spread, is therefore doubtful.

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11

Developing GIS Skills for Veterinarians in Developing Countries

P. Sharma
A.R. Cameron

Abstract

The Australian Centre for International Agricultural Research Project No 9204 in Thailand and Lao People's Democratic Republic investigated the role of geographical information systems (GISs) in the collection, management and analysis of animal health data. If GIS technology is adopted there is a need to identify the skills required and the manner in which animal health workers can acquire these skills. This paper investigates these issues and proposes a GIS curriculum that is considered to be appropriate. It also examines other sources of information which veterinarians might use to achieve competency in the use of GISs.

Introduction

As is indicated elsewhere in this book, information technology is making rapid inroads into managing animal health data—a significant amount of this data can be collected, managed and analysed using computers and, in particular, using the tools of geographical information systems (GISs). We have also seen that the skill levels used by veterinarians with regard to information technology varies with the tasks they undertake—from routine technician-level tasks to advanced epidemiological modelling. This indicates that there is a need to define the required GIS skill levels for veterinarians so that appropriate training can be effected.

GIS skills can be split into two components: a conceptual/theoretical component and a methodological/practical ('hands-on') component. The theoretical component requires: an understanding of the fundamentals of geographical data; the way such data is represented in various models; and the way these representations influence various analysis operations—from simple mapping to advanced spatial modelling. (In the literature these skills are often referred to as 'spatial thinking'). The practical skills are simpler to define—they are skills involved in setting up a GIS and then using it for various operations. While methodological skills are wide in scope, in practice acquiring practical skills has involved mastery (at various levels) of a GIS software package.

Recently, Marble (1998) has pondered over the matter of the different levels of skill required for the various applications of GISs. While Marble's main concern was with the apex of a 'skills pyramid', his observations on the structure of the pyramid are of direct relevance for the training of veterinarians. Here we examine a basic GIS curriculum for animal health applications and the means by which it and other GIS training could be delivered. The chapter concludes with a brief discussion of some sources of further GIS information.

Defining GIS Skills

The widespread use of the GIS in veterinary applications shows that it has acceptance as a useful tool and reflects the fact that there are many aspects of animal health which are spatial in nature (Cameron 1998). However, veterinarians have to acquire appropriate skills relevant to GISs before they can make use of them. What are these skills? Are there varying levels of skills? How do they acquire the necessary skills? Some of the answers to these questions can be found in a recent paper which identifies various GIS skill levels and attempts to correlate them against various educational programs (Marble 1998; see also Figure 1 and Table 1).

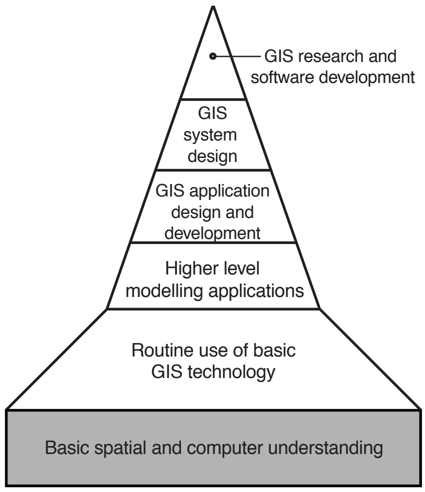

Figure 1. 'Marble's pyramid' of comprising six skill levels relating to the use of geographical information systems (GISs) (from Marble 1998).

The Marble GIS skills schema is based on the concept of a six-level skills pyramid (Figure 1, Table 1). The base of the pyramid (level 6) serves as the foundation; this level requires understanding of basic cartography, basic spatial analysis and basic computing. In theory, these are the current expected background skills of almost any professional dealing with data that has a spatial component[1]. At level 5, routine use of basic GIS technology is required. Users are expected to have sufficient skills to make effective use of basic GIS technology and to use GIS applications *created by others*. Above this level, we move to serious use (and serious users) of GIS technology with increasing expectations of programming skills. At level 4 we move to users who have skills which go beyond basic mapping, for example, and are able to use relatively complex spatial models. However, these are still 'off-the-shelf' software so the programming skills are significantly lower than necessary in the remaining levels of the pyramid.

1. Spatial or geographic data can be loosely defined as any data that is mappable. In case of animal health this involves a very wide set ranging from obvious spatial data (animal distribution, disease outbreaks etc.) to less obvious administrative data (location of veterinary officers, tracking of animal movements etc.).

For levels 3 and higher we expect much higher competence levels in spatial modelling and programming and we move to individuals who are capable of developing major applications and indeed are capable of developing new GIS software or new spatial models. While there is a critical need for individuals with such skills, the actual demand for them in the marketplace is relatively small. We should also note that there is a 'generational skill deflation' process at work brought about by rising expectations, i.e. what is an advanced skill with one 'GIS generation' becomes a routinely expected skill with the next one.

What is the appropriate GIS skill level for veterinarians? The answer is relatively simple. For veterinarians to learn GIS they must have an appreciation of 'spatial thinking' and the disciplinary origins of GIS. As much of development of GIS has come from geography, cartography, surveying and computing, veterinarians will have to acquire an appreciation of the basic concepts of these disciplines. The relevant minimum key concepts can be taught quite easily if appropriate animal health examples are used. This approach has been previously applied for another discipline (Bonham-Carter 1994).

Any veterinarian expecting to work with animal health data will be expected to have a good understanding of the foundation concepts—they will be expected to have an appreciation of basic cartography and basic spatial analysis; generic personal computer (PC) use skills would be desirable. Such a person would be expected to be a (printed) map user and be 'map-literate', i.e. able to (i) interpret spatial data presented as a map and (ii) identify spatial patterns (or lack thereof). Such people may be capable of operating an automated GIS software-based animal health application. They may have attended one or more 'GIS appreciation' seminars or short courses.

Table 1. Skills necessary to attain the six levels of 'Marble's pyramid' for competent use of geographical information system (GIS) technology (adapted from Marble 1998).

Skill Level	Comments	Computing skills required
1. GIS research and software development	Highly trained in geography, spatial analysis and computer science; capable of creating new analytic approaches and algorithms and/or implementing them as part of new software tools.	High level skills
2. GIS system design	Primary professional concern with the implementation of GIS technology in new complex situations; highly trained in high–level systems analysis, systems design, database design and design of user interfaces.	High level skills
3. GIS application design and development	Creating applications instead of using them; able to develop and implement sophisticated GIS applications that involve substantial spatial analysis and modelling; higher skills in programming, software engineering and database systems.	Medium level skills
4. Higher level modelling applications	A substantial investment in learning about formal approaches to spatial analysis; good grasp of basic computer programming and database systems; able to structure and operate complex models using map algebra using ARC NETWORK or other off-the-shelf GIS software.	Medium to low level skills
5. Routine use of basic GIS technology	Have a working grasp of the foundation materials and to know enough about GISs to make effective use of basic components of GIS technology and to use GIS applications created by others; able to handle and *understand* menu driven GIS operations; a working knowledge of the full capabilities of GIS technology.	Low level skills
6. The foundation: basic spatial and computer understanding	Basic cartography, basic spatial analysis, basic computing.	Generic personal computer use, skills using graphical user interface

The next level defines the required skill for the vast majority of veterinarians (especially in developing countries) who are likely to use GISs as a tool for their work. At this level users are expected to have foundation knowledge and be capable of using basic GIS technology routinely. These individuals are expected to know enough about GISs to make effective use of basic components of GIS technology and to use GIS applications created by others. They are expected to be able to handle and *understand* menu-driven GIS operations, as well as have a working knowledge of the full capabilities of GIS technology. The following basic curriculum (and the materials in the companion CD-ROM) is directed toward this level of skill.

Above this skill level we move into the domain of specialist animal health workers who, for example, may wish to develop specialist disease risk or disease spread simulation models or to model the economics of various disease control strategies. Such users will have to possess advanced modelling skills as well as programming skills if they are to develop their own applications. In developing countries, in the short run, this need can be easily met by either importing experts from outside or forming collaborative research arrangements with overseas institutions (a task greatly assisted today by the Internet and electronic communication in general).

A GIS Curriculum for Veterinarians

We have identified the basic skills required of the large proportion of veterinarians who are likely to be dealing with spatial data. We now examine the content of materials which would enable the appropriate skill level to be attained. To this end we present a *basic minimum curriculum* which covers both the fundamental concepts as well as the training required to achieve *minimum proficiency* in the use of a GIS software package.

GIS—some fundamental topics

The following section provides the summary of the knowledge required under the topics indicated below. Each of these topics is supported by an extended PowerPoint presentation in the companion CD-ROM. (It is strongly recommended that the summaries should be read before the presentations on the CD-ROM are examined).

- GIS overview
- GIS data—some considerations
- Spatial referencing

- GIS data conversion
- Databases
- GIS editing and pre-processing operations
- Cartographic issues
- Spatial analysis (1): attribute data
- Spatial analysis (2): overlay analysis
- Spatial analysis (3): distance relationships, neighbourhood operations, connectivity functions
- Raster GISs
- GISs for environmental planning and management
- GISs for animal health applications

Geographical Information Systems—overview

GISs have been defined as "automated systems for the capture, storage, retrieval, analysis, and display of spatial data" (Clarke 1995, p.13). GISs can be used for any area or application that depends largely on geographic data, i.e. data that is geographically referenced or is 'mappable'. As the scope is quite wide, it is not surprising that there are many definitions as well as many acronyms (LIS, NRIS, AM/FM etc) which cover the field referred to as GIS-related technologies.

GIS technology has its origins in geography, cartography, surveying and computer science—disciplines which deal with various aspects of geography and the associated geographic data. Its rapid development and widespread adoption over the past decade has been influenced very strongly by developments in computing in general, e.g. higher performance, lower cost, easier to use hardware and software and the continuous enhancement of the application capabilities of software. Over time GIS applications have become more sophisticated—changing from earlier static inventory type applications (basically, electronic versions of atlases or manual procedures) to current, real time, decision-support type management applications.

GISs are recognised as having three key components. These are data (as graphic map data and attribute data stored in a database), technology (hardware and software) and people. Data is perhaps the most important component as the way in which it is 'modelled' and its quality has important consequences—for example, the choice of the data model has important consequences for the resulting application. Better management and use of geographic data is the main reason for creating a GIS. Technology and people aspects are what make it happen and sustain it over time.

GIS data—some considerations

Like all useful data, geographic data is expected to possess desirable properties such as accuracy, timeliness, comprehensiveness, and acceptable cost. Other general issues relating to geographic data include: spatial extent (the area covered); scale (the detail in the system); the large volume (both attribute data and graphic data can make large storage demands); diversity (data of interest plus background data); and collection cost (despite technological advances, field collection of data can still be very labour intensive). Scale is important not only for graphic representation in map form but also as it impacts on other issues such as map coverage extent, data volume and data collection.

The concept of a data model is central to any discussion of geographic data—there is a need to convert/translate the complexity of the real world into a simplified model. This model, in turn, should preferably be amenable to the recording of data in a computer, such as a field in a table. A data model in GISs consists of a measurement framework and a scheme for representation (spatial, temporal and attribute). The measurement metrics of attribute data (nominal, ordinal, interval, ratio etc) have important implications for operations involving attribute data manipulation: within this framework the data collection procedure and the collection unit used can seriously impact on data quality. We should be aware that the collection unit used is only one of many possible spatial frameworks that could be used. The modifiable areal unit problem is a well-researched area in geography.

Major sources of geographic information—maps, aerial photographs, remotely sensed imagery and digital datasets—are available from various vendors. Today, in most developed countries there is a declining emphasis on production of printed maps by mapping agencies as geographic information collection is shifting to either remote sensing or to the use of global positioning systems (GPSs) for field data collection. Increasingly there is integration of GPSs and GISs for field data collection.

Spatial referencing

It is essential to geo-reference data if we are to input it into a GIS and perform various spatial operations. A major feature of the GIS is its ability to integrate (put together) graphic data—for this to happen all datasets have to share the same geo-referencing framework. (e.g. Existing map data in a GIS may be in one projection and new data acquired by a GPS unit may be in another projection.) There are two types of geo-referencing: *discrete* and *continuous*.

Discrete referencing systems employ referencing which is essentially 'local' in character and usually does not usually involve the use of a coordinate system. A master index (key map) depicts all features that form part of the system. Ease of use is the main feature of these systems. Data that are geo-referenced this way have to be converted to a known coordinate-based referencing system for input into a GIS.

Continuous referencing systems which are coordinate-based can either refer to three-dimensional (the earth as a globe—*x,y,z* referencing) or two-dimensional (the earth represented in map sheets—*x,y* referencing). Two important issues arise here: (i) how accurate an assumption do we wish to make about the Earth—a sphere, spheroid or a geoid? and (ii) what compromises we are prepared to make when converting (or flattening) the 'round' Earth into a flat map?

Historically, for mapping purposes, it was necessary to have local adaptations (involving local datums etc.) of the coordinate referencing system. However, with improvements in surveying technology, we have seen the advent of a more integrated system for worldwide surveying and a move to a global standard based on the World Geodetic System (WGS84 and later variations). Adoption of global standards has been made much easier by the widespread use of GPS devices.

GIS data conversion

In GISs, data conversion has two commonly used interpretations: (i) when used in the narrow sense, it refers to the process of converting existing information to a digital format for use in a given GIS software package; and (ii) in its broader interpretation, it refers to the often complex process of building databases for GISs.

Data conversion is usually costly and a major expenditure item in setting up a GIS. This situation is brought about by an interaction of several factors including the large quantity of data (frequently of indifferent condition/quality) and the complexity of the conversion task. The data conversion process involves a *plan* (including manuscript collation, preparation, information filtering), *conversion* using the appropriate method*, edits/transformations*, *format conversions* (if necessary) and *data structuring* (making the graphic data more 'intelligent' by building topology).

The general (and accelerating) trend has been towards collection of data in digital format so the main conversion problem is related to existing data—especially true in developing countries where the availability of data in digital form is still very limited. There are many conversion methods; all are benefitting from the general improvement of both hardware and software used in conversion. Raster scanning is now playing a major role—especially as the first step in 'heads-up' digitising; however, automated data conversion remains a dream. Automated data conversion is where a map or similar data source can be scanned and all its geographic features and properties recognised and extracted by 'smart' software and converted into a GIS database. It is important to recognise that the data conversion process can introduce significant errors—only some of these can be detected automatically by software (especially so in the case of graphical data).

The converted graphic data in vector packages is stored simply as coordinates, i.e. as 'spaghetti' data. This is relatively 'dumb' data, i.e. it has no information on spatial relationships (such as adjacency, intersection and connectivity). As such any spatial query becomes a tedious process unless topological structures are created. After topology has been built, the system is able to respond to queries by using topological information rather than by a tedious processing of coordinate data (to generate geographic features every time a query is made).

Databases in GIS—some issues

GIS data relates to geographic features or objects such as wells, districts or roads. This data consists of the position of the feature (spatial data) and its other attributes. Thus GIS data can either be spatial (graphic/map) or attribute (textual). Currently, in most GIS software packages the two data types are stored in separate databases. The spatial data is usually stored and managed by a proprietary software while the attribute data is stored in some commonly available database package such as dBASE, ORACLE or INGRES.

The creation of a database represents an attempt at a structured and systematic effort to collect useful data which can be accessed in different ways to help users make decisions. A data dictionary is an important tool which can be used to achieve this objective by controlling and documenting data globally. A data dictionary is the critical component of a complex piece of software commonly termed a DBMS (database management system). (A related but wider concept is a metadata.)

Relational databases are the most common type of database structures in use today although some applications are based on hierarchical structures. Relational databases are popular largely because of their flexibility in design and their ability to support ad hoc queries. In a relational database data is stored in tables which can be linked if they have fields (keys) in common—considerable attention has to be paid to these linkages in the design phase. This flexibility can produce inefficient arrangement of tables or a data structure which can produce serious data management problems over time. Normalisation is one of several techniques for deriving an efficient storage arrangement—it helps in identifying linkages and reduces data duplication.

GIS editing and pre-processing operations

GIS editing operations attempt to correct errors introduced during the data conversion process. (It *may* also be possible to correct other types of errors at this stage.) It is generally easier to avoid, identify and correct errors in attribute data; it is much more difficult to perform similar operations on graphic data—mainly because it is difficult/impossible for the current generation software to identify many 'variations from the original data' as errors. Vector GIS software (if it supports topology) is able to identify many common errors in graphical data—the user is then able to edit these.

Often, even when the data is 'clean' (error-free) certain operations have to be performed before the data is fully useable for various analyses. These can be labelled pre-processing operations and include transformations, edgematching, clipping, format conversions, map generalisation and map abstraction.

Edgematching is the process of digitally joining individual map sheets into a seamless map (i.e. without seams or joins). In a large scale GIS, even though such a seamless map is created for the user, the software may actually store the seamless map as tiles. Tiles can be of any shape which is appropriate for the intended application.

The need for format conversion arises from the fact that different software packages generally have incompatible formats—some of this represents change over time although much of it relates to self-interest on the part of vendors in promoting their proprietary formats. Over the years various industry groups have put considerable effort into reducing this incompatibility. The development of the Spatial Data Transfer Standard and the OpenGIS are two well known efforts in this area.

Map generalisation is the process of reducing detail of a map layer. This may be necessary for various reasons but the most common is the need to generate a map at a smaller scale than the source ('original'). Thus, while the database might have been created at 1:50 000 scale there may be a need to produce maps at 1:250 000 for example.

Cartographic issues

Mapping is an important component of many (if not most) GIS applications. The mapping task has two components: (i) *design*, a creative process which adheres to some basic rules and (ii) *drawing*, artistic drudgery with formal rules (which can be addressed relatively easily by computers). When discussing benefits of automation, procedural benefits are usually identified; however, better utilisation of data is probably the more significant benefit. From relatively primitive beginnings in the 1960s, computer cartography has evolved to dramatic visualisation and interactive mapping over the World Wide Web today.

Maps should reflect cartographic knowledge about map design. Cartographic rules and conventions reflect the fact that a map is essentially a communication tool—as such it always has a purpose and is directed to an audience. A map has a visual grammar or structure—good map design requires that map elements be placed in a balanced arrangement within the neat line. Cartographic conventions cover all aspects of map design.

A map has some clearly identified elements (parts): medium (size, resolution, shape/orientation), figure (title, symbology, text), ground, reference information (data source, date of data collection, date of mapping). It is very important to provide reference information in digital mapping; this is a significant change from the past when mapping was done by various mapping agencies and any particular map was a sheet in a well documented series.

Spatial analysis (1): attribute data analysis

There is a common perception that 'GIS = maps'. Despite the size of many cartographic databases, much of the GIS data is still stored as attributes in textual form. This should not come as surprise for location is only one of the many possible attributes of a geographic feature/object. Analysis of attribute data is mainly by traditional statistical/quantitative methods.

Attribute data screening and profiling includes sorting, distribution statistics, plots and cross-tabulations; as in the case of all statistics, one should always be aware of the important role of measurement metrics in all of these operations. Transforming attributes may be *either* to reduce the information content by reducing a detailed source into a simpler form *or* to increase the information content by increases in the measurement level. Queries may be simple or complex and can include one or more attributes. While very complex attribute queries can be formulated they are found wanting when even a relatively simple geographic search (such as the location of the nearest Veterinary Officer) is involved. Hence the need for spatial equivalents of DBMS queries.

The search for explanation can be by simple procedures such as cross tabulations, scattergrams or statistical procedures (e.g. correlation analysis), or by complex multivariate models (e.g. factor analysis or cluster analysis). Procedures such as residual analysis highlight the special character of spatial data.

Spatial analysis (2): overlay

Overlay analysis is synonymous with the GIS. As Chrisman (1997) has stated, the need for overlay analysis stems from the fact that many problems in geographic analysis require the integration of data from a number of sources. In these situations, the process of overlay discovers the basic spatial relationship between objects using geometric measurements. Then attributes of the sources can be analysed or combined. Overlay involves geometric and attribute analysis phases and is often the simplest way of attaching attributes to geographic features.

While the overlay operations have different terminology and differing implementation in raster and vector data models, the operational basics are similar. Map algebra permits sophisticated overlay-based operations in raster implementations. Also, while the popular process involves polygons (reflecting its origins in sieve mapping type techniques) the process can include various combinations of polygons, points and lines. Overlay can involve two or more layers in unweighted or weighted combinations.

Spatial analysis (3): distance relationships, neighbourhood operations, connectivity functions

There are GIS tools which discover/reveal distance relationships implicit in a spatial representation. These have also been developed into a set of generalised methods that operate on neighbourhoods (or the local area around a feature which has been defined by some criteria). Thus, distance can be used to create a graphical object or a 'geographical feature'—as a data subsetting operator where distance is used as a query condition. Distance can be a negative or a positive factor in location—we can use it as a measure of attraction or we can use it for exclusionary purposes. Distance is most commonly measured in units of length but can be measured in other units such as travel times.

The SEARCH function underlies most neighbourhood operations. SEARCH requires three basic parameters: (i) the *target* (a feature of some description), (ii) the *neighbourhood* (the area surrounding the feature), and (iii) the *functions* (e.g. AVERAGE, DIVERSITY, MAJORITY, TOTAL etc.) which return a value for the attribute/s of interest.

Buffers can be generated around any feature type (for example, five kilometres from a village, or 500 metres around a creek). Buffer construction in a vector-type GIS is relatively simple and precise. Raster data has problems if cell size is not a multiple of the required distance (and there are also problems with measuring diagonal distances); however, there are advantages as well, e.g. when used in neighbourhood operations.

Thiessen polygons: a mosaic of polygons where any location within a polygon is closer to the point in that polygon than to the points of neighbouring polygons. These are created by (i) drawing lines connecting nearest points (Delaunay Triangles), (ii) then drawing perpendicular bisectors of connecting lines and (iii) finishing by creating polygons. 'All points are equal'—often not a valid assumption. Thiessen polygons are often used for data interpolation, effectively creating polygons from point observations. They are used more commonly for demarcating areas of influence around given points, e.g. for delineating service areas of hospitals or for delineating market areas of large shopping complexes or similar entities.

The rationale of connectivity functions is similar to neighbourhood operations—includes functions that accumulate values over the area being traversed. Impedance (or friction of space) is a measure of the cost of traversing space. In the model there are interconnection specifications, movement rules and measurements units. ROUTING and ALLOCATION are fundamental to many GISs in urban areas. Connectivity functions are generally vector based—for example, the shortest distance between two points calculations.

Raster GIS issues

Raster and *vector* are two common data models used in GIS. There was considerable debate (which in the 1980s was very partisan) on the relative merits of each but the prevalent view now is that they are complementary models. While the appropriateness or suitability for the task should be the basis for selection, there is considerable evidence that the features of the software package, the training of key individuals and historical precedent all play a significant (and less than objective) role.

In the raster model an area of interest is divided into a regular grid of cells—each cell contains a single value; one set of cells and associated values is a layer. (It should be noted that the grid cell arrangement is only one of many possible tessellated models.) There is a need to consider: resolution, coding method, and discrete versus continuous data. A raster can be created by (i) manual coding, (ii) scanning, or (iii) by digitising and transforming to raster format. As cell size is known, geo-referencing to real world coordinates is not always necessary (cf. vector data).

Raster GISs have the usual capabilities that most vector GIS packages have although the actual implementation of a given function may be significantly different. Generic functions include data input and management, various housekeeping functions, operations on various layers, and various output/display functions.

Given the fixed cell size the raster model excels at various types of simulation and spatial modelling (pollution modelling, soil erosion models etc.). The model is more capable (than vector) in integrating remote sensing data. Disadvantages of raster models include large data volumes when the resolution is high. However, if lower resolutions are chosen then we have the potential for poor representation of objects, loss of information, change in spatial relationships and 'jagged' displays. Also while raster GISs are excellent in manipulating polygon data, they have difficulties with handling point and line data.

GIS for environmental planning and management (EPM)

Environmental applications were the earliest applications of the GIS, largely because they avoided many of the data issues/problems faced by later applications.

As much of environmental planning and management involves dealing with spatial data, it is not surprising that the GIS has a 'natural' home here. These applications are able to utilise almost all features of the GIS for tasks such as baselines/inventories, scoping screening and evaluation, modelling/prediction, communication, implementation administration, monitoring, environmental design, and impact assessment.

EPM applications tend to have a large spatial data component and a variety of modelling is possible; modelling slight variations in parameters may produce significant variations, particularly with regard to potential spatial impact. GISs are often able to perform these operations and display the results. EPM application areas include environmental planning, environmental impact studies, social management/ erosion studies, forestry, natural and other hazards, recreation, wildlife, and numerous similar applications.

Environmental applications as well as data used have changed dramatically. The three key aspects of this change are currency (from relatively static to some very dynamic data sets), spatial resolution (from coarse 40 acre cells to under 5 metre pixels), and data structures (from raster only to mixed raster/ vector). There has also been a change in the purpose and objectives of application from 'atlas' type applications to operations and management applications. Environmental databases to include: geographic reference framework information, jurisdiction-wide natural resources data, backdrop data to the referencing framework, and other associated (usually specialised or greater detail) data.

Illustrative case studies include: the Rundle Land Management Information System (data integration, identifying options), GIS for North Queensland Rainforests (data integration, management scenarios and monitoring of a World Heritage Area), GIS and Forestry Tasmania (data integration, renewable resource management, achieving operational efficiency), GIS for highway route selection (data integration, corridor study, environmental impact assessment), GIS for landfill selection (data integration, raster GIS, site selection).

GIS for animal health applications: a case study from Thailand and Lao People's Democratic Republic (PDR)

Research was carried out in two study sites: (i) the provinces of Lampang, Lamphun, and Chiang Mai in northern Thailand, and (ii) the Vientiane Municipality in Lao PDR. The objective was to develop methods to improve the collection and management of animal health information, focusing specifically on the use of active surveillance techniques for data collection and the use of GIS for data management. Active surveillance involves the collection of statistically valid estimates of the level of disease through the use of structured survey techniques.

Under normal circumstances it is necessary to have a complete sampling frame to select a random sample from a population. A GIS-based analysis was carried out in Thailand of the completeness and accuracy of available first-stage sampling frames. To address the situation where no reliable sampling frame exists, a modification of a random geographic coordinate sampling technique was developed. This technique involves the selection of random coordinates, followed by the identification of all villages within a fixed radius of the selected point. When more than one village lies within the selection radius one of the villages is chosen at random. During analysis, in order to avoid bias towards sparsely located villages, results are weighted proportionally to the number of villages within the selection radius.

To assist with the practical implementation of this technique, an application was developed using *ArcView*. This program selects random points and indicates the selection radius. Using the program, the efficiency of the technique can be dramatically improved by using interpreted satellite imagery or aerial photographs to scan selected points and eliminate those located far from any villages or agricultural areas. This decreases the amount of wasted field effort required. Field activities can be further simplified with the use of a GPS unit.

The ability of the GIS to improve the management of animal health information was studied, focusing on disease reporting, outbreak management and outbreak visualisation. Existing systems for reporting disease in developing countries generally rely on tabular or textual presentation of data. Disease maps are able to convey information about the amount and distribution of disease. The use of disease maps for reporting was examined, including various constraints in presenting information and potential solutions to these constraints. These include the use of incidence maps to adjust for differences in the total underlying population, standardisation to adjust for differences in population structure, and risk maps which take into account of the level of confidence in the data.

The GIS developed in northern Thailand was used to develop a disease outbreak response management system. In the event of an outbreak of foot-and-mouth disease, ring vaccination of a buffer zone around the affected village is used to prevent spread of the disease. The system developed in *ArcView* allows the user to identify the affected village, and then reports on the total number of animals in the surrounding area, the required roadblock locations for livestock movement control, and an estimate of the workload for responsible district veterinary officers.

Another application was developed to assist with the visualisation and interpretation of disease outbreak data. The system presents an 'animation' showing the location of outbreaks over time. This system reveals new patterns which are not apparent when either the spatial or temporal pattern of disease outbreaks are examined alone.

The research demonstrated that appropriate active surveillance techniques and GISs could be effectively implemented in a developing country to improve the collection and management of animal health information.

Base skills in the use of common GIS software

This section will examine the practical technical skills required for the effective use of a GIS by veterinarians in developing countries. As these skills relate largely to competency in the use of computer software for GISs, this discussion will use one such package, *ArcView* GIS, as an example. The skills described are those required to reach level 5 in Marble's pyramid (Figure 1, Table 1), enabling the user to perform basic menu-driven operations and analysis within an 'off-the-shelf' GIS package, or a custom designed GIS-based specialist tool (e.g. the outbreak management program described above). The skills listed here are described in detail in training notes in the companion CD-ROM.

The main purpose of the practical course presented in the CD-ROM is to make users understand the basic operations of a GIS package by creating a very simple GIS application. It attempts to achieve these by covering the following activities:

- basic understanding of the operating system (e.g. *Windows 95*);
- drawing maps;
- working with maps;
- choosing what to display in a theme;
- changing the appearance of a view;
- working with tables;
- using geographical information;
- printing maps; and
- creating and editing themes.

Basic operating system use and starting ArcView

At the most basic level, users must be comfortable with the computer hardware and operating system (e.g. Microsoft *Windows 95*). They need to be able to use a graphical user interface to perform such basic operations as running a program and managing files—skills required to navigate through any application software. A good understanding of data storage and directory structures is needed. Once the program is running, users need to understand user interface conventions, such as the use of drop-down menus, buttons, minimising, maximising and moving windows etc. A good appreciation of the basics of the operating system should help the user avoid getting 'lost' in the system.

Included in these basic skills is an understanding of how to use the program's help system and other on-line documentation that might be available. When users understand the most basic concepts and are given access to self-training resources such as effective on-line help, skill levels can improve rapidly through practice and experimentation. Users benefit from the key feature of the Windows operating system—a relatively standardised approach to applications development. Thus individuals familiar with the Windows operating system already have an idea of how a GIS package like *ArcView* would operate.

Drawing maps

An important use of a GIS is to present complex information visually by producing maps. Users therefore need a good understanding of how visual communication is most effectively used. (Not surprisingly, a map on the screen is the most common view that greets GIS software users.) Thus viewing, drawing and modifying maps is often the first task that is undertaken in training. In *ArcView*, drawing basic maps requires users to *Open* a new *View* window for displaying the map, and then opening (loading) an existing theme from computer's memory. Themes can also be displayed by selection in the *View* Table of Contents.

An important task in displaying maps is selecting the way in which data will be displayed. This requires an understanding of basic cartographical principles. By selecting a theme in the Table of Contents, the user can edit the theme's legend. This enables data from the theme's attribute table to be displayed in a number of different ways. Examples include a *single symbol or colour* for all features, *graduated colours* proportional to a value in the attribute table, *graduated symbols*, or a *unique colour or symbol* for every different value in the attribute table. Understanding how each of these options affects the viewer's perception of the map is important when using maps to communicate a message.

When using graduated colours or symbols to represent a continuous variable, the values of the variable must be grouped into categories, each represented by a different colour or symbol. The way in which this categorisation of data is performed also has an important impact on the perception of the data contained in the map. Examples of categorisation schemes include equal interval, equal area, natural breaks, quantile and standard deviation. Once correctly categorised the appearance and interpretation of a map can be further enhanced by selecting appropriate colours, fill or line patterns, and symbols. The *ArcView* legend editor, fill, line, symbol and colour palettes give the user access to a wide range of options for effective data presentation.

Working with maps

As map display scales vary with different applications, users need to understand basic map manipulation techniques such as zooming and panning. Users *zoom in* (changing the display scale to see more detail) and *zoom out* (changing the display scale to see less detail). *Panning* involves 'shifting' the map so different parts of it can be viewed at the given scale (at the given scale the map is larger than the display area of the screen). Basic attribute data can also be displayed through the use of feature labels (manual or automatic) or the use of the *Information* tool (clicking on a feature to display its attributes). Distances can be measured directly from the map using the *Distance* tool.

Choosing what to display in a theme

To enhance the use of the map as a tool for visual communication it is often necessary to selectively display some features and to hide others in order to remove irrelevant information and allow the viewer to focus on the important issues. Users must therefore be able to modify what features are displayed in a theme by using the theme's definition. This requires users to have a basic understanding of Boolean logic, enabling them to select certain features which meet a combination of criteria, e.g. using operators such as >, <, =, AND, OR, and NOT. More advanced Boolean expressions can be created using some programming commands.

Changing the appearance of a view

When working with views, a greater depth of theoretical background is required to understand the operations. Many of these operations are essential if spatial data integration is the desired objective. It is often necessary to effect transformations so that all map data is in same projection and at the same scale.

Setting map units enables the GIS to relate the geographical data to its real-world location. This in turn allows various measurements and transformations to be performed which would not otherwise be possible. Setting map units (e.g. to decimal degrees or metres) requires a knowledge of the way in which the *ArcView* theme (shape file) was prepared. The user is also able to set the projection of the view. This is important for the accurate display of data or the combination (integration) of data from different sources, and requires a good understanding of map projections.

Working with tables

In order to work with attribute data (as opposed to simply viewing the attributes of geographical features) users must understand the use of *Tables*. Tables are displayed and manipulated in a table window. Table operations include opening an attribute table, opening an unlinked data table, sorting records, searching for records, counting records, adding and editing data. Subsets of data can be selected using Boolean logic as mentioned above, e.g. select properties under $120 000.

Joining tables is an important operation in the use of a GIS. During a join, an external data table (not necessarily a part of the GIS application) is linked to a theme's attribute table. This allows visual display of external data on the map. Another useful operation is the generation of summary statistics by summarising tables such as COUNT, SUM, AVG etc.

Using geographical information

The real power of a GIS is its ability to analyse information based on spatial relationships. To utilise this power, users need to understand spatial operations within a GIS. A simple but powerful way of achieving this within *ArcView* is the 'select by theme' operation. Users are able to select features in a theme, based on their spatial relationship to features in the same or another theme. Spatial relationships available include the selection of features that are 'completely within', 'completely contain', 'have their centres in', 'contain the centre of', 'intersect', or are 'within a distance of' features in another theme. Buffering is a related operation which involves the creation of a buffer zone around features (i.e. a defined distance from a given feature—e.g. within 5 kilometres of a disease outbreak village).

Spatial joins offer a third approach to examining spatial relationships. Spatial joins are analogous to joins performed on a table, but items are joined based on spatial relationships rather than attributes.

Printing maps

While maps can be created, displayed and manipulated on the screen relatively easily, a higher level of skill is required for producing and printing maps. This difficulty stems partly from cartographic considerations and partly from technology. The latter has become less important in the Windows environment especially with regard to printer/plotter driver software and the matching of screen colours and printer colours. Higher cartographic skills are required as printed maps tend to become more complex in cartographic terms and also because a 'screen-to-page' transformation is required as the screen image is usually smaller than the printed map.

In *ArcView*, the appearance of the printed map is determined by using a template or a *Layout*. Layouts allow the positioning of maps and other graphical elements on the page using graphical tools; they also allow standardisation and reuse of maps. In addition to maps (derived from View windows), legends, scale bars, north arrows, charts, tables, text as labels and as metadata, graphic elements and graphic file images can all be added to a layout. (The minimum metadata on the printed map must include the map projection used, the source of data, the age of data and the date of map printing.)

Creating and editing themes

ArcView enables the user to create or edit new themes (point, line or polygon themes). While some spatial data is already available in digital format, applications will still require new data to be digitised. The basic spatial data required by veterinarians in developing countries (and available as maps) are likely to be administrative boundaries (polygons) and village/settlement/farm locations (point), both of which are useful for many GIS applications. More specialised data (e.g. the location of livestock markets or the location of quarantine inspection points) may need to be digitised.

Data can be digitised either on the screen using a mouse or from a hard-copy map using a digitiser. On-screen digitising is appropriate for minor edits or when the map has been scanned at an appropriate resolution for digitising. On-screen digitising is also useful if raster images of non-map data (e.g. aerial photographs or satellite images) are available and selected features are classified and extracted for use in vector format. These images can be displayed within *ArcView* and digitised using a mouse.

Digitising hard-copy maps requires a digitising tablet. While the process is relatively simple and the skill can be acquired with simple training, it is important that users have a good understanding of map projections and geo-referencing (the use of 'tic points' for example) to ensure correct registration of the digitised data.

Delivery of GIS Training Requirements

Short courses

The 'pressure-cooker' method of training individuals, especially when they need to acquire some specialist skill for their everyday tasks, is very common. Short courses are the most frequently used (and effective) method for getting individuals 'up to speed' in a particular technique or technology. This approach would be appropriate for epidemiologists who wish to acquire basic understanding of GISs or the basic skill in the use of a GIS software such as *ArcView* or *MapInfo*. Such a course can be conducted over varying periods of time—ranging from one or two days to up to three months.

The main appeal of short courses is the short duration and narrow focus. They are most effective when individuals who complete such courses use their knowledge and skills in their everyday work—when this 'reinforcement' does not happen the loss of 'force-fed' skills is very rapid.

Tertiary programs

Tertiary institutions traditionally cater for the formal education component of the GIS education market. At university level, degree or diploma type programs dominate. For example, at the University of Queensland (in Brisbane, Australia) postgraduate Certificate and Diploma programs as well as a Masters program in GISs are available. The Postgraduate Certificate is flexible in that it allows individuals with relevant industry experience to enrol without an undergraduate degree. The same program can also be undertaken as a non-credit, 12 week short course—this may be especially suited to the needs of veterinarians in developing countries. Research only options for postgraduate work in GISs are also available as Master of Science (MSc) and Doctor of Philosophy (PhD) degrees.

Vendor-delivered courses

These vary from vendor to vendor but are similar to the short courses in format—courses typically are of a week or less in length (although courses of longer duration do exist). This duration is usually dictated as much by the need to offer training in 'bite sized chunks' as by the need to keep costs down. With few exceptions the courses are focussed on competency of software use rather than in an understanding of the general principles. However, these courses are quite valuable in that they are product-specific and usually have been tested in different contexts. As in the case with short courses, such vendor-based training is likely to be more effective when undertaken by individuals who will use the software on a regular basis after training (see also http://www.esri.com/training/).

Distance education

While distance education (in the form of 'correspondence courses') has a long history in training programs, it is the recent improvements in technology that have made it a viable option in situations where face-to-face teaching may not be possible. Improvements in printing technology (e.g. the use of desktop publishing and the greater use of colour) and more widespread availability of videotapes have made a major contribution to distance education. However, it is the introduction of CD-ROMs with interactive multimedia that has changed dramatically the nature of distance education courses. Multi-channel audio means that English as well as other language soundtracks are easily possible (e.g. a training program could have audio tracks in English, Bhasa Malaysia, Thai and Tagalog). Software training (in particular) has benefitted from use of colour, capture of actual screens and the inclusion of operational software on CD-ROMs. Some of these can be viewed on the companion CD-ROM. (Kingston University is an example of where a university level GIS course is offered by distance education—http://www.kingston.ac.uk/geog/gis, for a set of extended references see Bill Thoen's *Distance Learning in GIS* at http://www.hio.hen.nl/~zielman.)

Other Sources of Information About GISs

Vendors

In addition to product documentation, most vendors have other promotional materials illustrating uses of their products. Some of the larger vendors go beyond promotional materials and also provide a wide range of technical reports—e.g. The Environmental Systems Research Institute's (ESRI's) White Paper series. The advent of the Internet has meant that much of this material is on-line and electronic copies can be down-loaded from vendor sites by any user anywhere in the world.

Textbooks

There is no shortage of textbooks on GISs—ranging from introductory texts to advanced research publications. A recent query on the 'amazon.com' database yielded a listing of over 500 GIS or related publications. A selection of recent texts would include the following: Bonham-Carter, G.F. (1994) *Geographic information systems for geoscientists: modelling with GIS*, Pergamon, New York; Burrough, P. and McDonnell, R. (1997) *Principles of geographical information systems*, Oxford University Press, Oxford; Chrisman, N. (1997) *Exploring geographic information systems,* John Wiley & Sons, New York; DeMers, M. (1997) *Fundamentals of geographic information systems*, John Wiley & Sons, New York.

The Web

The Web is a major source of GIS information—from raw data to reports on advanced GIS research. The Web has made it much easier to disseminate GIS-related information than any other means previously used. A selection of well known, major sites include:

- *government* (United States Geological Survey—USGS, http://info.er.usgs.gov/research/gis;
  Ministry of Agriculture, Fisheries and Food, United Kingdom, http://www.maff.gov.uk)

- *vendor* (Environmental Systems Research Institute—ESRI, www.esri.com; CARIS GIS, http://www.hdm.com/gis31.htm)

- *research and education agency* (National Center for Research into Geographic Information and Analysis—NCGIA, http://www.ncgia.ucsb.edu)

- *university* (The Geographer's Craft at University of Texas, http://www.utexas.edu/depts/grg/gcraft; EpiVetNet, http://epiweb.massey.ac.nz)

- *international agency* (Food and Agriculture Organisation—FAO, www.fao.org/sd/EIdirect/gis).

The task of searching through the hundreds of major sites has been made easier by organisations and individuals who have made available lists of sites.

Some examples of these lists include:

- United States Geological Survey's Other useful links http://info.er.usgs.gov/research/gis/title.html;

- United States Census Bureau's 'The GIS Gateway' http://www.census.gov/geo/www/gis_gateway.html;

- Mike's 'GIS on the NET' http://fox.nstn.ca/ ~ mkostiuk/gispage.html); and

- GinfoServer http://www.geo.uni-bonn.de/members/haack/gisinfo.html.

Conferences and workshops

Conferences and Workshops and the published proceedings played a major role in the development of the discipline. The major conference series in the area :

- GIS*(year)*—held every year in Canada—the meeting has strong bias towards natural resources and environmental management;

- GIS/LIS*(year)*—held every year in United States of America (USA)—covers the whole range of GIS application areas;

- URISA*(year)*—held every year in USA and Canada—this is the annual meeting of the Urban and Regional Information Systems Association;

- ESRI UC*(year)*—held every year in USA—the Annual User Conference for the software products of Environmental Systems Research Institute (mainly ARC/INFO and *ArcView* GIS software packages).

Conclusion

This paper has identified the GIS skills required and has established a basis for veterinarians to acquire appropriate skills in GIS. It has defined a basic curriculum both for background theory as well as for practical skills by providing considerable appropriate material on the companion CD-ROM. It has also indicated GIS information that is available from various sources.

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12

Interfacing GIS with Economic Models for Managing Livestock Health

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Abstract

Decision making about animal health has substantial information requirements. Often information on which to base major disease control expenditure decisions is severely lacking. A coordinated approach to data collection between economists, geographers and veterinarians can be highly effective in providing data to support animal health programs. Experience from a project involving the development of an animal health geographical information system (GIS) and economic evaluation of foot-and-mouth disease control strategies in Thailand is reported. A number of possibilities for the interfacing of economic modelling and GIS to provide decision support in management of animal health programs are noted. Constraints to integration included different research paradigms and data related problems. Various sources of data for economic analysis are identified with respect to the Thai project.

Introduction

An animal health research project in Thailand has involved geographical information system (GIS) development and cost–benefit analysis of a foot-and-mouth disease (FMD) control program together with evaluation of information systems for control of diseases in cattle in Queensland, Australia[1]. GISs provide a powerful means of managing animal health information (Sharma 1994). In the joint Thai–Australian animal health project, a GIS has been developed to undertake various analyses of livestock populations in three provinces in northern Thailand.

Livestock diseases can impose very high costs on producers, consumers and traders: hence public animal health programs can have a high payoff. However, decision making about animal health has substantial information requirements. Sometimes, optimal policies are readily apparent even with limited data. At the other extreme, a desperate lack of sound information upon which to base major expenditure decisions may be apparent. A variety of data sources, of varying cost and reliability, are available. Acquisition of data needs to be viewed in a cost–benefit context: benefits will depend on who uses the information (private and public sector, locally to nationally) and for what purposes (e.g. planning animal health programs, monitoring disease eradication).

This paper discusses the opportunities for integrating economic analysis with information systems technology to generate information to support public animal health programs, and examines data sources and information management with respect to disease control decisions.

Managing Livestock Health

Animal health management presents a number of tasks for livestock authorities in terms of planning, monitoring and outbreak control, as indicated in Table 1. The objective is typically to reduce the incidence of particular diseases or to eradicate them entirely. Such programs require a close understanding of the factors associated with outbreaks (risk factors), and tailoring of control measures on a regional basis. Risk factors include high livestock density, spatial gaps in protection coverage, disease transfer by livestock imports (legal and illegal), intermingling of herds, feeding offal to

1. The work reported here has received financial support under the Australian Centre for International Agricultural Research (ACIAR) Project 9204, entitled *Animal Health in Thailand and Australia: Improved Methods in Diagnosis, Epidemiology, Economics and Information Management.*

pigs, predisposition by poor nutrition, and weather conditions. Monitoring involves information collection by means of passive or active surveillance, i.e. routine reporting or special purpose sampling.

Decisions about animal health measures are made by producers and government (local or village through to national). Decision-makers have substantial information needs concerning present animal health status and effectiveness of control programs. Both GIS and economic models are, in essence, methods of generating quantitative and qualitative *information* to be used in a *decision-support* role. Managers typically possess prior information which, combined with intuition and judgement, leads to tentative decisions or policies. Information provided by electronic information systems and technical specialists—including economists—augments existing knowledge, serving to confirm or challenge tentative decisions. Economics may be viewed as part of the information system, and the information system as one component of an animal health program.

Table 1. Management aspects of disease control and eradication.

Aspect of management	Components
Planning	Disease prevention measures
	Deciding control and eradication (C&E) components by species and region
	Determining expenditure and infrastructure development
Risk analysis/modelling	Determining relative importance
	Ameliorating in a cost-effective manner
Monitoring animal health	Monitoring incidence in commercial and village stock
	Monitoring vaccination coverage and protection levels
	Monitoring changes in risk factors
	Reporting to international agencies
Emergency response to outbreaks	Keeping track of new cases
	Determining the response strategy (ring vaccination, stamping out, quarantining)
	Distribution of resources (veterinarians, vaccine etc.)

Objectives and outputs of GIS and economic models

A GIS is used to store, analyse and map geographically referenced data, capabilities which are particularly useful for identifying and monitoring disease risk factors. The process of overlaying allows spatial relationships between variables, such as between disease incidence and various risk factors to be examined. GISs are also particularly well suited to coordination of data from throughout a country to gain an overall regional and national picture, and for generation of reports to international agencies. GISs may be used to aid in planning animal health programs, monitoring animal health and program performance, and responding to outbreak emergencies (disease epidemics).

Economists consider animal health programs from a social cost–benefit perspective. Their interest is in costs incurred by disease, costs of control, and benefits gained by control—from the producer through to the regional and national level, as well as for consumers. Economists are also interested in supply and demand relationships and associated 'elasticities', such as how a livestock industry can expand in terms of access to land and feed resources. Economic analysis may be used to determine if a control and eradication (C&E) program is desirable (on social cost–benefit grounds) or, if a program has been judged acceptable, to examine the most cost-effective way to implement it.

Interfacing Possibilities

There are a number of ways in which a GIS could be interfaced with economic modelling, as indicated in Table 2. These range from applying economic calculations in the design of the GIS, through to using GIS output as input for economic analysis to a high level of integration to perform dynamic simulation of proposed disease control strategies.

Table 2. Forms of interfacing of geographical information systems (GISs) and economic models.

Type of integration	Examples
Design of the information system	Sampling design, scope of the GIS, degree of centralisation
Use of GIS output in economic analysis	Use of maps, charts and tables of densities of animal populations, production parameters, disease control measures
Mapping of economic data	Spatial representation of livestock density, price differentials, values, disease costs, control expenditures, movement control points
Overlaying animal health and economic data	Relating risk factors and livestock values
Livestock production and economic models as add-ons or interfaced with GISs	Interfacing of input–output models
Integrated design of GIS, epidemiological and economic models	Dynamic simulation of disease control strategies

The GIS facilitates a spatial approach to economic analysis. A number of variables of economic significance may be mapped by district, province or region. FMD control strategies need to be designed on a regional basis, with different packages of control measures by region depending on risk status and eradication progress. For example, 'stamping out' would not normally be confined to regions where outbreaks are infrequent. In planning a C&E program there is a need to determine origins of reinfection (e.g. illegal stock imports, remote villages with low vaccination, areas where village herds intermingle in the cropping season). Price gradients will influence movements into the country (legal and smuggling) and movements within the country (for feeding on or sale).

The mapping of livestock values, disease costs and so on could help in designing control strategies. Economic data on aggregate value of animals located in an area and cost of carrying out control measures by regions would be useful for deciding on controls. In principle, the spatial distribution of total value of animals could be represented in a GIS. Areas containing a higher valued collection of animals should be given greater priority for public response to an outbreak of a contagious disease if more than one area is involved, other things being equal. Spatial information or eradication costs would assist in deciding whether and where to strive for regional eradication.

The spatial pattern of vaccination coverage could be examined in relation to that of vaccination cost, and opportunities for cost-effective increase in coverage identified. E.g. the issue of whether greater effort to vaccinate village swine is warranted could be investigated.

GIS models which incorporate data on livestock prices and show stock movements could also be highly useful in indicating areas of different degrees of risk of spread of livestock diseases. Risk indicators might be prepared for various regions. Cost-effectiveness of vaccination programs could be monitored on a district or regional basis. There is a possibility of linking GIS models of livestock data to regional input–output models and economic multipliers, such as the economic impact of an outbreak of a significant livestock disease in a region could be specified and predicted reductions in output and income mapped. Opportunity also exists for integrating or interfacing dynamic and stochastic epidemiology/economic simulation models with animal health GISs.

The tactical response to a disease outbreak involves rapid and critical decisions. Responses can range from 'do nothing' to highly expensive measures involving immediate quarantine, ring vaccination and stamping out of infected animals and others with which they may have had contact. GISs could be designed to predict or simulate the disease spread from a point source. Combined with epidemiological and economic analysis, it may be possible to determine optimal response policies for various outbreak scenarios in advance.

In a cost–benefit study, livestock species and herd size distributions contained in a GIS database could be used to aggregate disease cost and control costs and benefits through to regional and national totals.

Obstacles, Constraints and Unrealistic Expectations

While there are many possibilities, in practice, the interfacing of GISs and economic models faces a number of constraints (Table 3). Only the general constraints are discussed below—major constraints related to data are discussed in the following section.

Table 3. Constraints on integration of geographical information systems (GISs) and economic models.

Constraint type	Examples
Philosophical and methodological differences	Paradigm differences Lack of understanding of analysis capabilities Subjectivity of economic analysis
Unrealistic expectations	A comprehensive (national) animal health GIS? Centralism versus local empowerment Economic analysis as an add-on
Differing data requirements	Economic analysis for stakeholder groups Scale of representation Incentive systems and behavioural responses
Unsuitability of data for spatial representation	Inadequate sample size
Data availability and other practical constraints	Difficulties in obtaining animal health data Sensitivity to disease disclosure

Philosophical and methodological differences

Interdisciplinary research presents problems in that people have a learning-time in becoming familiar with the paradigms, methods, capabilities and opportunities of professionals in another discipline. For example, few economists have training or familiarity with GISs and understand the capabilities available, tending to think of GISs as automated mapping facilities.

Another difficulty arises in that economists often work with subjective information, sometimes being forced to resort to 'guesstimates' and 'heroic assumptions' where scientific evidence is absent, and to rely heavily on sensitivity analysis. For example, it is particularly difficult to estimate the cost to producers of livestock diseases such as FMD. Passive surveillance is notoriously inadequate for obtaining an indication of disease incidence and cost (Ogundipe et al.1989), changes in weight gains and mortality and reproduction rates due to FMD are not well documented, and little is known about the extent of compensatory weight gains after the disease. Economics is an inexact science, in which practitioners sometimes have to synthesise subjective data from a variety of sources. The uncertain nature of this information does not rest easily with the data quality control and error checking of spatial geographers.

Unrealistic expectations

When embarking on a joint project, geographers and economists can have unrealistic expectations of each other's contribution. An economist may expect an 'all singing all dancing' animal health information system to be developed, with details of livestock populations and performance parameters, disease incidence, vaccination and protection levels, and so on, by district throughout the country. The system could include biophysical modelling to predict future livestock numbers, production, trade flows and disease protection and health status. It could be linked with remote sensing to arrive at estimates of livestock on the ground and to track livestock movements. Such an all-encompassing system would provide a wealth of information for economic analysis. The ideal from an economic perspective would be to have a model which could simulate outcomes for various disease control strategies.

It is probably still futuristic to imagine that a national animal health GIS could be developed that does everything livestock authorities would want. A national system may be neither necessary nor feasible to develop, or at best exorbitantly expensive. In any case, there is a tendency nowadays not to develop large centralised information systems, but rather to set data definition and management standards centrally and have local data repositories which can be accessed from all points in a network. This allows local ownership and updating of data using agreed standards and also permits universal access.

The role of economics is often perceived by other disciplines as being to place dollar values on impacts as an add-on once technical detail of a program has been resolved. At this stage, it can be too late for economists to make a meaningful contribution. Economic considerations are relevant to the design of programs and the comparisons of policy alternatives. A comparison of the 'with program' and 'without program' cases requires a thorough understanding of current livestock production systems and alternative program options.

Differing data requirements

A GIS to support a disease eradication program for a particular disease has to be national in scale but allow for regional variation. Economic analysis similarly has to incorporate regional variations yet take a national perspective. All stakeholder groups have to be considered—in general terms producers and consumers, but also including traders and exporters. A GIS can be expected to focus on spatial factors relating to animal health, including stock populations, risk factors, disease control practices and disease incidence. The approaches are not a natural match. The economic 'model' has to be more eclectic. There is common ground in that the objective of both is to provide decision support for a cost-effective control program. Economics is more information-using, while a GIS is more data-generating, though both have substantial data requirements. The scale of a GIS must be defined explicitly, e.g. 1 in 10 000 000. Economics attempts to accommodate a range of scales, but rarely attempts to make these scales explicit.

Much of the information needed for economic analysis is not normally represented in an animal health information system. The cost of disease to owners of cattle and buffalo involves loss of production, reproduction, draft and transport. Impacts on consumers arise from changes in the prices of meat and other livestock products. Also important is the impact of disease eradication on allowing access to foreign markets. When examining the response to livestock owners to disease reporting or vaccination programs, economists need to consider livestock owners' resources, attitudes and practices. They are concerned with incentive systems and behavioural responses to them. Obviously, these same considerations could be included in spatial analysis.

Unsuitability of data for spatial representation

Much of the information useful for economic analysis does not lend itself to spatial representation. An example from the Thai study is the level of FMD protection as revealed by active surveillance (involving taking blood specimens and determining FMD titres) from 30 villages spread over three provinces, in which the number of observations is too small to interpolate between observation and derive density contours.

Data unavailability and other resource and practical constraints

While considerable potential exists for integration of GISs and economic analysis, the data needed to generate relevant information for spatial analysis simply may not be available. Access to data can be a major constraint for economic analysis of livestock systems in a distant country, with a different language, with sensitivities about disclosure of livestock disease levels, particularly when there are no project officers speaking the local language. Livestock authorities do not always regard animal health information be a public good, for fear of jeopardising trade prospects.

Information Requirements for Economic Analysis

The above discussion raises questions about what data are needed to carry out social cost–benefit analysis of animal health programs. Animal diseases can cost many millions of dollars to producers (in production, reproduction, draft and transport), to industry (as a constraint on genetic improvement and intensification of production), to traders (including international trade) and to consumers (Harrison and Tisdell 1997). C&E programs partially eliminate these costs, while themselves incurring costs of veterinary infrastructure and services, vaccination, stock movement controls, response to outbreaks (including quarantining, additional vaccination and 'stamping out' of infected animals), information systems and extension. Estimates of these various cost components, and the extent to which disease costs will be eliminated, are needed when comparing animal health program options. Such information is a basis for decision support in guiding planning and management decisions at the individual producer, industry body and government (local to national) levels. As well, information is needed on how producers are likely to respond to the incentives or regulations involved in C&E programs. Since the measures adopted in any animal health program are likely to vary between locations, data may be needed on a provincial or regional basis.

Data requirements of economic modelling are highly variable. They can range from the farm scale to the national scale, from simple dollar values to behavioural data and from simple numeric indication of numbers to details of infections by sex and age. Such varied requirements are unlikely to be managed by a centralised national system; even a distributed system may be unable to achieve this because some of the required data can only be obtained by sophisticated interviewing by well-trained interviewers—such data collection is not likely to be collected as part of a traditional animal health information system.

Data need to be collected for three types of coverage, namely thematic, spatial and temporal. Spatial data relate to individual enterprise or farms, villages, districts, provinces and whole countries. Time series data require periodic collection, such as regular surveys. Not all data collected are released, for example, release may be restricted to aggregated data at the provincial level. It would be unrealistic to think that any national statistical system could satisfy the needs of all researchers, either in terms of resolution or in terms of themes covered. No developed country has been able to achieve this largely because it has not been possible to achieve agreement on the minimum design requirement of such a system. Animal health data may pose some additional problems: diseases may be episodic and livestock owners may have incentive to conceal information.

Important animal health data usually include the basic 'demographics' of the animal population (animal type, sex, age), disease and mortality statistics by animal type as well as movement data (i.e. animals born/slaughtered, bought/sold). These data would enable a minimal production–disposition analysis to be conducted.

Sources of Data for Economic Analysis

Identifying data sources can become something of a challenge. Experience of the Thai project suggests some potential sources as follows:

Animal health information systems

Progress is being made in development of animal health information systems, including electronic databases and GISs (for example Morris 1991; Ramsay 1997). Unfortunately, these are often set up to capture data that are easily collected across a country, or are needed for official reporting purposes, rather than data which are relevant to planning and monitoring disease control programs. They rarely contain data suitable for substantial epidemiological analysis let alone economic analysis of disease planning and monitoring programs.

Periodic reports by government departments

Various government departments produce periodic livestock statistics. In Thailand, annual reports by the Department of Livestock Development (e.g. DLD 1996) and the Office of Agricultural Economics (OAE 1996a) provide a snapshot of animal industries, including livestock populations, turnoff numbers, market prices, foreign trade, vaccination numbers and numbers of disease cases. Comparing statistics for different years yields information on trends. Reports in the local language contain more detailed on some aspects than those designed for an international audience (OAE 1996b).

Occasional government reports

These often deal with specific issues, such as the Thai FMD C&E strategy (DLD 1997a) and proposal to establish a new FMD-free zone (DLD 1997b).

Reports of international agencies

Data for some diseases are forwarded monthly to the Office International des Epizooties (OIE) and available in monthly bulletins, annual reports and electronically on the World Wide Web (ASEAN/OIE 1997). These tend to be subsets of infection and mortality data available in national government reports.

Active surveillance

Random sampling of village livestock and taking blood samples and testing for seroprevalance provides reliable information of protection levels but is costly and time consuming for field and laboratory staff. Abattoir sampling suffers from bias in that age, source area and health status distributions are likely to be unrepresentative, and 'markers' can be detected for some past or chronic diseases only.

Results of biological research projects

Animal health and production research projects in the target country and elsewhere will provide an indication of the likely normal performance and perhaps impacts of diseases. Transferring results of research conducted elsewhere to a particular developing country is a useful guide though imprecise.

Reports of previous economic investigations

These studies can produce conflicting results, but provide ballpark figures for economic analysis. Their usefulness can be limited because circumstances have changed or there may be disagreement with some of the assumptions in the light of new information. Also, their spatial coverage may relate to another part of the country or have used a more generalised data collection unit. For Thailand, the two previous cost–benefit analyses for FMD eradication that are available have conflicting results (von Kreudener 1985; Bartholomew and Culpitt 1992).

Village surveys

Official statistics often provide little information about small-scale village livestock producers, and survey methods may be essential to obtain data about livestock numbers, management systems and performance parameters. Due to language problems, sometimes these are best carried out by local agencies such as universities (e.g. Thani et al. 1996).

Eliciting expert opinion

Where documented data are scarce, resort may be needed to expert opinion, e.g. from veterinary epidemiologists. This may involve direct interviews, Delphi surveys or focus groups. Delphi surveys seek consensus estimates while avoiding direct interaction between experts so as to avoid bias due to dominance by individuals due to rank or personality. Focus groups on the other hand promote interaction between experts to stimulate deeper thinking. While subjective 'guesstimates' are not backed by 'asterisked significance levels' they may provide highly useful and robust data.

Public media

Sometimes information of value can be obtained in newspapers and television reports—for example, Maneerungsee (1997) provides details of Thai feedstuff prices and tariff policy.

Input–output and closed general equilibrium (CGE) modelling

These techniques can provide estimates of the impacts on income and employment of changes in levels of activity on particular sectors, including livestock production. They rely on input–output tables derived from national accounts together with supporting data, and are not highly precise, but can provide important macroeconomic estimates (e.g. Purcell et al. 1996).

Simulation and epidemiological modelling

Animal health program options may be evaluated through computer simulation experiments with models of livestock systems. This approach is relatively data demanding and costly, but can yield high quality information. Cameron et al. (1995) simulated protection levels against FMD of cattle and buffaloes in Thailand under various vaccination programs, while Ramsay (1997) applied simulation to evaluate vaccination programs for cattle disease in Australia.

Market research

Studies of consumer behaviour yield estimates of demand elasticities and hence how demand and price will respond to a change in production as a result of improved animal health. Market research may also be applied to determine how availability and prices of stockfeeds will respond to an increase in livestock numbers. Various techniques are available to predict international demand for livestock products such as 'balance sheets' of predicted supplies and demands and econometric models.

Data usefulness, reliability and cost

The various sources above may be evaluated in terms of the nature of the data they provide, and its quality (relevance to economic analysis, comprehensiveness, accuracy, timeliness and cost). Official statistics can be obtained 'off the shelf' at little cost, and provide a guide to base livestock production figures. However, under-reporting is a universal problem with passive surveillance systems. For example, official statistics indicate that in 1988 one only beast died from all infectious diseases in the whole of Thailand (OAE 1996b). The official statistics also tend to be at a low level of detail. Livestock owners may not be able to identify diseases or causes of death, and veterinary field and diagnostic services may be inadequate to assist them. Livestock owners may not bother to notify authorities of disease cases for lack of incentive to do so or because they may fear economic loss, say from affected stock being destroyed without full compensation. Livestock authorities or statistical agencies may under-report disease incidence for fear this will have adverse trade impacts. Hence, passive disease reporting (including data submitted to international agencies) is unlikely to be accurate enough for economic analysis. Active surveillance will provide much more accurate information, but due to high cost is likely to be applied for specific problem locations only. Livestock owner surveys and simulation modelling can also provide high quality information, but at high cost. Departmental reports, newspapers and so on provide occasional and opportunistic data.

Validation of Livestock Data

Validation of data on livestock disease reporting is an important but neglected activity. Various strategies can be adopted, such as a check may be made for consistency of values for a particular variable in different data sets. For example, such a check has been able to pick up discrepancies in reported numbers of FMD cases from various Thai statistics. Another approach is to seek subjective estimates from experts to compare with published values, taking into account variations in definitions. Where concern remains as to data reliability an expedient in economic studies is to carry out sensitivity analysis in which uncertain parameters are set at pessimistic and optimistic levels.

Extent of Interfacing in ACIAR Project 9204

Construction of the GIS map base and data layers such as livestock populations naturally precedes interdisciplinary use of the system. ACIAR project 9204 had a modest aim of trialling information technology in three northern provinces in Thailand, and little time was available to undertake integrated modelling. A late project start and early curtailment of planned survey work in Thailand limited availability of data at the individual property level. Some mapping of variables of economic interest was performed, although the higher forms of integration listed in Table 2 were not achieved. Further mapping—such as mapping of 'price surfaces' of live animals and livestock trade movement patterns—would have been useful from an economic perspective.

From the Thammasat Univeristy database of approximately 60 000 village records it was possible to map livestock numbers by species by province, district and sub-district throughout Thailand. This indicated in a clearly understandable way that cattle are relatively widely distributed throughout the country, while pigs concentrate near Bangkok—reflecting the differences between traditional and commercial farming operations. These spatial distributions provide an indication of where concentrations are greatest and where control measures would be likely to be most rewarding. The GIS also provided maps of herd sizes, enhancing understanding of village livestock production systems.

Concluding Comments

Greater acceptance is needed of the requirement to collect data for economic analysis as part of monitoring the progress of animal health programs. Data at varying resolutions are required for various economic analyses of disease C&E programs. Official statistics which provide country-wide coverage and are available over time are limited to basic statistics. Techniques such as simulation and Delphi surveys of experts can be used for arriving at estimates when detailed producer surveys are not possible. A coordinated approach to data collection between economists and veterinarians is essential if useful data are to be obtained.

So far there has been little use of GISs in Thailand to map economic data and to employ economics in conjunction with GISs of animal data to determine appropriate animal health programs or response strategies for outbreaks of contagious animal diseases. Various opportunities exist for integration of the two methodologies in the generation of decision-support information for animal health programs. The more obvious involve spatial mapping of livestock density, outbreaks and vaccination coverage. At a more ambitious level, dynamic simulation of livestock populations, production and health status are technically possible. Problems concerning data availability, data scale and data quality are the major impediments to interfacing GISs and economic models. The ACIAR project has provided an opportunity for interaction between economists and geographers which has raised awareness of the possibilities of integration of research methods.

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13 Distribution of Benefits from Improved Animal Health

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Abstract

The productivity of livestock producers will increase with improved animal health. Increased productivity would lead to a shift to the right in beef supply. In this chapter economic surplus is used to examine the distributional effects of a shift in supply. The type of shift in supply is an important factor in determining whether producers gain from an increase in productivity, while consumers always gain if the shift in supply results in a decrease in price.

In a free domestic market without exports, consumers will always benefit from a shift to the right in supply because the price decreases. Producer benefits depend on the type of shift. In the case of an unrestricted export market, domestic consumers in Australia and Thailand would not benefit from a shift in supply to the right in their country because both countries are small producers of beef on the world scale. However, beef producers would benefit from such a shift.

Where import quotas are in place, as is generally the case for beef export markets, it is predicted that domestic consumers and quota holders will benefit from a shift in supply to the right. However, in this situation it is possible that producer surplus will decrease following the shift in supply. If improved animal health leads to an increase in the size of markets, in addition to higher productivity, domestic producers will benefit but domestic consumers may not.

Introduction

If governments are involved in collecting animal health information and providing animal health programs, and producers are required to contribute to the cost of these programs, it is important to determine who benefits from them. The distribution of benefits from improved animal health is considered in this chapter.

The gathering of additional animal health information can affect supply of livestock products if used to increase productivity. Similarly, eradication of a trade-limiting disease such as foot-and-mouth disease could affect the productivity of cattle producers, resulting in a shift in supply. Disease eradication could also affect demand by allowing access to higher-priced export markets. If productivity is increased, one expects livestock owners to have increased profits. However, the situation may not be as simple as this because an increase in supply can affect market prices and the benefits of improved productivity will be distributed between various sections of the community. It is, therefore, important that assessment of benefits from improved animal health is carried out within a valid economic framework.

The analysis outlined in this chapter examines the distribution of benefits between producers and consumers in terms of economic surplus concepts. In the chapter, trade in livestock products is discussed first with special emphasis on beef trade by Thailand and Australia. Then the concept of economic surplus, and the effects of improved animal health on aggregate supply, are examined using comparative static analysis. The effects of movements in supply of meat products on domestic producer and consumer surplus are then determined.

In developing a first model, the effects of a shift in supply in an unrestricted domestic market are examined. A free international trade model is then developed, followed by a model that includes the effects of trade restrictions in the form of quotas. Effects of an increase in demand brought about by eradication of a trade-limiting disease are then examined.

International Trade and Production of Beef: Thailand and Australia

This section provides information on beef production and markets for Thailand and Australia. The information is used later in this chapter to examine distribution of benefits from changes in productivity in these countries and responses in export markets.

The international market for livestock products is affected by tariffs and import restrictions imposed by the main importing countries. While barriers to trade are being reduced progressively, the market is still far from allowing free trade. Thailand is a net importer of cattle, beef and milk. In comparison, Australia is a major exporter of cattle and beef. In this section, world production of beef and veal is examined, followed by a brief analysis of Thailand's trade in cattle and beef and then an examination of Australia's trade in beef. A more complete analysis of trends in production and trade of cattle, beef and pigs in Thailand is contained in Smith and Harrison (1997) with further analysis in Murphy and Tisdell (1996a and 1996b), Tisdell et al. (1977), Murphy et al. (1997) and Kehren and Tisdell (1998).

The world's major beef producing countries are indicated in Table 1. Australia is a relatively small beef producer in international terms, providing 3.6% of total world production, while Thailand produces approximately 0.39%. The United States of America (USA) (20%) and the European Union (16%) are the major world producers.

Table 1. Major world producers of beef and veal by country, 1992

Country	Quantity (kt carcass weight)	Fraction of world total (%)
Australia	1 834	3.60
Argentina	2 520	4.96
Brazil	3 950	7.77
Canada	910	1.79
Columbia	630	1.24
European Union	8 367	16.46
Japan	592	1.16
Mexico	1 660	3.27
New Zealand	518	1.02
South Africa	745	1.47
Thailand	191	0.39
Former Soviet Union	6 494	12.77
United States of America	10 613	20.88
World	50 835	100.00

Source: ABARE (Australian Bureau of Agricultural and Resource Economics) (1994).

In 1995 Thailand exported a small amount of beef (2.7 kt), all to Lao People's Democratic Republic (PDR). Cattle and buffalo are also exported live from Thailand, with 16 019 cattle and 4 027 buffalo exported in 1995 (Thai Department of Livestock Development 1995). Of the cattle and buffalo exported, the largest number were exported to Malaysia with a small number (92 cattle) exported to Lao PDR (Thai Department of Livestock Development 1995).

As indicated in Table 2, Australia was the world's largest exporter of beef and veal in both 1992 and 1993 followed by the European Union and the USA.

Table 2. Major exporters of beef and veal, 1992 and 1993.

Country	Quantity (kt carcass weight)	
	1992	1993
Australia	1 197	1 146
European Union	1 139	1 096
United States of America	601	578
New Zealand	426	456
Argentina	296	275
Canada	159	190
Uruguay	123	104
China	75	140
India	77	90
Costa Rica	22	25
Sweden	8	8

Source: ABARE (1994).

Most of Australia's exports of beef are consigned to countries in the Pacific rim. The United States and Japan are the main importers of Australian beef. In 1993 these two countries imported approximately 70% of the beef and veal exported from Australia. The importing countries and the quantity of Australian beef they imported in recent years are presented in Table 3.

Table 3. Major importers of Australian beef and veal, 1992 and 1993

Country	Imported volume (kt boneless beef)	
	1992	1993
United States of America	371.7 (45.2%)	274.4 (34.7%)
Japan	217.7 (26.5%)	280.5 (35.5%)
Canada	51.8 (6.3%)	84.3 (10.7%)
Republic of Korea	97.3 (11.8%)	53.1 (6.7%)
Taiwan	36.5 (4.4%)	32.8 (4.2%)
Thailand	0.34 (0.04%)	0.99 (0.13%)
Papua New Guinea and the Pacific Islands	12.1 (1.5%)	12.3 (1.6%)
United Kingdom	6.1 (0.7%)	5.2 (0.6%)
Total exported	822.5	790.4

Source: ABARE (1994).

The beef market in the Pacific rim is highly regulated with most countries, including the USA and Japan, imposing trade restrictions. In the USA, the restrictions take the form of 'voluntary' limitations on the quantity exported by each country to the USA in association with tariffs. In Japan, restrictions take the form of ad valorum tariffs together with a system of quotas (Harris et al. 1990; Reithmuller et al. 1990)

Economic Surplus for Assessment of Improved Animal Health

An important consideration in the evaluation of the benefit of improved animal health is the distribution of those benefits within society. Calculation of *economic surplus* usually includes both distribution and magnitude of benefits. Economic surplus is the sum of two components: benefits to producers or *producer surplus*; and benefits to consumers or *consumer surplus*. Economic surplus has been used by several authors to examine the benefits of specific animal health activities (Amosson et al. 1981; Berentsen et al. 1992; Ebel et al. 1992; Anaman et al. 1994; Ott et al. 1995) and various aspects of pest control in agriculture (e.g. Auld et al. 1987) as well as the economic impact of agricultural research and development (Davis et al. 1987). If supply, demand, or both shift, there will be a change in economic surplus—typically including a change in both producer surplus and consumer surplus.

The Effect of Shifts in Supply on Economic Surplus without Trade

In this section, the change in economic surplus from a shift in supply is examined in the context of a closed economy. The effects of different types of shifts in supply are examined as well as factors that affect the size and distribution of economic surplus.

The change in economic surplus is the change in producer surplus plus the change in consumer surplus. In Figure 1, when supply shifts from S_0 to S_1 the change in consumer surplus is area $P_0M_0M_1P_1$. The change in producer surplus is area $P_1M_1A_1$ less area $P_0M_0A_0$; or alternatively, producer surplus can be calculated as the increase in total surplus (which can be reduced to area $A_0M_0M_1A_1$) less the increase in consumer surplus.

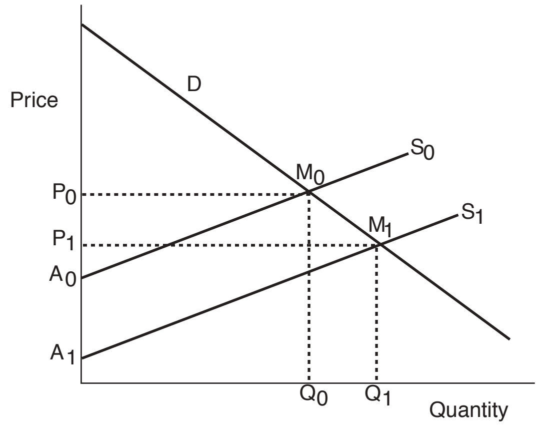

Figure 1. Change in economic surplus with a change in supply.

Where producers improve productivity, supply will move to the right (Ott et al. 1995). Two principal types of supply shift were identified by Lindner and Jarrett (1978), namely *divergent* and *convergent*, with the *parallel* shift as an intermediate case. The change in economic surplus has been shown to vary considerably with different types of shift in supply with the type of shift affecting the size, direction and distribution of changes in economic surplus (Duncan and Tisdell 1971; Lindner and Jarrett 1978; Rose 1980; Wise and Fell 1980). Differences in the size of economic surplus, as large as three fold, were estimated for different types of shift in supply (Lindner and Jarrett 1978). Miller et al. (1988) reported the effects of various types of shift in supply on producer surplus alone.

In divergent shifts of supply, the absolute vertical distance between the two supply curves increases as the quantity supplied increases (Lindner and Jarrett 1978). There are two types of divergent shifts, *pivotal* and *proportional*. In the case of a divergent shift, it is implied that absolute reductions in average cost are greater for marginal firms than for inframarginal firms. That is, the increase in efficiency is less for the more profitable, lower-cost farmers at the left of the supply curve than for the less efficient farmers operating at the right of the supply curve (Duncan and Tisdell 1971; Lindner and Jarrett 1978).

Amosson et al. (1981) assumed a pivotal shift in supply when examining implications of alternative bovine brucellosis control programs. Miller et al. (1988) found that a downward pivot of supply will decrease producer surplus when the equilibrium lies in part of the elastic or any of the inelastic parts of the demand curve. This applies to any supply and demand curves that are linear or power functions. The implication is that because demand in agricultural markets tends to be inelastic, using pivotal changes in the supply curve will predetermine the nature of the change in producer surplus (Miller et al. 1988).

A convergent shift in the supply curve occurs where the absolute cost reduction at inframarginal levels of of output is greater than at marginal levels of output. Convergent shifts in supply are more likely to occur from technological and organisational innovations which are scale dependent than from biological innovations (Lindner and Jarrett 1978). For example, a technological innovation is more likely to be used by more efficient, lower cost farmers. The effect, therefore, is to improve the efficiency of the farmers who are producing at the left of the supply curve (Lindner and Jarrett 1978).

Parallel shifts to the right in supply occur when improvements in efficiency are not scale or efficiency dependent and imply the same absolute reduction in average costs for both high and low cost producers. A parallel shift in supply will always result in increased consumer surplus. Producer surplus will also increase from a parallel shift in the supply curve if demand is not perfectly inelastic.

A parallel shift in supply was assumed by Ott et al. (1995) who examined the national economic benefits of reducing livestock mortality. Ebel et al. (1992) made the same assumption when examining the welfare effects of the national pseudorabies eradication program in the USA. In both cases, an increase in consumer and producer surplus was predicted. Ebel et al. (1992) examined three separate groups with different levels of herd infection and assumed a parallel shift for each of these as a way to determine the effect on producer surplus for each level of disease.

When supply shifts to the right, the equilibrium price for meat would be expected to fall, resulting in an increase in consumer surplus. Producer benefits depend on the type of shift, with divergent shifts resulting in smaller benefits to producers than either parallel or convergent shifts (Norton and Davis 1981).

Demand elasticity is also important in determining the size, direction and distribution of a change in economic surplus. As demand becomes more inelastic, producers are likely to experience a decrease in surplus following a change in productivity (Norton and Davis 1981). In addition, if supply is more elastic than demand, consumers will tend to receive a larger share of benefits than producers.

Effect of a Shift in Supply Where Beef Is Exported

The effects of a shift in supply on domestic economic surplus where a proportion of the beef is exported are now examined. A disaggregated commodity supply and demand model along the lines of that developed by Edwards and Freebairn (1984) is used. Separate sectors for the home country and the rest of the world are specified. World demand is obtained by the horizontal summation of demand specifications for the home country and the rest of the world as illustrated in Figure 2.

Effect of a shift in beef supply when exported into a free market

Figure 2 illustrates the demand curves where beef is exported into a market without import restrictions. The domestic demand curve is D_d, the foreign demand curve D_e, and the total demand curve D_t.

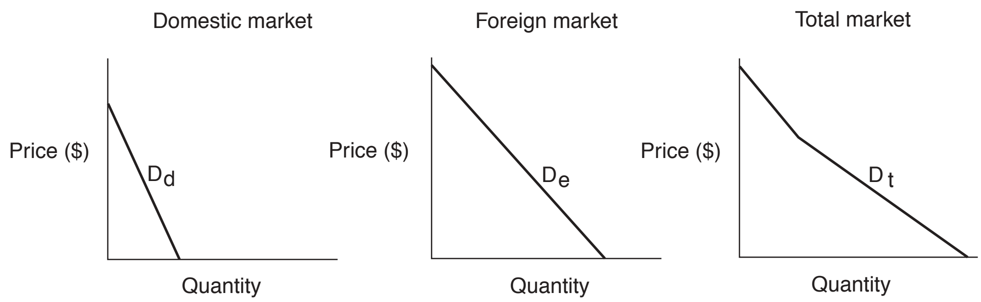

Figure 2. Demand for beef when traded internationally.

The total demand curve and the supply curve of domestic producers are illustrated in Figure 3. In this case a shift in supply from S_0 to S_1 results in a change in equilibrium price from P_0 to P_1 and quantity demanded from Q_0 to Q_1.

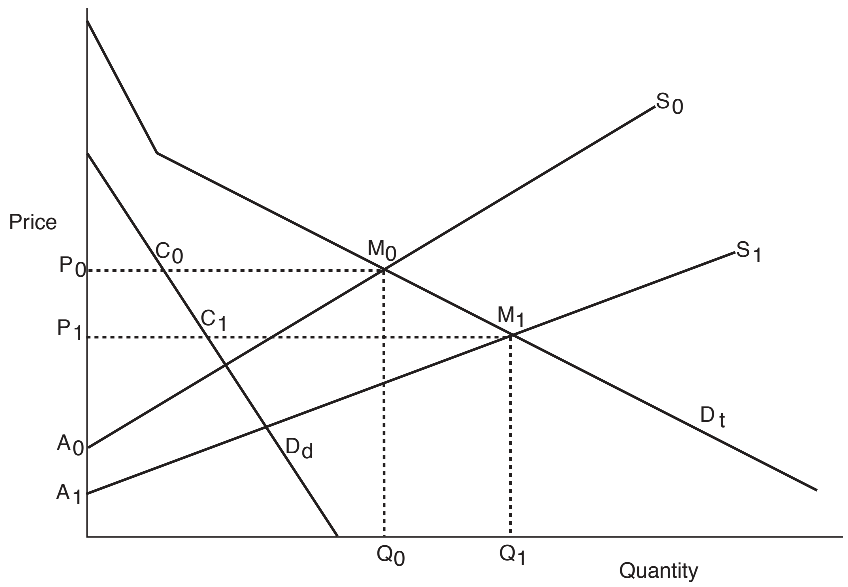

Figure 3. Benefits from a shift in beef supply due to additional animal health information in a free market with exports.

Total benefits due to a shift in supply are represented by the area $A_0M_0M_1A_1$. The change in consumer surplus is area $P_0M_0M_1P_1$, of which $P_0C_0C_1P_1$ goes to domestic consumers and $C_0M_0M_1C_1$ goes to consumers in the rest of the world. The change in producer surplus equals the total change less the change in consumer surplus or $A_0M_0M_1A_1$ minus $P_0M_0M_1P_1$.

The effects of a parallel shift in supply with this type of model were assessed by Edwards and Freebairn (1984). They determined that a country's producers will always gain from a parallel supply shift when costs in the rest of the world are not affected. A reduction in costs confined to a country comprising part of a market will reduce price by less than the reduction in costs unless demand in the market as a whole is completely inelastic and supply in the whole market is perfectly elastic. Edwards and Freebairn (1984) also demonstrated that when the country being examined accounts for 20% or less of world production, and the shift in supply occurs in both the country and the rest of the world, the country's producers will benefit as long as the ratio of reduction in costs in the country to reduction in costs in the rest of the world is greater than 1:4. This means that while producers in a country gain little when, for example, animal health information reduces costs in the rest of the world as well as their own costs, they will only lose from such a shift if cost reductions in the rest of the world are considerably larger than their own.

This information can be used to estimate whether domestic producers will benefit from a supply shift when product is exported into a free market. As demonstrated in Section 2, both Australia and Thailand meet the criteria of a small producer country as defined by Edwards and Freebairn (1984). Therefore, Australian and Thai beef producers would be expected to benefit from a parallel shift to the right in supply if the additional animal health information only increases efficiency in Australia or Thailand respectively. Australian and Thai consumers would not receive any benefit in a free market. Because these countries are small producers on an international scale, a small increase in beef production in either country would be expected to have only a small impact on the total amount of beef produced in the world and therefore a small impact, if any, on the world price of beef.

Effect of a shift in supply for an exporting country when an import restriction is in place

This section examines the effect of a quota or import restriction imposed by an importing country on domestic economic surplus following an improvement in the efficiency of beef production. The situation for a small producing, exporting country is examined where exports are into a single large overseas market. This is the situation for Australia exporting beef into the USA market.

The effect of a production quota on distribution of benefits when a country is a large exporter of a good was examined by Alston et al. (1988). They determined that all benefits from an improvement in efficiency of production accrued to producers and quota holders while domestic consumers did not receive any benefits.

Figure 4 presents the effects of an import quota on beef demand curves. In Figure 4, D_o represents demand in the USA market. The import restriction limits USA market demand to Q_q. The total demand curve is D_{tq} and is made up of the sum of domestic and restricted USA demand curves. All product sold into the USA market is sold at the USA market price and demand in the USA market is elastic. In the situation of the small producing country, the import quota will not be filled while the domestic price exceeds the overseas market price (p). Once the domestic price equals the USA market price, the import quota would be filled. While the quota is being filled, the price would not vary as the quantity exported from Australia would not have a discernible impact on total supply in the market and, therefore, would not affect the USA price. When the import restriction is filled, increased supply would cause the price to fall because the market would be again be restricted to the domestic market.

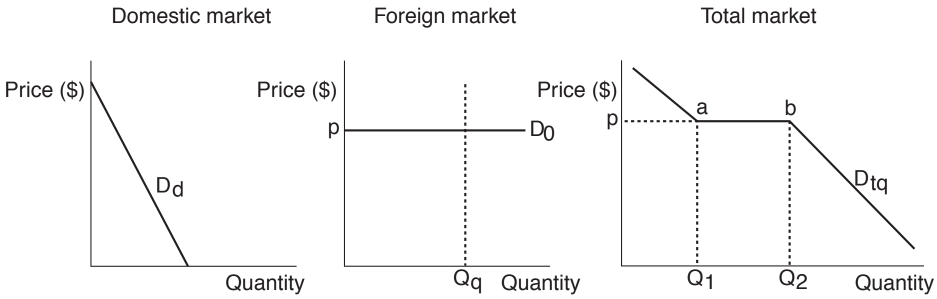

Figure 4. Effects of an import quota on beef demand for a small producer exporting into a large market.

Figure 5 illustrates combined domestic and trade demand curves with an import quota in place and the effects of a shift to the right in supply. In this situation, total benefits due to a shift in supply are represented by area $A_0M_0M_1A_1$. The total increase in consumer surplus is area $P_0M_0M_1P_1$. The increase in domestic consumer surplus is area $P_0C_0C_1P_1$. The area $C_0M_0M_1C_1$, which is total consumer surplus less domestic consumer surplus would not accrue to the consumers in the USA because the price in the USA would not change. This benefit would instead go to holders of quotas.

The change in producer surplus equals the change in total benefit less the change in consumer surplus or $A_0M_0M_1A_1$ minus $P_0M_0M_1P_1$. Whether producer surplus increases or decreases would depend on the type of shift in the supply curve and the elasticity of supply. With a pivotal shift in supply, it is possible that producer surplus would decrease with an import quota in place.

The examination reported in this section suggests domestic consumers would benefit from a shift to the right in supply where import restrictions are in place in the overseas market, because once import restrictions are filled the domestic price would fall. The effect on producer surplus is less clear.

With a quota in place and with inelastic supply the domestic price would fall (as illustrated in Figure 5). Under these circumstances it is probable that most benefits from a shift in supply would go to the holders of quotas and domestic consumers. The effect of the shift on beef producer surplus is uncertain and dependent on the type of shift in supply. It is possible that domestic producers may not benefit unless they are the holders of quotas.

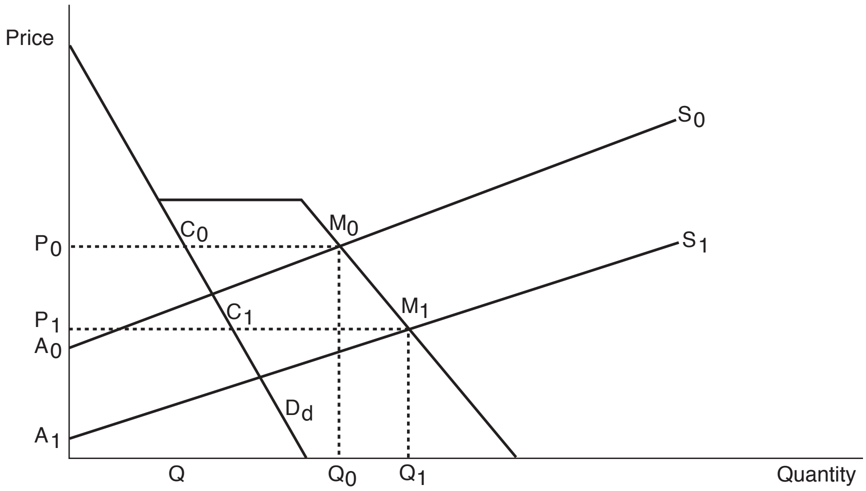

Figure 5. Effects of a quota on distribution of domestic benefits following a shift in beef supply to the right.

If the export market is smaller, as is the case for Australia exporting into the Canadian market, it is possible that the export price will fall as the quota is filled because enough product is exported to affect the export market price. This effect is illustrated in Figure 6. Provided the price decrease is not large the effect on the distribution of benefits would be small and similar to the situation depicted in Figure 5.

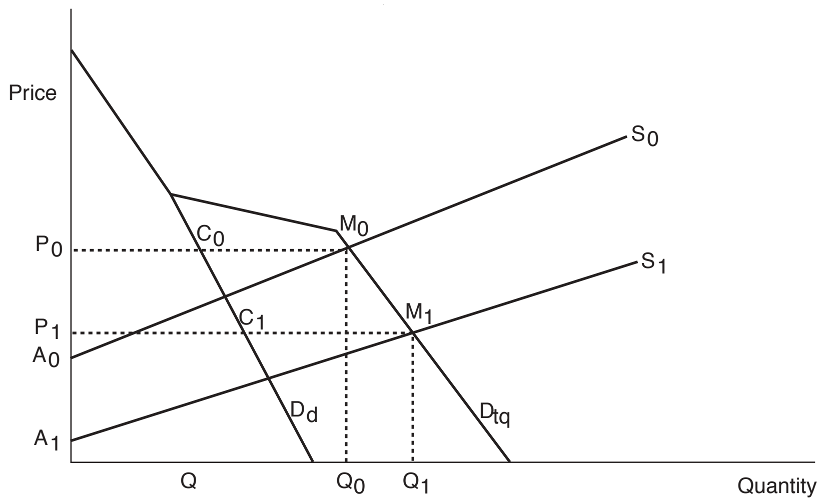

Figure 6. Effect of a quota on the distribution of domestic benefits following a shift to the right in beef supply where the export price decreases as the quota is filled

Change in Producer Surplus after Collection of Additional Information on Disease Caused, for Example, by *Babesia bovis*

As demonstrated above, the type of shift in supply plays an important role in determining whether producer surplus increases or not as a result of that shift. In this section, a general comment on the possible effects of extra animal health information on beef supply is made. The distributional effect of the use of additional information on the incidence of disease caused by *Babesia bovis* is then examined.

Use of additional animal health information to improve the efficiency of beef production would probably result in a shift in the Australian beef supply curve to the right that would be divergent if the disease occurred throughout Australia. This is because many producers are already making appropriate decisions either to control or not control a disease and the additional information will not improve efficiency. It is also likely that producers currently controlling a disease appropriately are the more efficient, lower cost farmers producing at the left of the supply curve and referred to by Lindner and Jarrett (1978) as inframarginal producers. Therefore, producers who are not making an appropriate decision will benefit most from the additional information, and these are probably the less efficient, marginal producers producing at the right of the supply curve (Lindner and Jarrett 1978).

The possible effect of additional information about disease caused by *B. bovis* in Central Queensland is now examined. Disease caused by *B. bovis* occurs only in areas where the vector *Boophilus microplus* is present. Therefore, additional information on *B. bovis* would not be used by producers or affect the supply of beef outside the area where *B. microplus* occurs. If producers in Central Queensland, where disease caused by *B. bovis* occurs are inframarginal producers on the Australian beef supply curve, then the shift in supply following the use of additional information on disease caused by *B. bovis* would be convergent. In this situation, using the model developed above, producers would gain from the shift, with an increase in producer surplus. If, however, producers in Central Queensland are marginal producers then the shift in supply is likely to be divergent and it is possible producer surplus will decrease.

Change in Economic Surplus with the Opening of New Export Markets

Livestock diseases have been recognised as having large potential costs in terms of export markets lost. International recognition of disease-free status in relation to particular diseases can result in increased export opportunities and potential for large economic benefits. This is the situation for Thailand should foot-and-mouth disease be eradicated.

The effects of improved animal health are considered in this section with respect to two scenarios. First, while improved animal health would be expected to reduce production costs, moving supply to the right, the price effect could be more than offset by increased exports resulting in increased domestic prices (Harrison and Tisdell 1995). Figure 7 depicts the impact on economic surplus of improved animal health resulting in new trade opportunities with an associated increase in price. The result in the example illustrated would be a reduction in domestic consumer surplus from $P_2P_0M_0$ to P_2P_1m and an increase in producer surplus equivalent to $P_1M_1A_1$ less $P_0M_0A_0$.

Second, in some situations the price effect from access to an expanded market may not be offset by increased exports and it is possible for both domestic producers and consumers to benefit if animal health improvement opens new markets. Such a situation is illustrated in Figure 8 where domestic consumer surplus would increase from $P_2P_0M_0$ to P_2P_1m. Domestic producer surplus would also increase to $P_1M_1A_1$ less $P_0M_0A_0$, considerably more than the increase in producer surplus expected without opening new markets.

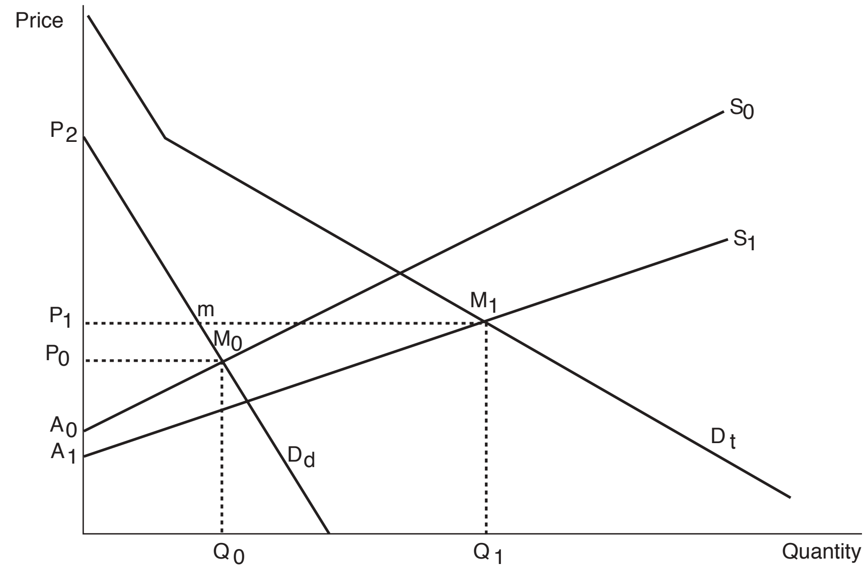

Figure 7. Change in consumer and producer suplus resulting from access to a new export market.

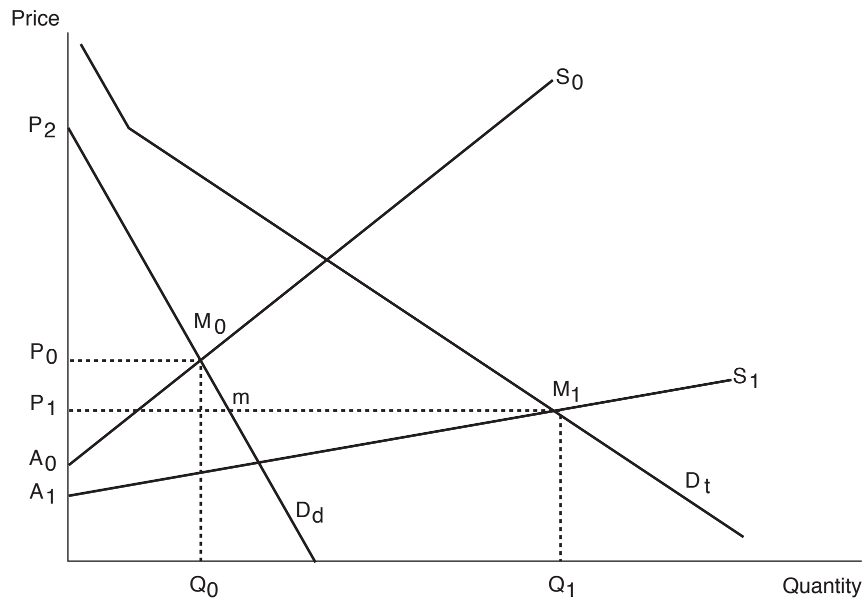

Figure 8. Change in economic surplus resulting from access to a new export market where consumer surplus increases.

Conclusions

The analysis carried out in this chapter demonstrates the difficulties in determining the distribution of benefits from improved animal health and the need for an economic analysis to determine the beneficiaries. The particular distributional consequences of progress to improve the health of livestock depend on economic market parameters. Several factors affect distribution of benefits, including the type of shift in supply, presence of trade restrictions, elasticity of supply and demand, and whether new export markets are opened as a result of improved animal health. These factors need to be considered in any analysis because, for example, the type of shift determines whether producers benefit, while opening new export markets can reduce domestic consumer surplus.

Further development of the analysis described in this chapter to enable its use in economic analysis of animal health programs needs to be carried out, and definition of the effects of improved animal health on the size and distribution of benefits under different trading conditions would be of interest.

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