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Decision Support Systems in Animal Health

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1. Introduction

The safety of food derived from animals has received significant public media attention in recent times and it is likely that this trend will continue in the short to medium term future. Examples of diseases in humans arising from the consumption of animals or animal products at the centre of recent food safety scares include variant Creutzfeld-Jakob disease (Anonymous, 2000), *Salmonella Typhimurium* DT104 (Threlfall et al., 1994), *Salmonella Enteritidis* (Anderson, 1996) and *Escherichia coli* O157 (Rangel et al., 2005). Of additional concern to the general public are infectious diseases of livestock, particularly those that have required large numbers of animals to be pre-emptively slaughtered or culled as part of control and eradication measures. Since 2000 there have been a number of large outbreaks of infectious disease in farmed animal populations that have been managed using pre-emptive slaughter or culling. This approach to disease management has raised questions about the legitimacy, ethics and long term future of intensive farming practices. Examples include the outbreak of classical swine fever (CSF) in The Netherlands in 2000 and foot-and-mouth disease (FMD) in the United Kingdom in 2001. Infectious disease has impacted heavily on the health and productivity of livestock populations in Southeast Asian countries in recent times. Highly pathogenic avian influenza (HPAI) H5N1 has emerged as a disease of international concern not only because of its ability to cause illness and death in poultry and humans, but also by its capacity to disrupt poultry trade and to threaten food security in resource-poor countries.
To deal with infectious disease outbreaks in domestic livestock populations quickly and efficiently it is essential that animal health authorities have access to appropriate information to guide decision making. Animal health information includes (but should not be restricted to) details of the population at risk and details of incident cases of disease conditions of interest. This information allows the distribution of disease to be described in terms of the established epidemiological triad of individual, place and time. Individual animal-level analyses include estimates of the number of cases per head of population and for various subsections of the population (e.g. animals of a given age, sex, breed or type). Spatial analyses provide insight into geographical factors influencing the distribution of disease (e.g. proximity to pollutants, farming practices characteristic of a given area). Temporal analyses provide insight into short and long term variations in disease frequency. All three categories of analysis are useful in that firstly they provide an objectively measured point of comparison once control measures have been implemented and secondly, they provide information that can be used for hypothesis generation about factors associated with, or causing disease. Collection of additional information about the environment in which animals are located and events they

are exposed to over their lifetime allows these hypotheses to be tested which in turn allow authorities to identify risk factors for disease. Concentrating surveillance and control activities on animals or farm premises with identified risk factors then allows (often scarce) resources to be more effectively targeted at the sector of the animal population in greatest need of attention.
In this chapter we provide an overview of the infrastructure required to carry out the analytical procedures outlined above using an animal health decision support system (DSS). The chapter is divided into three main sections. In the first we provide a description of an animal health DSS and review DSSs currently in operation in various countries throughout the world. In the second we provide a description of how these systems are implemented in developing countries. The third and final section looks to the future, briefly outlining the planning that should be done by developing countries to ensure that current animal health DSSs continue to meet their needs well into the future. We conclude by proposing that a standardised format for recording and storing animal demographic, productivity and health data needs to be agreed on. Widespread adoption of this format will help to make animal health DSS components more readily transferable from one jurisdiction to another, ultimately reducing their cost and in doing so helping alleviate one of the important obstacles to more widespread uptake of this technology.

2. Animal health decision support systems currently in use

A DSS is an interactive, flexible and adaptable system (including, but not limited to, computer-based systems) comprised of relevant databases, technologies and appropriate analytical techniques to identify problems, predict consequences and provide solutions for improved decision making (Turban, 1995). An animal health DSS should have two main goals. The first is to provide authorities with the ability to trace animals from 'farm to fork', an essential requirement for food safety and documenting health status for domestic and international trading partners. The second is to provide a means to detect the emergence and re-emergence of diseases, allowing appropriate deployment of field operations and resources to deal with identified problems if and when they occur. Such a system promotes transparency in the state of animal health, allowing animal health policies to be based on the best available evidence.
A key component of an animal health DSS is a so-called 'data warehouse' which provides the facilities to capture, store and link all relevant information about an animal population of interest (Figure 1). Relevant information in this context includes demographic details of the population at risk, details of where that population resides, disease events, and the results of laboratory and residue analyses. We acknowledge that most (if not all) countries producing food from animals already have established facilities to record some, or even all, of this information. The key feature that distinguishes a DSS is that the various tables listed in Figure 1 are linked using unique individual animal and/or farm identifiers to form a coherent relational database design. This allows the analyst to easily extract details of (for example) diseased animals, their location of origin and the identities of farm locations they might have visited throughout their lifetime. At the population level, the burden of disease in an animal population can be quantified in terms of incidence and prevalence. Maps of the distribution of diseased animals can be produced and interpreting in context of the distribution of the population at risk. An additional requirement of a DSS is that it needs to be both flexible and user friendly for those interrogating the system and those interpreting the information it produces.

EpiMAN (Sanson, 1993) is an early example of an animal health DSS with a data architecture similar to that shown in Figure 1. The system combines a database management system, a geographic information system, a graphic user interface to allow the user to conduct descriptive analyses of infectious disease outbreak data, manage resources (e.g. scheduling of patrol visits) and run a simulation model to evaluate the effect of alternative control measures. EpiMAN was originally developed to manage data that would be generated during the course of an outbreak of FMD. The motivation for doing this was that timely analysis of outbreak event details would allow control and eradication activities to be fine-tuned as the epidemic progressed, as individual circumstances dictate (Sanson et al., 1999).

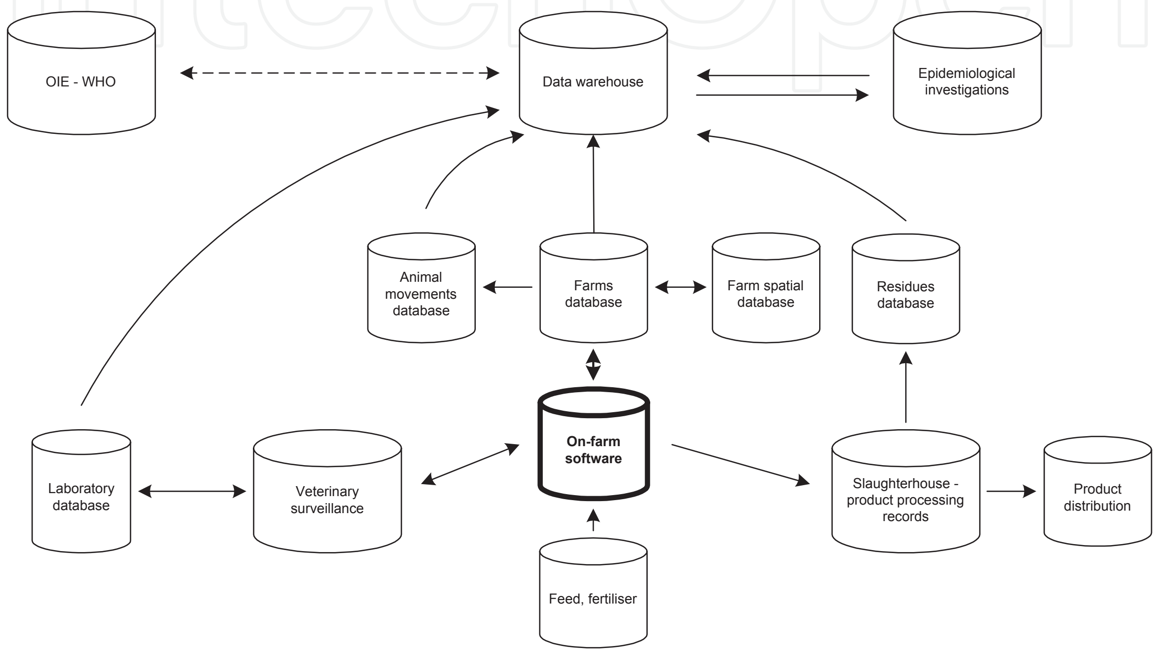

Fig. 1. Schematic diagram showing how on-farm data, veterinary practice records, diagnostic laboratory data, slaughterhouse processing records, details of residue assessments and animal movements might be integrated within an animal health decision support system (Morris, 1997; Stevenson et al., 2007). OIE = Office International des Epizooties; WHO = World Health Organization. Reproduced with permission from the New Zealand Veterinary Journal.

Another, more recently developed animal health DSS is the Rapid Analysis and Detection of Animal-Related Risks (RADAR)[1] system which has been in operation in the United Kingdom (UK) since 2003 (DEFRA, 2011; Lysons et al., 2007; Paiba et al., 2007; Scudamore, 2003; Smith et al., 2006). RADAR brings animal health and demographic data together in a standardised format to support research and the reporting requirements of a wide group of stakeholders. RADAR integrates data sets from existing systems and transforms them into a common coding system called the extraction, transformation and loading process. The system derives additional information from raw source data automatically using a variety of calculations and algorithms with metadata fully adherent to the UK government's e-Government Metadata Standards (Roberts, 2004).

[1] URL: `http://www.defra.gov.uk/foodfarm/farmanimal/diseases/vetsurveillance/radar/index.htm`

Before RADAR animal health information in the UK was collected and stored by different authorities using different nomenclatures, collection standards and coding systems. This meant that collation of information was slow and integration of different data sources difficult (Morris et al., 2002). The RADAR project has been conducted in three phases. The first (2003-2005) focused on the establishment of the data warehouse managing details of the cattle population, details of salmonella and exotic disease cases and analytical tools. The second phase (2005-2006) enhanced data cataloguing and reporting tools and extended the scope of data collection to other species (sheep, pigs, goats, and deer) and other diseases. This information has been used for the investigation and control of a range of animal health issues such as surveillance for salmonella in dairy cattle and poultry (Evans & Jordan, 2003), cattle movement patterns (Vernon & Keeling, 2009), bovine tuberculosis (Green et al., 2008), bluetongue (Wood et al., 2008), avian influenza (Knight-Jones et al., 2010) and FMD (Paiba et al., 2007). The third and final phase (2006-2013) expanded species coverage to include horses, companion animals and wildlife (Smith et al., 2006). An example report from RADAR is shown in Figure 2. Figure 2 shows the density of poultry premises (expressed as the number of premises per 100 km^2) throughout Great Britain. By simply identifying the location of the poultry population at risk animal health authorities are better placed to carry out a range of activities to maintain poultry health: identify high risk areas for disease transmission, target surveillance activities and monitor poultry movement.

In 2002 the Swiss government funded development of a system titled KODAVET (*Koordiniertes Datenverwaltungs und Analysesystem des Veterinärdienstes Schweiz*), subsequently renamed ISVET (Presi & Heim, 2010). The purpose of the system is to manage information related to both food producing and companion animals (Schaller, 2006; Stärk et al., 2006). Unique, individual animal identifiers and mandatory reporting of livestock movement events mean that animals can be tracked through the system throughout their lifetime. A feature of ISVET is that it provides a standardised facility for generating and storing health certificates for producers as well as scheduling routine inspection visits by Swiss Federal Veterinary Office staff. The system links a number of databases, including those from local veterinary offices in the cantons, the National Animal Movement Database and the National Database of the Federal Office of Agriculture. This project is on-going and has provided information useful for decision making and efficient use of resources (Swiss Federal Veterinary Office, 2009).

Partial animal health DSS systems exist in a number of countries such as Australia (The National Livestock Identification System)[2] (DAFF, 2006), Argentina (The Sanitary Management System database, maintained by the National Service for Agrifood Health and Quality, SENASA), and New Zealand (AgriBase[3] Sanson & Pearson, 1997). In Brazil the *Serviço de Rastreabilidade da Cadeia Produtiva de Bovinos e Bubalinos* (SISBOV)[4] provides the facility to register all cattle and buffalo born in Brazil or imported into the country since July 2002 (Bowling et al., 2008; Cardoso & Cardellino, 2004). The primary purpose of SISBOV is to allow tracing of registered individuals to meet international market requirements. The system provides the government with information to enhance the control of cattle herds, particularly management of FMD free zones and high risk areas.

The examples cited here are by no means exhaustive and the reader is referred to Stevenson et al. (2007) for a more detailed review and critique of systems in place within individual countries. A key point is that while most countries producing food derived from animals

[2] URL: https://www.nlis.mla.com.au/
[3] URL: http://www.asurequality.com/geospatial-services/agribase.cfm
[4] URL: http://extranet.agricultura.gov.br/primeira_pagina/extranet/SISBOV.htm

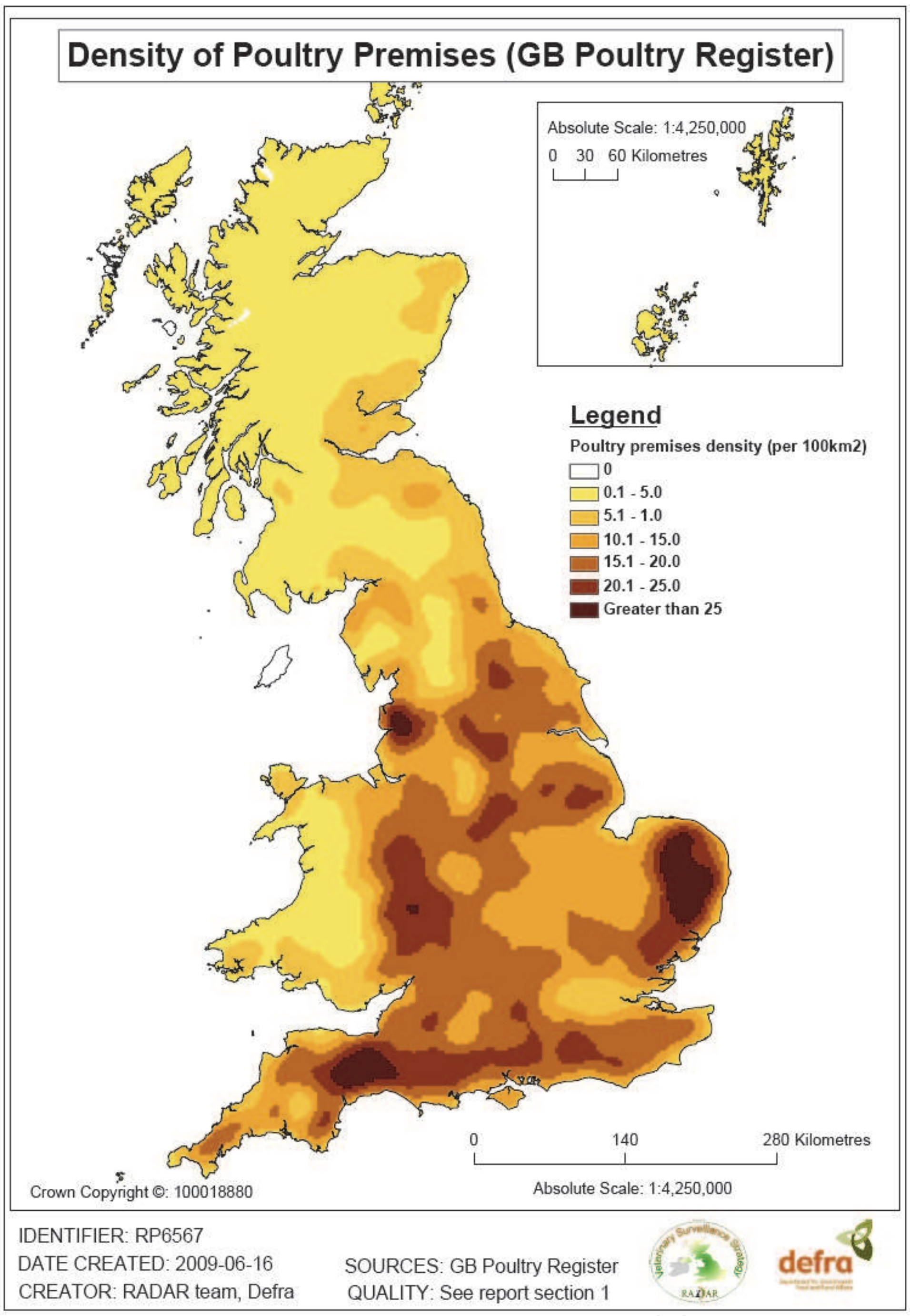

Fig. 2. Map of Great Britain showing the density of poultry premises (expressed as numbers per 100 km^2).

for export have components of a DSS in place few, if any, are capturing and using all of the data elements shown in Figure 1. The reason for this is that individual system components are expensive and time consuming to implement, requiring substantial changes in infrastructure and behaviour of users of the system. For example, implementation of an animal movement database means that livestock producers are no longer able to freely move animals from one location to another. Systems need to be established to issue movement permits as well as a mechanism to police the system to ensure that all movement events are recorded and appropriate penalties are applied to those that ignore system directives. Substantial information technology infrastructure needs to be built to record and store collected information and finally, facilities need to be put in place to retrieve and analyse data that is actually recorded. Given the time and expense required to set up workable system components we predict that it will take a number of years before 'full' DSSs become commonplace. A powerful facilitator of progress has, in the recent past, been exotic infectious disease outbreaks and the emergence of novel disease conditions such as bovine spongiform encephalopathy and HPAI H5N1. It is likely that progress in this area will be driven by a need to deal with these types of hazards in the short to medium term future.

3. Animal health decision support systems in developing countries

The key difference between developed and developing countries in terms of recording of animal health information is that developing countries often lack a system for identifying and recording the location of individual farm enterprises. A second point of difference is that recording of disease event information in developing countries is generally restricted to diseases classified as List A by the OIE.

Because sampling frames listing the identity of individual farm enterprises are not available in developing countries it is common for animal health details to be aggregated at the tertiary administrative unit level. In the case of Vietnam (for example) this is the commune. In the outbreaks of HPAI H5N1 that have occurred in Vietnam since December 2003 the commune has been the official unit of interest to define outbreak locations (MARD, 2005; Pfeiffer et al., 2007; Phan et al., 2009).

Similar area-based systems are in use in other Asian countries. For example, in the recent outbreaks of HPAI H5N1 in Thailand the location of affected flocks was assigned at the village level using codes managed by the Thai Department of Livestock Development. These details were then aggregated to provide summaries at the sub-district level, as shown in Figure 3 (see also Tiensin et al. 2007 and Tiensin et al. 2009 for examples). In the early days of the epidemic of HPAI H5N1 in Indonesia outbreak details were recorded at the district (secondary administrative unit) level (Gilbert et al., 2008; Pfeiffer, 2006). Modifications to the Participatory Disease Surveillance and Response (PDSR) database now allow disease event information to be recorded at the individual *desa* (village) level (Perry et al., 2009).

A number of factors work against animal health authorities in developing countries in terms of the amount and level of detail of animal health information able to be routinely recorded. The first is that the majority of production units are small-scale and managed at the individual household level. For example, backyard poultry are ubiquitous in many Southeast Asian countries such as Cambodia, Lao PDR, Thailand, Vietnam and Indonesia. In addition, the distribution of backyard herds and poultry flocks (in particular) are under a constant state of change as stock are frequently moved and sold. Rural areas, where animal disease problems tend to be greater, are characterised by poor communication networks and transport infrastructure (Baldock et al., 1999). Livestock owners are therefore often unable to contact veterinary staff and it is difficult for veterinary staff to access livestock, which means that provision of services and collection of the necessary information related to outbreak events is either delayed or non-existent.

The Transboundary Animal Disease Information System (TADinfo),[5] developed by the Food and Agriculture Organization of the United Nations, provides an off-the-shelf and flexible

[5] URL: `http://www.fao.org/ag/againfo/programmes/en/empres/tadinfo/about.html`

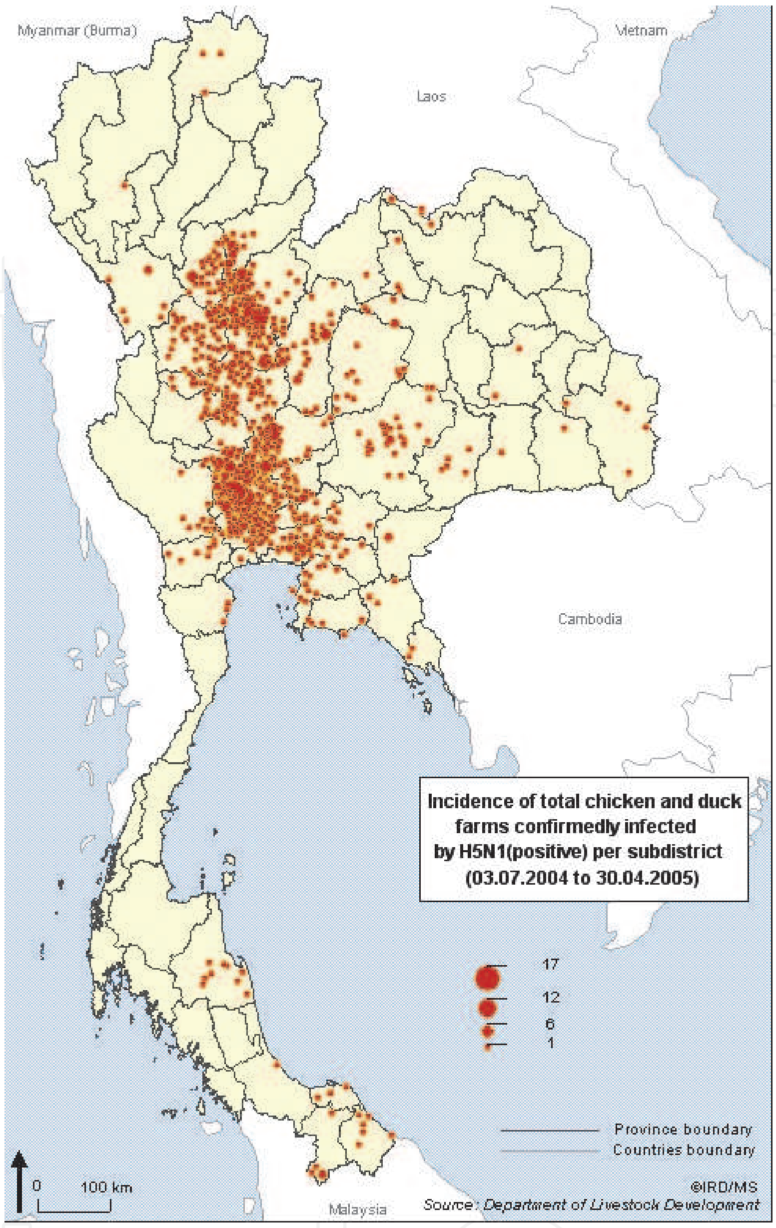

Fig. 3. Map of Thailand showing the incidence of chicken and duck farms confirmed with HPAI H5N1, by sub-district (Souris et al., 2010). Reproduced with permission from the International Journal of Health Geographics.

solution for recording many of the items listed in Figure 1 (Kamata et al., 2006; 2009). The system is fully customisable, combining a relational database with a mapping system that allows users to record details of disease observations, abattoir surveillance, livestock census details and vaccination records. The smallest unit of interest within the system is user defined with typical choices being either the individual farm or small area (such as the village).

Choice of an appropriate unit of interest at the time TADinfo is deployed is important. If, for example, a country initially uses the small area (e.g. village) as the unit of interest and then, at some later date decides to change over to a system based on individual farms data incompatability issues will arise: inference about disease risk at the individual farm level cannot be made using aggregated data. On the other hand, switching from an individual farm-based system to one based on small areas (while uncommon) presents little problems since it is straightforward to aggregate farm details to the small area level. These issues need to be thought through carefully by animal health authorities at the time these systems are first implemented. In particular, consideration needs to be given to the likely animal health information needs of the country 10-15 years into the future as well as immediate requirements.

4. The future

In developed countries a major focus of animal health is to maintain food safety and provide transparent evidence of a country's disease status for the purpose of international trade. In developing countries, on the other hand, animal health activities tend to mainly concentrate on the control and management of infectious diseases such as FMD, CSF and HPAI H5N1. Some countries, such as Thailand, are at a crossroad exporting food of animal origin (chicken meat) to other countries (Bowles et al., 2005) while at the same time having to deal with infectious disease outbreaks affecting predominantly backyard livestock enterprises. It is likely that many developing Asian countries will follow in the footsteps of Thailand, moving away from predominantly subsistence farming to becoming exporters of animal product. For this development to progress smoothly it is essential that a credible track record in food safety is developed and maintained so these issues do not become a future trade barrier. On-farm use of pesticides, anthelmintics, antibiotics and fertilisers are details that could be recorded within a DSS, providing a means for monitoring usage trends which might then allow steps to be taken to avoid unacceptable chemical residue concentrations being held up as a future trade barrier (Theresa Bernardo, personal communication). Developing countries therefore need to develop a planned approach to data management, recognising that over time there will be a need to move away from using animal health data to control infectious disease outbreaks towards documentation of disease and chemical residue status to trading partners and consumers.

Given the expense of designing and implementing DSS components we propose that a standardised format for recording and storing animal demographic, productivity and health data needs to be agreed on. Widespread adoption of this standard will help to make animal health DSS components more readily transferable from one jurisdiction to another, ultimately reducing their cost and in doing so helping to alleviate one of the important obstacles to more widespread uptake of this technology.

Just as, if not more important, than the development of the technology and infrastructure for data collection, it is vital to provide veterinary staff (particularly those in developing countries) with the appropriate analytical skills so that maximum value is derived from data that are actually collected. As an example, extremely large numbers of records are collected by animal movement databases, even in countries of moderate size. One of the skills required when analysing this data is the ability to summarise movements at the national level and then to 'drill down' on specific areas of interest identified from summary analyses (Aznar et al., 2011; Martínez-López et al., 2009). Extracting the maximum value out of animal movement data sets requires a range of analytical skills including epidemiology, social network analysis, and spatial statistics. Other analytical procedures, for example the design of disease surveillance strategies, rely on a different skill set including knowledge of sampling theory and economics.

Issues related to system sensitivity and specificity arise when DSSs are used to detect emerging diseases in an animal population. If the analyst is too sensitive in terms of declaring a pattern of disease events as indicative of an emerging syndrome investigative resources will be wasted. If, on the other hand, the system is too specific then it is possible that emerging syndromes that should have been identified and acted upon will be missed. In order to 'get the balance right' it is essential that those involved in the analysis of DSS data are given the opportunity to become familiar with the natural pattern of disease within a given country, particularly its temporal (e.g. seasonal) and spatial features. Our only suggestion here is that these skills take many years to develop and part of the costing of implementing a DSS should include a component to select, train and appropriately renumerate skilled system analysts. Regular and ongoing collaboration with relevant stakeholders is important to maintain consistent data quality and to refine outputs so that literally, numbers can be turned into knowledge.

5. Conclusions

A decision support system of the type described in this chapter provides authorities with a valuable resource for recording, validating, storing and analysing animal health data. Outputs from such systems can be used to manage and control outbreaks of infectious disease in animals, identify factors associated with the presence of disease, provide an objectively measured point of comparison once control measures have been implemented and provide an additional means to detect emerging disease syndromes.

As we have shown, a DSS is comprised of a number of components, some of which are expensive and time consuming to implement. For this reason, the current situation is that many food producing countries throughout the world have individual components of a full system in place and fully operational systems are the exception rather than the rule.

Unlike the situation in developed countries, developing countries tend to use DSSs for the management and control of infectious disease outbreaks with data typically aggregated at the small area level. Animal health managers in developing countries should be aware that, over time, focus will shift away from management and control of infectious diseases towards food safety and transparent documentation of animal disease status. A planned approach to animal health data management is therefore required, inevitably meaning that the unit of interest of DSSs need to shift away from the small area level to that of the individual producer.

Given the expense of designing and implementing DSS components we propose that a standardised format for recording and storing animal demographic, productivity and health data needs to be agreed on. Widespread adoption of this format will help to make animal health DSS components more readily transferable from one jurisdiction to another, ultimately reducing their cost. Just as important is the need to provide veterinary staff with the appropriate analytical skills so that maximum value is derived from the data actually collected.

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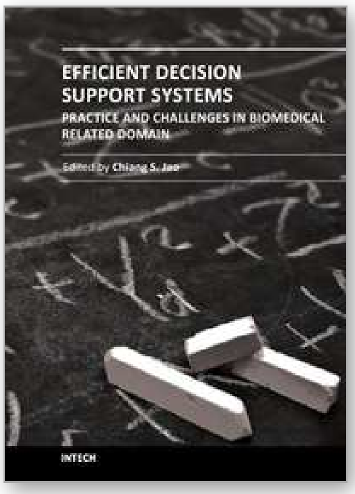

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