The Risk of Foot and Mouth Disease Entering China through the Movement of Animals from Upper Mekong Region Countries

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This thesis is presented for the degree of Doctor of Philosophy
Murdoch University, 2012
DECLARATION

I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution.

Signature_

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ABSTRACT

In the Greater Mekong Sub-region (GMS), Foot and Mouth Disease (FMD) is the most important trans-boundary animal disease affecting the livelihood of livestock owners. To contribute to the long term goal to control FMD in south-eastern Asia, the South East Asia and China FMD Campaign (SEACFMD) has been implementing a progressive control approach based on sound epidemiological inputs and principles. A major risk to the regional program is the emergence of new strains of FMD including the Pan-Asia topotype serotype O, the serotype type A and the serotype Asia 1 that was confirmed in China at the beginning of 2009.

Due to the rapid development of China, the price of meat and its demand have grown quickly over the past ten years. This trend has resulted in an increase in the number of livestock moving from south-eastern Asian countries to China. Although Chinese law and the import-export policy prohibit these movements, these informal movements pose a high risk of introducing new serotypes to China and spreading the disease to FMD free areas in China.

Prior to the study reported here, there was little information written in English concerning the development of veterinary science in China and the history of FMD outbreaks in the country. This study collected and analysed existing historical records of FMD in China, and hypothesised on the potential source of the disease for China. Subsequently, the study collected and analysed existing data on FMD from countries in the Upper Mekong Region to understand the disease’s epidemiological pattern. Epidemiological tools, such as Geographical Information Systems (GIS), risk
assessment and epidemiological modelling, were used to study the epidemiology and the patterns of FMD spread into Yunnan and Guangxi Provinces in China.

This epidemiological study was the first study to evaluate the risk posed by informal animal movements between countries in the Upper Mekong Region and China. It was designed to provide the epidemiological basis for progressing zone status for FMD in the Upper Mekong Region with particular emphasis on the Yunnan and Guangxi Provinces. A systematic analysis was undertaken to evaluate the compulsory vaccination policy in China. The opinions of Chinese veterinary workers were also collected to identify the current problems with the control of FMD in China.

Foot and Mouth Disease was probably introduced into China from Europe in the 19th century. However the research reported in this thesis found that the current highest risk to China was through the movement of animals along the Mekong River, compared to movement along alternative land routes. The two most important factors influencing this risk were: the prevalence of FMD in the exporting country; and the control strategy adopted in China. The current control of FMD in China is based on compulsory vaccination of livestock and the prohibition of livestock movements between south-eastern countries and China. Although the vaccination program has been very successful in China, with more than 70% of animals protected, this strategy requires significant amounts of government financial support and could be more effective if targeted to areas of highest risk. The results of this research indicate that it is not feasible or possible to prevent all livestock movements into China from neighbouring countries. It is recommended that an intensive FMD vaccination program is developed...
and implemented in the GMS to reduce the number of susceptible animals in the region.

It is also recommended that the movement of livestock/animal products between the Upper Mekong Region countries and China be legalised through the development of formal and appropriate import regulations. Adopting these practices and developing an active surveillance system should help reduce the spread of FMD within the Greater Mekong Sub-region.
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<td>AB-CRC</td>
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<td>ACIAR</td>
<td>Australian Centre for International Agricultural Research</td>
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<td>ADB</td>
<td>Asian Development Bank</td>
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<td>AgELISA</td>
<td>Antigen Enzyme-Linked Immunosorbent Assay</td>
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<td>ASEAN</td>
<td>Association of Southeast Asian Nations</td>
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<tr>
<td>BEI</td>
<td>Binary ethylenimine</td>
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<tr>
<td>BHK</td>
<td>Baby Hamster Kidney</td>
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<td>Brunei</td>
<td>The Nation of Brunei</td>
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<td>CBR</td>
<td>Cost Benefit Ratio</td>
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<td>C.I.Q</td>
<td>China Entry-Exit Inspection and Quarantine Bureau</td>
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<td>CFT</td>
<td>Complement Fixation Test</td>
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<td>China</td>
<td>People’s Republic of China</td>
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<tr>
<td>DIVA</td>
<td>Differentiation of Infected from Vaccinated Animals</td>
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<tr>
<td>EDA</td>
<td>Exploratory Data Analysis</td>
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<tr>
<td>ELISA</td>
<td>Enzyme-Linked Immunosorbent Assay</td>
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<td>EuFMD</td>
<td>European Commission for the control of Foot and Mouth Disease</td>
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<td>FAO</td>
<td>Food and Agricultural Organisation</td>
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<td>FMD</td>
<td>Foot and Mouth Disease</td>
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<td>FMDV</td>
<td>Foot and Mouth Disease Virus</td>
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<td>GDP</td>
<td>Gross Domestic Product</td>
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<td>GIS</td>
<td>Geographical Information Systems</td>
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<td>GMS</td>
<td>Greater Mekong Sub-region</td>
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<td>Guangxi Province</td>
<td>Guangxi Zhuang Autonomous Region</td>
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<tr>
<td>HPAI</td>
<td>Highly Pathogenic Avian Influenza</td>
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<td>LAMP</td>
<td>Loop Mediated Isothermal Amplification</td>
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<tr>
<td>LAOS</td>
<td>Lao People's Democratic Republic</td>
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<td>LFD</td>
<td>Lateral Flow Device</td>
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<td>LPBE</td>
<td>Liquid-Phase Blocking ELISA</td>
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<td>LSD</td>
<td>Least Significant Difference post-hoc test</td>
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<td>mAb</td>
<td>Monoclonal Antibodies</td>
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<td>MOA</td>
<td>Ministry of Agriculture of the People's Republic of China</td>
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<td>mPCR</td>
<td>multiplex Polymerase Chain Reaction</td>
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<td>MTM</td>
<td>Malaysia-Thailand-Myanmar region</td>
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<tr>
<td>NCBI</td>
<td>National Center for Biotechnology Information</td>
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<td>NIH</td>
<td>The National Institute of Health (United States of America)</td>
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<td>NSPs</td>
<td>Nonstructural Proteins</td>
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<td>OIE</td>
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<td>OIE RCU</td>
<td>Office International des Epizooties Regional Coordination Unit</td>
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<td>OIE SRR</td>
<td>OIE Sub-Regional Representation</td>
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<td>PCP-FMD</td>
<td>Progressive Control Pathway for Foot and Mouth Disease</td>
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<td>PCR</td>
<td>Polymerase Chain Reaction</td>
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<td>PLA</td>
<td>The Peoples’ Liberation Army</td>
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<td>RRL</td>
<td>Regional Reference Laboratory</td>
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<td>RT-LAMP</td>
<td>Reverse Transcription-Loop Mediated Isothermal Amplification</td>
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<tr>
<td>RT-PCR</td>
<td>Reverse Transcription-Polymerase Chain Reaction</td>
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<td>SEA</td>
<td>South East Asia</td>
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<td>SEACFMD</td>
<td>OIE South East Asia and China Foot and Mouth Disease Campaign</td>
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<td>SEAFMD</td>
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<tr>
<td>Singapore</td>
<td>The Republic of Singapore</td>
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<td>SRR</td>
<td>OIE Sub-Regional Representation</td>
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<td>SRR SEA</td>
<td>OIE Sub-Regional Representation for South East Asia</td>
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<tr>
<td>TAD</td>
<td>Trans-boundary Animal Disease</td>
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<td>UMWG</td>
<td>Upper Mekong Working Group</td>
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<td>US$</td>
<td>United States of America dollar</td>
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<td>VI</td>
<td>Virus Isolation</td>
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<tr>
<td>VNT</td>
<td>Virus Neutralization Test</td>
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<tr>
<td>WRL</td>
<td>World Reference Laboratory</td>
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<td>WRLFMD</td>
<td>World Reference Laboratory for Foot and Mouth Disease</td>
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<tr>
<td>YASVI</td>
<td>Yunnan Animal Science and Veterinary Institute</td>
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<tr>
<td>YTSAVDL</td>
<td>Yunnan Tropical and Subtropical Animal Viral Disease Laboratory</td>
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Chapter 1. General Introduction
Chapter 1. General Introduction

1.1 Disease Background

Foot and Mouth Disease (FMD) is a highly contagious epizootic disease which has had a devastating effect on animal industries for many centuries (Mahy 2005). The aetiological agent of the disease is Foot and Mouth Disease Virus (FMDV) which belongs to the Aphthovirus genus of the family Picornaviridae. Seven serotypes of FMDV have been identified which contain numerous subtypes and topotypes (Rodriguez and Gay 2011). Importantly immunity induced by infection or vaccination against one serotype, subtype or topotype does not confer immunity to infection against other serotypes, subtypes or topotypes (Rowlands et al. 1983).

Foot and Mouth Disease Virus can affect all cloven-hoofed animals including domesticated animals such as pigs, sheep and cattle, and more than 70 species of wild artiodactyls such as camel and deer (Bachrach 1985; Gibbs et al. 1975; Wernery and Kaaden 2004). One important reason for FMD being considered an A-class contagious viral disease by the World Organisation for Animal Health (OIE) is that FMDV can spread quickly by a variety of ways. Historically FMD has been recorded in all livestock-containing regions of the world, although many countries have eradicated the disease (Grubman and Baxt 2004).

The methods for diagnosing FMD include recognition of the characteristic clinical signs in affected animals and laboratory tests (Reid et al. 2000). The diagnostic techniques recommended by OIE include agent isolation technologies, such as virus isolation, the
enzyme-linked immunosorbent assay (ELISA) and nucleic acid recognition methods (polymerase chain reaction (PCR) assays), and serological tests technologies such as the virus neutralisation test, solid-phase competition enzyme-linked immunosorbent assay, liquid-phase blocking enzyme-linked immunosorbent assay, and nonstructural protein (NSP) antibody tests (OIE 2012b). The disease control strategies applied are usually focused around the rapid diagnosis of the disease, implementation of quarantine and restriction in the movement of livestock and livestock products, adoption of suitable vaccination procedures, and a thorough understanding of the epidemiological pattern of the disease (Edwards 2004).

1.2 Research Background

Although FMD is currently found on every continent, except for Northern America, Antarctica and Australia Oceania, it is now a goal to eradicate the disease from the world (FAO and OIE 2012). The research reported in this thesis was jointly supported by the OIE South East Asia and China Foot and Mouth Disease (SEACFMD) Campaign, the Australian Centre for International Agricultural Research (ACIAR, project AH/2006/025), the Australian Biosecurity Cooperative Research Centre (AB-CRC), Murdoch University, and Yunnan Animal Science and Veterinary Institute (YASVI). This research was designed to further the understanding of FMD in south eastern Asia, with an emphasis on the People’s Republic of China (China).

The SEACFMD Campaign, which commenced in 1997, is organised through the Office International des Epizooties Regional Coordination Unit (OIE RCU) in Bangkok, Thailand. The campaign involved eight countries (Indonesia, Laos, Malaysia, Myanmar,
Philippines, Thailand, Vietnam and Cambodia) in the Association of Southeast Asian Nations (ASEAN) region until 2009 (Edwards 2004). In 2010 three new members were admitted to the South East Asia FMD Campaign (SEAFMD), the Nation of Brunei (Brunei), China and the Republic of Singapore (Singapore). Subsequently the official name was changed to the South East Asia and China FMD Campaign (SEACFMD). As the campaign has grown, its international influence and its geographic range have also grown (OIE 2011b).

As one of the key economic and development regions, the Greater Mekong Sub-region (GMS) plays an important role in both Asia and the world. A number of organisations conduct work and research on livestock and livestock disease in the GMS, including the Food and Agricultural Organisation (FAO), OIE and ACIAR. These three organisations have funded research programs to determine the patterns of animal movements among the GMS countries (Scoizec 2009) and consequently the risk of transmission of FMD to animals within the region (Cocks et al. 2009).

Because of rapid socio-economic development in China and the growing economic gap between China and its neighbouring GMS countries, an increasing number of animals enter China, both legally and illegally (Scoizec 2009). These animal movements are likely to pose a substantial animal disease risk to China (Luo and Wei 2002). From late 2008 until early 2010, Dr Axelle Scoizec (Veterinary Consultant) and Dr Phouth Inthavong (Department of Livestock and Fisheries, Lao PDR) interviewed traders for the ACIAR project AH/2006/025: Understanding Livestock Movement and the Risk of Spread of Trans-boundary Animal Diseases. This research was conducted within Laos to
understand animal movements within Laos and across its borders, including that with China. The research of Scoizec and Inthavong highlighted the new animal movement directions with an increasing number of livestock entering China, and the potential opportunity for disease transmission through these animal movements.

1.3 Research Aims

China has undertaken animal disease control programs and research into animal diseases for many years, however; because of historical isolation and language differences these contributions were not made available to other countries. In the 21st Century China, as the largest developing country, has started to take an increasingly important role in almost every industry in the world. Understanding the history of FMD, as well as the present situation of this disease, in China will benefit the global control and eradication of FMD. The research reported in this thesis was designed to provide the epidemiological basis for progressing zone status for FMD in the Upper Mekong Region, with particular emphasis on Yunnan Province of China. The specific aims of the research reported in this thesis include to:

- Review the history of FMD outbreaks and key research undertaken in the world, with particular reference to China, to hypothesise on the potential sources of FMD in China.

- Support the Upper Mekong zoning proposal by conducting statistical studies to understand the situation of FMD in the Upper Mekong Region.

- Use epidemiological tools, such as risk assessment and epidemiological modelling,
to understand the patterns of spread and the risk of transmission of FMD to China from neighbouring Upper Mekong Region countries.

- Introduce the existing FMD control strategies in China, use meta-analysis to assess the efficiency of the compulsory FMD vaccination campaign, and present the opinions of a group of Chinese veterinary workers on the current FMD control strategy adopted in China.
Chapter 2. Literature Review
Chapter 2. Literature Review

2.1 Reviews on FMDV

As mentioned in Chapter 1, the causative pathogen of FMD, Foot and Mouth Disease Virus (FMDV), is a Picornavirus. Its genomic RNA spans approximately 8 kb and it is a positive-sense single-stranded RNA virus (Moriwa et al. 2007). Foot and Mouth Disease Virus is divided into 7 major serotypes: O, A, C, SAT-1, SAT-2, SAT-3 (Southern African Territories 1, 2, 3) and Asia-1, which have approximately 30–50% differences in the VP1 gene from each other (Belsham 2005).

2.1.1 Persistence and Transmission of FMDV

Foot and Mouth Disease Virus can survive in animal products, as well as in the external environment under suitable conditions. As early as 1927, the British Foot and Mouth Disease Research Committee recorded that below a temperature of 2° to 7°C FMDV could survive for up to 21 days in bled guinea pig carcasses and for at least 35 to 46 days in unbled guinea pig carcasses. The virus can survive for longer periods in bone marrow than in blood (up to 87 days in bled guinea-pig carcasses and up to 96 days in unbled guinea-pigs carcasses). Similar findings were found for both cattle and pigs (Henderson and Brooksby 1948). Generally, the virus is inactivated within one to three days after the animal is slaughtered, but can survive for several months in carcasses (especially in internal organs, bone marrow, lymph and haemal nodes, glands and residual blood) if the carcasses are kept in cold condition (Callis 1996). The virus in salted beef and pork has been shown to remain infective for more than 47 days. In salted beef or bacon stored between -9°C to -13°C, FMDV can survive for up to 76 days in
bone marrow (Henderson and Brooksby 1948).

Milk is an important vehicle for the spread of FMD and has attracted the attention of many scientists (Callis 1996; Hugh-Jones and Wright 1970). The virus multiplies in the mammary gland soon after the animal is exposed to infection (about 2.2 days) and clinical signs of disease then appear (Blackwell et al. 1981). Although temperature usually has a viricidal effect, it has been demonstrated that FMDV can survive pasteurisation in milk. The fat molecules in whole milk can protect the virus against inactivation during this process (Tomasula and Konstance 2004) and consequently more FMDV can be harboured in whole milk than in skim milk. In contrast, FMDV is inactivated in cheese because of the acidic conditions developed during the manufacturing process (Tomasula and Konstance 2004).

Recognising the transmission pathways of FMDV is important in understanding the spread of FMD. Firstly, FMDV can be transmitted to susceptible animals by direct contact with diseased animals or their bodily discharges (OIE 2012d). Secondly, FMDV can be transmitted indirectly through contaminated motor vehicles, animal handlers, animal products such as milk and meat, and fomites. In addition, under favorable conditions, aerosols containing FMDV can potentially travel hundreds of kilometres, allowing spread of the disease even across country boundaries (Gloster et al. 2010; Mahy 2005). Foot and Mouth disease is considered to be a Transboundary Animal Disease (TAD) because of the highly infectious nature of the disease meaning that the prevention and control of FMD is dependent upon international co-operation.
For the purpose of improving global animal health and welfare and veterinary public health, the World Assembly of Delegates of the OIE have agreed on adopting the OIE Terrestrial Animal Health Code as measures to protect international trade of terrestrial animals and their products (OIE 2012h).

In the code, preventive measures, such as using physical or geographical barriers and establishing protection zones, are recommended to prevent FMDV being transmitted from FMD infected countries/zones to FMD free countries/zones. Animals which are FMD susceptible should not leave the infected zone unless they need to be slaughtered in designated slaughter houses. The code of the OIE also recommends that importing countries or zones always require an international veterinary certificate to confirm that the imported animals/animal products (include semen and in vitro produced embryos) meet the conditions recommended by the OIE Terrestrial Animal Health Code (OIE 2012g).

2.1.2 Clinical Signs and Diagnosis

Foot and Mouth Disease has an incubation period between 2 and 12 days. Clinical manifestations caused by this vesicular disease include 2 to 3 days of high fever, blisters on the tongue, buccal mucosa, nose, oral cavity, teats and feet (particularly the interdigital space), foamy saliva, hypersalivation and lameness. Cattle and pigs housed under intensive conditions show more severe clinical signs than do small ruminants (sheep and goats) (OIE 2010c).

Although FMD may also result in myocarditis and death (especially in young animals),
most infected animals recover from the disease. However the majority of surviving animals suffer from decreased body weight and reduced production because of depression or loss of appetite. These signs can result in economic losses for the livestock owner, however even greater losses are associated with loss of trade and/or markets (Mahy 2005; OIE 2010c).

Clinically FMD is difficult to distinguish from other vesicular diseases, consequently laboratory diagnosis of suspected diseased animals is important (Morrissy 2011a). Samples can include vesicular fluid (from unruptured or freshly ruptured vesicles), blood and oesophageal–pharyngeal fluid from living animals and myocardial tissue from dead animals. For biosecurity reasons, collection and dispatch of samples needs to be processed under strict conditions and the samples analysed in approved laboratories (RRL 2006).

One of the earliest widely used serological tests for diagnosing FMDV was the Complement Fixation Test (CFT). Compared to the earlier developed cross-immunity test, the CFT is faster and cheaper (Longjam et al. 2011) and the CFT gradually replaced the cross-immunity test from the 1920s to the 1960s. In 1988, British scientists from the World Reference Laboratory (WRL) reported that the CFT had a low sensitivity and was difficult to operate. They found that a sandwich ELISA test was more sensitive, reproducible, economical and practical (Ferris and Dawson 1988). In the same study, a liquid-phase blocking ELISA (LPBE) was also suggested as an alternative test for the diagnosis of FMDV. This method is now an approved test for the diagnosis of FMD (OIE 2012d).
With the development of ELISA technology, another traditional test, the virus neutralization test (VNT), was also replaced. The reasons for this were that the VNT requires live virus and is a complex test (Kitching 2004). Although the ELISA can identify FMDV directly from field samples, it still takes several days to identify the serotype and subtype from the FMDV isolates. Subsequently, convenient, quick and highly effective molecular biological tests were developed.

According to the OIE Manual of Diagnostic Tests and Vaccines for Terrestrial Animals, the ELISA is now the preferred serological test for detecting the virus and identifying its serotype (OIE 2012b). However, the OIE manual also recommends serological tests be undertaken to detect antibodies to viral Nonstructural Proteins (NSPs). The NSP targeted tests can also provide information on replication of the virus, although they do not confirm the affecting serotype. Consequently tests targeted at the viral NSPs are approved by the OIE and are widely adopted to identify immunity resulting from natural infection, as opposed to that induced by vaccination (Ma et al. 2011; OIE 2012b).

According to the OIE Manual of Diagnostic Tests and Vaccines for Terrestrial Animals, methods to detect nucleic acids of FMDV are important components of virus recognition and detection (OIE 2012b). The Polymerase Chain Reaction (PCR) can be applied to various types of clinical samples and has a much higher sensitivity than the “gold standard” Virus Isolation (VI) test (Hoffmann et al. 2009). The reverse transcription-polymerase chain reaction (RT-PCR), multiplex polymerase chain reaction (mPCR), and real-time polymerase chain reaction (Real-Time PCR) have all been used for detecting FMDV and analysing its molecular structure (Longjam et al. 2011).
The molecular diagnosis of FMD is not restricted to nucleic-acid-based PCR technology. Other technologies include recombinant antigen-based 3ABC-ELISA, Differentiation Infected from Vaccinated Animals (DIVA) based diagnosis, and DNA microarray technology for analyzing FMDV polymorphisms (Longjam et al. 2011). Some more recent technologies also developed include phage display technology and pen-side technology (Longjam et al. 2011; Schmitz et al. 2000).

While most FMD diagnostic methods require time consuming operating procedures, skilled laboratory personnel and precise test instruments, a pen-side test can produce results in the field. These tests were originally developed for detection of Rinderpest Virus (RPV) and were designed to be simple, rapid and accurate (Bruning et al. 1999). A chromatographic strip based pen-side and Lateral Flow Device (LFD) have been developed for the field diagnosis of FMD. The LFD method uses the monoclonal antibodies (mAb) and provides results within a few minutes of testing (Bruning et al. 1999; Ferris et al. 2012; Kitching 2004).

Even though the sensitivity and specificity of the chromatographic strip test are not as high as the antigen enzyme-linked immunosorbent assay (AgELISA) (Longjam et al. 2011), it has significant advantages in its ability to provide a rapid field diagnosis. Other new pen-side tests include the Loop Mediated Isothermal Amplification (LAMP) and its new version Reverse Transcription Loop Mediated Isothermal Amplification (RT-LAMP) (Longjam et al. 2011). All of these molecular tests are designed to provide an accurate and fast diagnostic result in the surveillance and control of FMD (Dukes et al. 2006; Longjam et al. 2011).
2.1.3 Control of Foot and Mouth Disease and Vaccine Development

At present, both the FAO and OIE are adopting the Progressive Control Pathway for Foot and Mouth Disease (PCP-FMD) as their main strategy for the global control of FMD (Figure 2.1) (FAO 2011). According to the PCP-FMD strategy, the principles of the strategy include:

- “active monitoring for FMDV circulation and understanding the epidemiology of FMD are the foundation of a control program, and therefore activities to meet these requirements are common in all stages. The improved information generated is of benefit nationally and regionally. The monitoring of outcomes (indicators of control effectiveness) within a national FMD management system, is included at the higher stages; active monitoring for FMDV circulation and understanding the epidemiology of FMD are the foundation of a control program, and therefore activities to meet these requirements are common in all stages. The improved information generated is of benefit nationally and regionally. The monitoring of outcomes (indicators of control effectiveness) within a national FMD management system, is included at the higher stages;

- activities in each PCP stage are appropriate to the required reduction in virus circulation and mitigation of disease risk to be achieved;

- activities and their impacts are measurable in each Stage, comparable between countries, and generate information and potential benefits to national as well as international stakeholders;

- the optimization of resource use for FMD control is achieved through the targeting
of measures to the husbandry systems and critical risk points where the impact on disease control and/or virus circulation will be greatest.”

Measures recommended by the OIE for the control of FMD include a zoning approach, routine vaccination, a surveillance programme, a stamping out policy and emergency vaccination (OIE 2012c). Once a diagnosis of FMD is made strict restrictions on the movement of animals and vehicles and quarantine should be enforced as quickly as possible. Tracing and surveillance actions should be undertaken to determine the source of the outbreak and potentially infected animals. Areas and countries that are FMD-free should immediately stop importing any animal or animal products from an outbreak area (Kahn 2010; OIE 2012f).

Figure 2.1 Foot and Mouth Disease Control Activity Stages of PCP-FMD (FAO 2011)

For the purpose of controlling and eradicating FMD, vaccination has been used for a long time as the main strategy in many countries. German scientists collected fluid from the vesicles on the tongues of infected cattle, and then inactivated the virus with
formalin and consequently developed the first inactivated FMD vaccine (Lombard et al. 2007; Rodriguez and Grubman 2009). In the 1950s, the virus used for production of the vaccine was cultured on cattle tongue epithelium in vitro. This inactivated vaccine production method lasted for around ten years, before Pirbright laboratory discovered a better media for growing FMDV - Baby Hamster Kidney (BHK) cells. Subsequently, formaldehyde was replaced with binary ethylenimine (BEI) to inactivate the virus. Initially aluminium hydroxide or saponin was used as an adjuvant in vaccine production. These adjuvants meant that the vaccine could not protect pigs from FMD, unlike cattle.

In the 1970s, oil emulsion was discovered to be an effective adjuvant in vaccines for pigs (Mahy 2005; Rodriguez and Grubman 2009).

Aluminium hydroxide gel adsorption is an effective way to inactivate FMDV, and the current widespread application of industrial ultra-filtration and chromatography is considered necessary for purifying FMDV. These measures can filter out contaminants and interference proteins, so that unwanted allergic reactions in vaccinated livestock can be avoided. The OIE Manual of Diagnostic Tests and Vaccines for Terrestrial Animals (2012) indicates that routine vaccination with safe, stable, and effective vaccines is an essential way of keeping animal health status in many diseases (OIE 2012a). In the 21st century, FMD vaccines are required to be made from relevant serotypes and subtypes to induce protection against the current circulating FMDV.

Production of vaccines requires growing FMDV, inactivating the virus, concentrating the antigen and purifying the vaccine. The OIE provides guidelines on the general requirements of a good quality, safe and effective vaccine. These guidelines include
managing the seed virus, vaccine manufacturing, virus titres and inactivation control, final product batch tests, vaccine registration, requirements for antigen banks, and emergency vaccine preparation (OIE 2012b).

Nevertheless, the current vaccines cannot provide long-term protection, or cross-immunity against multiple serotypes. In the future molecular vaccines (recombinant protein and peptide vaccines, empty capsid vaccines, live attenuated vaccines) are hoped to overcome some of problems associated with currently available FMD vaccines (Rodriguez and Grubman 2009).

2.2 Reviews on FMD Outbreaks in the World

The following part of this thesis summarises data on outbreaks of FMD from the OIE and the FAO World Reference Laboratory for Foot and Mouth Disease (WRLFMD). Although many countries are now free from FMD, the disease has previously been present in all livestock-containing regions of the world (Figure 2.2). For the period from 1996 to 2004, the average number of outbreaks reported each year in OIE member countries was around 50 (Figure 2.3). During this period some countries became free through the use of a vaccination strategy combined with active epidemiological surveillance (Figure 2.4).
Figure 2.2 Outbreak History of FMD Prior to 1996 (OIE 2012e)

Figure 2.3 Number of Outbreaks of FMD in OIE Member Countries (1996 - 2004) (OIE 2012e)
2.2.1 Review of the Global Situation of FMD

In the 1950s, some Western European countries suffered from between 10,000 and 100,000 outbreaks of FMD each year. With the dramatic improvements in vaccination technology and the establishment of comprehensive vaccination policies, outbreaks in Europe stopped in 1989 (Grubman and Baxt 2004). However, the comprehensive use of vaccine requires a large financial resource, as well as infrastructure and labour. Furthermore disease can be spread by vaccination teams through poor biosecurity. Consequently in 1992, Western Europe adopted a non-vaccination policy for the European Community countries (Brown 1992). By the end of the 20th century, many developed countries had stopped vaccinating; however outbreaks continued in areas of the Middle East, Africa and Asia (Grubman and Baxt 2004).

According to the OIE, less than one third of its member countries are recognised as
FMD free (Valarcher et al. 2005). The disease is endemic or has occurred sporadically in the other two thirds of the member countries (Figure 2.5). In the 21st century there have been significant outbreaks of FMD in Europe, South America and Asia. This may be, in part, associated with a reduction of, or stopping of, the use of vaccines against FMD (Thomson 2002).

Figure 2.5 Reported Outbreaks of FMD (2005 – 2011) (WAHID 2012)

2.2.2 Review of FMDV Serotype O

Foot and mouth disease virus serotype O is one of the widest distributed serotypes (Knowles and Samuel 2003). In the 1960s, serotype O was divided into 11 subtypes according to antigenic differences (Davie 1964). In the 21st century, molecular biology technology has helped scientists understand the virus at a genetic level. In 2001, based on the FMDV VP1 gene variation, serotype O was divided into eight genetic lineage groups which were known as eight topotypes (Figure 2.6) (Samuel and Knowles 2001).
In 1997, serotype O reappeared in Taiwan, after being absent for 68 years. This recurrence affected most of Taiwan and more than 4 million pigs were killed during the control process. The direct and indirect costs of this outbreak reached US$ 1.6 billion (Yang et al. 1999). The pandemic strain was shown by the World Reference Laboratory for FMD in the UK to be the Cathy topotype (Mahy 2004). Other than this serotype O (Taiwan-97 strain, Cathy topotype), another type-O strain (Pan-Asia strain, ME-SA topotype) was detected in Taiwan in 1999 however no clinical signs were associated with this topotype (Knowles and Samuel 2003). The Pan-Asia strain was first isolated in India in 1990 and subsequently caused a series of outbreaks in many regions of the world. The strain spread to Saudi Arabia in 1994 as a result of livestock trading with India (Mahy 2004). Later in 1996, the strain spread to Turkey, and subsequently caused
outbreaks in Greece, Iran, Iraq, Syria and the Arabian Peninsular countries (Knowles and Samuel 2003; Mahy 2004). This Pan-Asia strain was also responsible for outbreaks in the 1990s in many countries in Asia including Nepal, Bhutan and China. In 2000, the serotype-O Pan-Asia strain was detected in South Africa for the first time. In 2001 this strain was isolated from the UK and subsequently from other European Countries. The re-emergence of FMD in 2001 in UK, which had been free since 1981, resulted in costs of over 10 billion USD to the economy (Knowles and Samuel 2003). Within a few years of 2000 the FMDV serotype O Pan-Asia strain also entered Russia, Japan, South Korea and Mongolia (Knowles and Samuel 2003).

Serotype O is currently the most widely distributed serotype, with some strains only infecting one animal species while others affecting more than one species (Klein 2009).

**2.2.3 Review of FMDV Serotype A**

As early as the 1970s, 32 subtypes of FMDV serotype A had been reported, making it the most diverse serotype. Serotype A was firstly confirmed in Europe in the early 1980s, and it was subsequently demonstrated that the serotype originated from South America. After an effective vaccination campaign in Europe, it disappeared for a while, only to re-emerge again in 1991 due to the introduction from Asia. Serotype A was also isolated from the Middle East in the 1980s, however this strain differed from the European strain. Outbreaks caused by serotype A in India have followed a more complicated pattern. A sequencing study undertaken in the early 21st century indicated that different serotype A viruses were responsible for outbreaks in different areas of India (Knowles and Samuel 2003). In Africa, type A strains were divided into six
2.2.4 Review of FMDV Serotype C

The FMDV serotype C can be placed into eight topotypes based on variation in the VP1 sequence. Historically serotype C has appeared in many regions of the world including Europe, South America, North Africa, Angola and Asia. All classical type-C viruses belong to the same topotype (Euro-SA topotype) (Knowles and Samuel 2003). From 1969 to 1976, serotype C spread from South America to Europe and then to the Middle East. This serotype appeared in the Philippines in 1976 and was found to be closely
related to the South American vaccine strain; however it evolved into a new topotype in the following years (Figure 2.8). Serotype C has been absent from Europe since 1989, from South America since 1994, from Asia since 1996 and from Africa since 1996. In the past two decades FMD serotype C has not been responsible for significant losses in the world (Kitching 2005). The reason for the disappearance of this serotype is unknown (Kitching 2005; Knowles and Samuel 2003).

2.2.5 FMDV Serotype Asia-1

Serotype Asia-1 is not as diverse as the other serotypes and is mainly restricted to Asia. However, in 2000 this serotype was found in Greece, although it has never been isolated from Africa. Isolates from outbreaks in the Middle East indicate that Asia-1 is commonly isolated along with other serotypes. This highlights the fact that animals can be infected with multiple serotypes at the same time (Kitching 2005). Outbreaks
occurred in Asia (Pakistan, India and Bangladesh) in the 1990s and the virus spread from Asia to Saudi Arabia in 1994, to Iran and Turkey in 1999, and to Greece in 2000 (Figure 2.9). Genetic studies have shown that subtypes of serotype Asia-1 are more similar to each other than are other serotypes. The reason for this may be because serotype Asia-1 originated much later than other serotypes or alternatively only a limited number of Asia-1 topotypes are able to survive the purification processes required for identification (Knowles and Samuel 2003).

**Figure 2.9 Origin of Isolates of FMDV Serotype Asia-1 (2003–2007)**

*Valarcher et al. 2009*

Different groups and their localities are indicated by different colours.

AR, Autonomous Region; SAR, Special Administrative Region.
2.2.6 Review of FMDV SAT Serotypes

The SAT serotypes are unique to the Southern African Territories (SAT) region (Figure 2.10). In southern Africa, African buffalo can be a host for FMDV and can carry the virus for up to five years (Bourne 2007). As a carrier, buffalo in Africa have the potential to infect domesticated livestock, so it is unlikely that SAT serotypes will ever be eradicated from Africa (Rweyemamu et al. 2008). There are three topotypes of FMDV SAT 1 in southern Africa, and several more topotypes can be found in eastern and western Africa (Reid et al. 2001). According to the sequencing research conducted by Knowles and Samuel (2003) on SAT 2, there are two topotypes of this virus in southern Africa and one of these has recently spread to the Middle East and eastern Asia. To date SAT 3 has not been found in other regions except for the southern parts of Africa. Three of its topotypes have been found in Zimbabwe, South Africa and Malawi, and an additional one has been found in Ugandan buffalo (Knowles and Samuel 2003).
2.3 Review on Outbreaks of FMD in China

As one of the oldest cultures in the world, China has a very long history of controlling animal diseases. Reviewing historical documents on disease control can help veterinary scientists to better understand animal diseases. In this section available historical data in China are reviewed to understand the contributions to veterinary science made by Chinese veterinary medicine workers, and the history of FMD in China is also reviewed to hypothesize on the possible sources of FMD for the country.
2.3.1 Historical Review of the Development of Veterinary Science in China

The majority of the research described in this section is based on research conducted by Dr. Yu Chuan (1924-2005), who was one of the founders of modern Chinese veterinary medicine (Wang 2004).

In 1973, the remains of 25 different species of animals were unearthed in Guilin, Guangxi Province. The ruin was named Zengpiyan Ruin by Chinese archaeologists. Of the animals unearthed only one domestic animal was found – the pig. It was concluded that the 67 pigs found were herded by humans approximately 9000 years ago (Li and Han 1978; Wang 2004). This is believed to be one of the earliest indications of animal controlling (herding) activities in China.

In Chinese primitive society, from ancient times until 2100 B.C., evidence has been found of increased animal breeding activity with the appearance of “sheds” for housing animals and the presence of needle shaped stones for acupuncture (Yang 1982). These findings demonstrated that veterinary activity had already commenced at this time in China.

During the period of slavery, from 2100 B.C. to 476 B.C., some slaves were chosen to be in charge of farming animals. However this job was despised and was considered to be a punishment (Yu 1991a; Yuan 2002). When inscriptions started to appear on bones or tortoise shells, diseases such as parasitism, dental disease and gastrointestinal disease were recorded in both human and animal patients. Moreover, animal castration and neutered male pigs were also represented by special Chinese characters (Yu 1991a).
In the Western Zhou Dynasty (1046 B.C. - 771 B.C.), veterinary medicine was described as a branch of human medicine for the first time. In a classical book in ancient China, *Zuo Zhuan* (722 B.C. - 453 B.C.), several severe animal diseases were described including rabies (Yu 1991a). In the book *Synopsis of Golden Chamber*, Dr. Zhang in the 3rd century described that “if six kinds of domestic animals (horse, sheep, cattle, pigs, dogs and chickens) are deceased by themselves, then they died of pestilence, which make their meat poison and are not eatable”, “if the meat has rice-like white spots, then the meat is not eatable” and “smelly rice, rotten meat and foul fish are harmful to humans” (Zhang and Tang 2010). This is the first documented record of the potential link between animal and human disease through consumption of food in China.

The era of feudal society in China started in 475BC. From 221 BC to 206 BC, the Qin Dynasty government introduced the first animal husbandry and veterinary law (Wen 1987). According to the law, animal breeders who bred fatter animals would be rewarded; conversely breeders who starved, abused, or stole animals would be punished or even executed (Cao 2003). Also it was stated that “if guests are from dukedoms by carriage, the yoke and horse harness on the carriage need to be fumigated by fire. Why? Parasites on drawing horses can accrete to the carriage.” (Filing-Group 1978). This is the earliest record of disinfection and quarantine in China.

In the Han dynasty (202 B.C. to 220 AD), in the book *Handbook of Prescriptions for Emergency*, a famous doctor in the Eastern Jin Dynasty (317AD to 420AD), Dr. Ge Hong, recorded that intestinal constipation should be treated by drawing and pounding the mass, and human rabies should be prevented by applying the rabid dog’s brain to the
bite mark. This method can be understood as the precursor of a rabies vaccine, more than 1500 years earlier than the French scientists Louis Pasteur and Emile Roux developed the first effective rabies vaccine in 1885 (Zhang 1987).

In the 6th century AD, in the book *Important Arts for the People’s Welfare*, some infectious diseases, such as strangles and tetanus, were mentioned (Yu 1991b). In the late 8th century, animal infectious diseases mentioned included actinobacillosis and epizootic lymphangitis. Animal parasitosis in the Tang Dynasty records included ascariasis, nematodiasis, sarcoptes and nasal myiasis (Yu 1991b).

Infectious diseases recorded in the Ming and Qing Dynasties (1368-1912) were likely to have included the diseases now known as rabies, tetanus, equine epizootic lymphangitis, cattle plague, emphysematous gangrene, malignant catarrhal fever, bovine pleuropneumonia, influenza, infectious bovine keratitis, classical swine fever and swine plague. Chinese veterinary medicine was reported to have developed quickly during the times of the feudal society (Jin 1985; Yu 1978; Zhang and Tang 2010).

2.3.2 The Possible Source of FMD in China

According to historical documents, epidemics of several animal diseases occurred in ancient China. These epidemics were mainly caused by rinderpest, classical swine fever and rabies (Zhang and Tang 2010). Prior to the 1890’s, no records of animal diseases exist in China that include cases of a disease matching the clinical signs of FMD.
2.3.2.1 The Earliest Record of FMD in the World

In 1514, the first reported case of FMD was made in Italy by Fracastorius. During the following three centuries, the disease became endemic in Europe because of intensification of the cattle industries and the increasing number of animal movements (Sobrino and Domingo 2001). The disease spread to France and Germany from Italy during the 17th and 18th centuries. In 1839, it was present in Great Britain and in 1871 in South America. The first record of FMD in Asia was in 1842, while in 1892 it was first reported in Africa (Brown 2003).

2.3.2.2 The Potential Pathway for the Spread of FMD from Europe to South eastern Asia

In the late 19th century, the first Asian country to report cases of FMD was Ceylon (now Sri Lanka) (Knowles 2005). Although colonial domination of Sri Lanka started in the 16th century (Ross et al. 1990), at this time it took several months for ships to travel from Europe to India. During this long journey, FMD infected livestock would have time to recover from the disease prior to arrival. This situation remained until the first half of the 19th century. With the invention of the steamship in the 19th century and the discovery of new and shorter routes, the voyage between England and India was reduced from months to between 35 and 45 days (Brinton 1968). At this time army troopships, as well as mail and commercial carriers, travelled between Europe and Asia. The food on these ships included fresh and salted meat (beef, pork, mutton), canned or tinned meat, sausages, bacon, butter, cheese and milk (McLean and Shackleton 1900). As FMDV can survive in milk or milk products (butter and cheese) for up to 45 days (Tomasula and Konstance 2004), and frozen bone marrow, carcasses and slurry for up to
3 months (Botner and Belsham 2011; Henderson and Brooksby 1948), there was the potential for distribution of FMDV through these unprocessed animal products. It is likely that FMDV was introduced to Ceylon and India from Europe and subsequently spread to other Asian countries along the route followed by the English army (Figure 2.11).

Figure 2.11 Map of the Spread of FMD from Europe to China

![Map of the Spread of FMD from Europe to China](image)

2.3.3 The Spread of FMD in China

Although China joined the World Organisation for Animal Health (OIE) in 1992, it did not fully engage in OIE activities until the 25th May 2007 because of the presence of Taiwan, which had been a member nation since 1954 (OIE 2007). Prior to 2007 little information on FMD was available from China. This section outlines the data on FMD available from official Chinese government reports and records.
2.3.3.1 The Spread of FMD from South eastern Asia to China

When FMD first occurred in Ceylon, China was under the control of the Qing Dynasty. At that time the Qing government applied an “Isolation Policy” as a national defence strategy. The Qing dynasty's isolationist policies included limiting and prohibiting any diplomatic relations and business with other countries (Xia 2002). This policy restricted the entry of animals and goods into China from other countries, except for tribute trading from Nepal, India, Myanmar, Vietnam, Thailand and Laos.

The earliest written record in China about FMD involved an outbreak in 1893 in the south-eastern border area (Yunnan Province and the Tibet Plateau) (Zhang and Tang 2010). These regions have common borders with Nepal, India, Myanmar, Laos and Vietnam. It is likely that the disease entered through cattle grazing in border areas or through the entry of infected beasts of burden (cattle) or products from infected livestock. In the late Qing dynasty there were three main land routes of tribute trade still open in China (Figure 2.12). All of these routes needed to cross either Tibet or Yunnan, where FMD was first reported in China.
These three paths of international trade were established approximately 4000 years ago and continued into the Qing dynasty. The first of these vital communication lines was called the “Tea Horse Roads” which connected India and Sichuang Province, China via Nepal, Tibet and Yunnan Province. The second was called “The Southern Silk Road”. It also connected India and Sichuan Province; however this involved travelling across Bangladesh, Myanmar and Yunnan Province. The third route was another route of “the Southern Silk Roads”. It connected Vietnam and Sichuan Province and crossed through Yunnan Province (Wang 2008b).

In the 19th century, the frontier trade between the Qing government and India, Nepal, Myanmar, Vietnam and Siam (the name of ancient Thailand) developed along these three routes. As well as the tribute trade, which involved the trade of official goods, free
trade was undertaken which involved trade of non-government goods. Imported and exported goods between China and Myanmar, Vietnam and Siam were transported by both boats and beasts of burden (horses and cattle) (Ding 2003). Through both official and unofficial trade, hundreds to thousands of cattle were used to transport goods from Myanmar to China (Ding 2003). Tonnes of goods and animals were also traded along the rivers as tribute to the Qing dynasty and included white elephants, ox horn, ivory and other animal products. A range of goods were exported from China including silk, porcelain and cotton cloth (Ding 2003). The beasts of burden potentially could have been the source of disease for Yunnan Province and Tibet.

2.3.3.2 The Spread of FMD in China: from south-eastern China to north-western China

The three trade routes identified were controlled and managed by the Qing government. The trading within China (from Tibet and Yunnan Province to Sichuan Province) mainly involved the use of horses and consequently the risk of FMD spreading further into China through these three communication lines was likely to have been low.

The next report of FMD in China was in Gansu Province in north-western China in 1902 (Shi 1992). Since then the disease has occurred frequently in Gansu Province. Another trading route could possible explain the introduction of FMD to this province. This route was a part of the first line (Tea Horse Roads), and extended into Gansu Province. In the late Qing dynasty (1900s), besides being used for the trading of tea and horses, this line, “Tang Bo Gu Dao” (Figure 2.13), was also used for promoting commercial trade in the Tibetan Plateau. Every year, many thousands of cattle and sheep and their products were imported into central China (Ren 2010). Private commercial
teams of oxen were used to make both short and long haul transportations along this line. The long haul transportation normally took three months for the round trip between Tibet and Gansu with the short haul trips lasting ten days and involved travelling between different Tibetan tribes (Wang 2008a). Due to this trade there was a significant opportunity for the spread of FMD from south-eastern China to north-western China.

**Figure 2.13 The Route of “Tang Bo Gu Dao”**

![Map showing the route of “Tang Bo Gu Dao”](image)

### 2.3.3.3 The Spread of FMD from south-eastern China into Inner Mongolia and eastern China

From the 1900s to 1940, FMD spread from Tibet to the Gansu Province, and then to Inner Mongolia and Eastern China (Shanghai City and its neighbouring provinces). The pathway for the distribution of FMD during this period was believed to have been facilitated by increased trading of animals and more rapid animal transport through the use of railways (Shi 1992) (Figure 2.14).
Gansu Province is one of the Hui nationality (the Islam faith) rendezvous points in China. In the late Qing dynasty, the Hui Nationality Uprising resulted in a sharp reduction in the human population in Hui and domestic animals kept by the Hui population almost disappeared. However livestock husbandry and transportation of livestock and their products by the Hui population recovered between the 1900s and 1930s.

**A. Trading from Gansu Province to the Inner Mongolia Province**

From the 1900s to 1930s, the Qing Dynasty Government was overthrown and the Nationalist Government established. The Hui merchants used equidae (mules, donkeys and horses), camels and boats for transporting livestock, wool, sheep skins and other animal products, such as sheep intestines, sheep oil and butter, to Inner Mongolia (Yuan
From Gansu to Inner Mongolia, there were two forms of transportation: in autumn and winter, camels were used since the Yellow River was frozen; whilst in spring and summer, wooden ships and rafts were used for transportation (Yuan 2007). From Gansu to Inner Mongolia took approximately 20 days via the Yellow River and 40 days by camel (Li 2009). It took 20 to 27 days to transport goods from Tibet to Baotou in Inner Mongolia.

B. Trading from Inner Mongolia Province to Hebei Province

In 1923, the completion of the railroad from Baotou City to Tianjin City in Hebei Province allowed transportation between the two cities within two days. The train used had special carriages for transporting livestock, with the number of carriages used for transporting goods being far greater than that for passengers (1534 for goods, 156 for people in 1924) (Duan 2011). In Inner Mongolia, goods from Gansu Province were loaded onto the train or trucks and transported to Beijing City, Tianjin City and Shanghai City for sale (Wang 2010). In 1920, 750,000 kilograms of wool was sold from Gansu Province to Tianjin City (Liu 2008).

C. Trading from Hebei Province Eastern China

During the 1930s, FMD spread along the route of the Jinpu Railway. Each year between 50,000 and 60,000 cattle were collected from Shandong Province and sold to Jiangsu Province and Shanghai City (Zhu and Yang 2010). According to the Jinpu Railway Train Time and Pricing Table, it took seven hours to travel from Tianjin to Dezhou in Shandong Province, allowing the rapid distribution of potentially infected animals and animal products. The trip from Tianjin City to Pukou City in Jiangsu Province took
approximately 39 hours for the 1000 km journey (Ma 2011). Consequently within two days, cattle and animal products could be transported from Hebei Province to cities in Eastern China.

In the 1930s, FMD was found in the province of Inner Mongolia and in the eastern parts of China (Shanghai City, Jiangsu Province) (Shi 1992). The virus potentially was transmitted along the major trading pathways from Gansu to Inner Mongolia and from Inner Mongolia to eastern China.

2.3.3.4 FMD Spread into north eastern China

North-eastern China consists of three provinces: Liaoning Province, Jilin Province and Heilongjiang Province. During the Qing dynasty, soya beans from north-eastern China were sold to southern China and cotton cloth, silk and tea were imported into China. Transport involved travel via sea, although no mention of transport of animals or animal products was documented (Xu 2004).

From 1931 to 1945, north-eastern China was occupied by the Japanese. During this time the region had a serious setback in its livestock breeding industry. For example in 1930 in Jilin Province there were 735,000 yellow cattle, 2,200,000 sheep and 4,162,000 pigs. However in 1945, the number had decreased to 670,000, 1,911,000 and 2,941,000, respectively (Li 2003). At that time, outbreaks of FMD in the Loess Plateau and North China Plain did not pose a threat to the north-east China Plain, since the other parts of China were under the control of military forces.

From 1948, north-eastern China was under the control of Chairman Mao’s People’s
Liberation Army (PLA). To improve the economic situation in the region it was prohibited to sell supplies to other places whilst imports were tax-free. These supplies included cotton, livestock and scientific equipment (He 2007). During this time, FMD outbreaks again occurred in China (1951-1954). These outbreaks spread to the three north-eastern provinces in the liberated area of China (Cheng 1990).

2.3.4 Review of the Recent Situation of FMD in China

2.3.4.1 A Period of a Lack of Information (1958 – 1980s)

From 1958 to 1967, China experienced the Great Leap Forward (1958-1960), Great Famine (1959-1961) and the Cultural Revolution (1966-1967). During this period natural disasters and man-made calamities resulted in slow economic and cultural development (Chen 2008). The period of economic depression in China lasted until the beginning of reform and opening-up period in the late 1970s to 1980s. During this time inadequate documents were maintained to determine the situation with respect to FMD in China.

2.3.4.2 Recent FMD status in China (1990s to 2011)

According to the Official Veterinary Bulletin, which was first issued in 1999, outbreaks of FMD occurred between 2005 and 2011. Data on outbreaks were collected and categorised according to province (Figure 2.15) with the highest number of outbreaks in north-western China, although none were reported in three provinces in north-eastern China.
According to the Official Veterinary Bulletin, FMD serotype Asia-1 was the main cause of these outbreaks being responsible for 46 outbreaks in 17 provinces. However in 2009 an epidemic caused by serotype A occurred and eight outbreaks in seven provinces were reported. In 2010 and 2011 no outbreaks of serotypes Asia-1 and A were reported. However, in 2010 and 2011 26 outbreaks of serotype O were documented in 10 provinces (Figure 2.16).
According to Chinese law, after outbreaks are reported, samples should be collected and sent to an authorised laboratory for confirmation and virus isolation. After confirmation a molecular epidemiological approach is applied to identify the potential source of the outbreak. According to the OIE/FAO FMD Reference Laboratory in China, the Lanzhou Veterinary Research Institute, serotype Asia-1 strains isolated in China from 2005 to 2009 were very closely related to the strains isolated from south-eastern Asian countries. Sequence analyses of the VP1 gene of serotype Asia-1 strains isolated from China from 2005 to 2009 demonstrated a very close genetic relationship with strains isolated from India in 1980 and 1981 and strains from Myanmar in 2006 (Figure 2.17). All of the serotype Asia-1 strains isolated from China belonged to the South-East Asian (SEA) topotype (Guo 2011).
The serotype A strains isolated originated from the same source but were different to historical Chinese strains (serotype A strains from 1950s to 1960s) (He 2012). Of these “modern” serotype A strains, Hubei and Shanghai strains showed 95.9% similarity with a Myanmar strain isolated from 2002, 95.7% similarity with a Thailand strain isolated in 2007, and 95.3% similarity with a Laos strain isolated in 2006 (He 2012). These findings support the belief that the FMDV serotype A which caused outbreaks in China from 2009 to 2010 was most likely introduced from South East Asia (Figure 2.18).
Serotype O strains isolated in China from 2010 to 2011 were confirmed to be Myanmar 98 and Pan Asia strains (Guo 2011; WRLFMD 2011). The Myanmar 98 strains detected in China had greater than 97% similarity with serotype O strains isolated from Thailand, Vietnam and Malaysia. The source of PanAsia strains in China most likely originated from Vietnam and Cambodia (Guo 2011) (Figure 2.19).
On account of the strong molecular evidence suggesting that FMDV in China originated from neighbouring south-eastern Asian countries, the situation of FMD in these countries is discussed in the next chapter. In particular the FMD control strategies adopted in the Upper Mekong Region countries were analysed to highlight the strengths and weaknesses of their policies for controlling FMD. A thorough knowledge of these control practices is needed when assessing the risk of new strains of FMDV entering China from the movement of livestock and their products from neighbouring countries.
Chapter 3. Epidemiological Pattern of FMD in the South-eastern Asia, Upper Mekong Region Countries
Chapter 3. Epidemiological Pattern of FMD in the South-eastern Asia, Upper Mekong Region Countries

3.1 Background of Mekong Region

The Mekong River is the 8th biggest river in the world. Trading between China and its neighbouring countries via the Mekong River is likely to have been undertaken for centuries; however official trading commenced in the early 1990s, and it subsequently has become the largest trade route linking China and other south-eastern Asia countries (Cai 1999). In 1992, Myanmar, Laos, Thailand, Cambodia, Vietnam and China (Yunnan Province) launched the Greater Mekong Sub-region Economic Cooperation Program to strengthen the co-ordination and development in the Greater Mekong Sub-region (GMS). This cooperative program brought great economic development into the GMS. For instance, in 2007 the total imports and exports between Yunnan Province and the other five countries was worth US$8.78 billion (He and Li 2008). In 2004, Guangxi Province formally joined the GMS program, becoming the second Chinese province to participate in this program. In 2007, the total imports and exports between Guangxi Province and Vietnam reached US$2.38 billion, a 62% increase compared with the previous year (He and Li 2008).

The OIE SEACFMD program developed a zoning approach to control FMD in south-eastern Asia, with the region being divided into three regions: Malaysia-Thailand-Myanmar (MTM) region, Lower Mekong region (Lower Mekong Basin) and Upper Mekong region (Upper Mekong Basin) (Edwards 2004) (Figure 3.1). To control FMD in the Upper Mekong Region and to understand animal movements, an Upper Mekong Working Group (UMWG) was established in 2003 with representation
from Myanmar, Thailand, Laos, Vietnam and China (Yunnan Province) (OIE 2006a).

The FMD situation in the Upper Mekong Region countries is likely to have a direct effect on the disease situation in China. In this chapter information on outbreaks of FMD in the Upper Mekong Region are summarised and analysed with respect to infecting serotypes and temporal and spatial distribution of the disease.

**Figure 3.1 Locations of Three Regions in South East Asia (where coordinated control programs against FMD have been established) (Abila 2005a)**
3.2 Materials and Methods

3.2.1 Materials

In this chapter, data from four of the five countries in the UMWG (Myanmar, Thailand, Laos and Vietnam) are presented. Data were collected from the OIE database, OIE meeting reports, ACIAR research reports, and from published and unpublished papers. Data on outbreaks of FMD and the movements of animals from 2000 to 2010 are presented to determine the epidemiological patterns of FMD during this period.

The data on outbreaks of FMD in the Upper Mekong Region Countries from 2000 to 2010 used in this chapter were collected from the online database of reports of FMD outbreaks administered by the OIE Regional Coordination Unit in Bangkok (www.arahis.oie.int/reports.php?site=seafmd). The outbreak data used in this analysis did not include any from outbreaks that commenced prior to 2000 and were on-going. Although the database is maintained by the OIE Regional Coordination Unit in Bangkok, data are entered and updated by the member countries. These countries have the right to change data if previously entered data are incorrect or if new data become available. The data used in this chapter were collected (downloaded) at the end of 2011.

This chapter also collected FMDV VP-1 gene sequence information for determining the genetic relationship between strains of FMDV isolated from the different countries. The VP-1 gene sequence information was collected from GeneBank® (www.ncbi.nlm.nih.gov/genbank).
3.2.2 Methods

3.2.2.1 Temporal Analysis
Outbreak data for FMD were organised chronologically in Microsoft® Excel®. Time Series Analysis was applied to show the relationship between time and FMD outbreaks in the Upper Mekong Region countries. The number of outbreaks from 2000 to 2010 was initially displayed in a scatter plot (Figure 3.2). The number of outbreaks was then divided into months and the impact of seasonality assessed by using a moving average model. The periodicity used in this model was one month and the endpoints weighted by 0.5. The package SPSS® Statistics Version 18.0 provided by SPSS Inc. China was used to statistically analyse data in this study.

3.2.2.2 Spatial Analysis
The prevalence in the different countries were presented in tabular and box-whisker plot formats. During the descriptive analysis skewness and kurtosis values were calculated (Sheskin 2011). If a distribution’s skewness and kurtosis values were both zero, then the data were considered to follow a normal distribution.

Subsequently, a parametric/nonparametric test was chosen to test the relationship between variables (countries) and the distribution of FMD. If the data were normally distributed then parametric tests were used, otherwise nonparametric tests were used. A $P$ value of 0.05 was selected as the level for significance. If there was a significant difference between countries, then the Mann-Whitney U Test was applied to compare the difference between any two countries. $P$ and U values were calculated from the
3.2.2.3 Distribution of Serotypes

The prevalence for the three serotype groups were presented in tabular and box-whisker plot formats. During the descriptive analysis skewness and kurtosis values were also calculated. Subsequently, a parametric/nonparametric test was chosen to test the relationship between variables and FMD as outlined in the previous section.

Data on the FMDV serotypes isolated from the countries in the Upper Mekong Region were collected from the OIE online database (www.arahis.oie). These data were organised, tabulated and graphically displayed with Microsoft® Excel®. Statistical analyses (as for spatial analysis) were used to compare the distribution of serotypes in Myanmar, Thailand, Laos and Vietnam.

Samples from some outbreaks from 2000 to 2010 had also been submitted to the World Reference Laboratory of FMD and the isolates sequenced. The VP-1 genes of the sequenced isolates were downloaded from GeneBank® and the data organised using BioEdit® Version 7.0.9 (Hall 1999). After gene editing, the VP-1 sequences were analysed with MEGA 4.1© (Tamura et al. 2007) using the Neighbour Joining method of the Bootstrap Test. In this test 1000 replications were undertaken and the Kimura 2-Parameter Neighbour Joining method was chosen to produce a phylogenetic tree. The phylogenetic tree displayed the genetic relationship between FMDV strains isolated from the Upper Mekong Region Countries from 2000 to 2010 (GeneBank 2012).
3.3 Results

3.3.1 Temporal Distribution of FMD in the Upper Mekong Region Countries

Data on outbreaks of FMD for the period 2000 to 2010 from the four target countries are summarised in Table 3.1. During this period a total of 3,685 outbreaks were reported from Myanmar, Thailand, Laos and Vietnam. The annual number of outbreaks only included the new outbreaks found in that year and excluded any outbreaks which were on-going from the previous year. A similar number of outbreaks were reported over the study period in Thailand and Vietnam (1,413 and 1,453, respectively). During this time Laos reported 611 outbreaks and only 208 outbreaks were reported in Myanmar.

<table>
<thead>
<tr>
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<td>7</td>
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<td>30</td>
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<td>34</td>
<td>52</td>
<td>50</td>
<td>35</td>
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<tr>
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<td>29</td>
<td>122</td>
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<td>2</td>
<td>41</td>
<td>60</td>
<td>55</td>
<td>18</td>
<td>0</td>
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<tr>
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<td>29</td>
<td>49</td>
<td>53</td>
<td>639</td>
<td>44</td>
<td>61</td>
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<td>223</td>
<td>726</td>
<td>152</td>
<td>179</td>
<td>303</td>
<td>327</td>
<td>3685</td>
</tr>
</tbody>
</table>

The total number of outbreaks each year is displayed in Figure 3.2. The number of outbreaks did not follow a definite pattern, although from 2000 to 2006, the number of outbreaks tended to increase. The lowest number of outbreaks was reported in 2007, and subsequently the number increased steadily.
Figure 3.2 Plot of the Number of Outbreaks of FMD Each Year in the Upper Mekong Region Countries (2000 - 2010)

The data were divided into months and the results are displayed in Table 3.2 and Figure 3.3.

Table 3.2 Monthly Outbreaks of FMD in the Upper Mekong Region Countries (2000 - 2010)

<table>
<thead>
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<td>107</td>
<td>31</td>
<td>27</td>
<td>33</td>
<td>13</td>
<td>39</td>
<td>24</td>
<td>23</td>
<td>5</td>
<td>0</td>
<td>327</td>
</tr>
<tr>
<td>Jul</td>
<td>36</td>
<td>4</td>
<td>14</td>
<td>41</td>
<td>22</td>
<td>10</td>
<td>14</td>
<td>3</td>
<td>16</td>
<td>4</td>
<td>0</td>
<td>164</td>
</tr>
<tr>
<td>Aug</td>
<td>16</td>
<td>20</td>
<td>10</td>
<td>30</td>
<td>13</td>
<td>16</td>
<td>8</td>
<td>4</td>
<td>12</td>
<td>51</td>
<td>0</td>
<td>180</td>
</tr>
<tr>
<td>Sep</td>
<td>11</td>
<td>8</td>
<td>7</td>
<td>83</td>
<td>20</td>
<td>11</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>78</td>
<td>44</td>
<td>273</td>
</tr>
<tr>
<td>Oct</td>
<td>15</td>
<td>23</td>
<td>11</td>
<td>63</td>
<td>10</td>
<td>19</td>
<td>8</td>
<td>7</td>
<td>9</td>
<td>36</td>
<td>56</td>
<td>257</td>
</tr>
<tr>
<td>Nov</td>
<td>16</td>
<td>33</td>
<td>33</td>
<td>106</td>
<td>43</td>
<td>7</td>
<td>6</td>
<td>24</td>
<td>10</td>
<td>30</td>
<td>81</td>
<td>389</td>
</tr>
<tr>
<td>Dec</td>
<td>19</td>
<td>17</td>
<td>23</td>
<td>65</td>
<td>68</td>
<td>12</td>
<td>44</td>
<td>35</td>
<td>11</td>
<td>36</td>
<td>74</td>
<td>404</td>
</tr>
</tbody>
</table>
There was no significant difference in the number of outbreaks between months (P < 0.05). There was an apparent spike in cases in March to May 2006. In Table 3.3 the results for the descriptive seasonal decomposition from Figure 3.3 are summarised, indicating the percentage difference between that particular month and the median. Fewer outbreaks occurred in July (61.7%) with the highest being in the months of January (185.9%) and December (147.3%).

**Figure 3.3 Plot of Outbreaks of FMD in the Upper Mekong Region Countries**
*(January to December, 2000 - 2010)*

![Graph showing the number of FMD outbreaks from January 2000 to December 2010.](image)

<p>| Seasonal Factors (%) in 12 Months from 2000 to 2010 |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>185.9</td>
<td>90.9</td>
<td>109.3</td>
<td>76.1</td>
<td>93.0</td>
<td>108.4</td>
<td>61.7</td>
<td>73.0</td>
<td>64.0</td>
<td>73.0</td>
<td>117.3</td>
<td>147.3</td>
</tr>
</tbody>
</table>

**3.3.2 Spatial Distribution of FMD in the Upper Mekong Region Countries**

The data summarised in Table 3.1 were tabulated and plotted to display the descriptive results and distributions of outbreaks of FMD in the four Upper Mekong Region...
There was only one outliner “○” and one extreme value “*” found in Thailand and Vietnam, respectively. Except for these two values, all other values were in the reasonable range, with Vietnam having the widest range.

Thailand had the highest median number of outbreaks (64) and Myanmar the lowest (median 16).

**Table 3.4 Descriptive Results of FMD Outbreaks in Laos, Myanmar, Thailand and Vietnam (2000 - 2010)**

<table>
<thead>
<tr>
<th>Country</th>
<th>Mean</th>
<th>95% CI</th>
<th>Median</th>
<th>Skewness</th>
<th>Std.Error</th>
<th>Kurtosis</th>
<th>Std.Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myanmar</td>
<td>19</td>
<td>13-25</td>
<td>16</td>
<td>0.413</td>
<td>0.661</td>
<td>-1.322</td>
<td>1.279</td>
</tr>
<tr>
<td>Thailand</td>
<td>129</td>
<td>47-210</td>
<td>64</td>
<td>1.488</td>
<td>0.661</td>
<td>2.285</td>
<td>1.279</td>
</tr>
<tr>
<td>Laos</td>
<td>56</td>
<td>25-86</td>
<td>55</td>
<td>0.602</td>
<td>0.661</td>
<td>-0.470</td>
<td>1.279</td>
</tr>
<tr>
<td>Vietnam</td>
<td>132</td>
<td>5-259</td>
<td>49</td>
<td>2.324</td>
<td>0.661</td>
<td>5.589</td>
<td>1.279</td>
</tr>
</tbody>
</table>

Figure 3.4 Box and Whisker Plots of FMD Outbreaks in Four Upper Mekong Region Countries (2000 - 2010)
The skewness and kurtosis values indicated that all four distributions were not normal and consequently the Kruskal-Wallis H test was used to examine the statistical difference between data from the four countries (Table 3.5). The results of this analysis indicated that there was a statistically significant difference between the countries ($H^2=15.26$, $P=0.002$) with the highest number of outbreaks in Thailand and the lowest number in Myanmar.

Table 3.5 Nonparametric Test Results of FMD Outbreaks in Four Upper Mekong Region Countries (2000 - 2010)

<table>
<thead>
<tr>
<th>Country</th>
<th>Mean Rank</th>
<th>Chi-square</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myanmar</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thailand</td>
<td>30</td>
<td>15.26</td>
<td>0.002</td>
</tr>
<tr>
<td>Laos</td>
<td>23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vietnam</td>
<td>27</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Mann-Whitney U Test was used to evaluate multiple comparisons between groups (Table 3.6). There was a significant difference between Myanmar and the three other countries (all $P$ values $< 0.05$). There was, however, no significant difference between any other countries ($P>0.05$).

Table 3.6 Results of Comparison of Prevalence between Countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Mann-Whitney U Test $P$ value (U value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Myanmar</td>
</tr>
<tr>
<td>Myanmar</td>
<td>------</td>
</tr>
<tr>
<td>Thailand</td>
<td>0.000 (7)</td>
</tr>
<tr>
<td>Laos</td>
<td>0.042 (30)</td>
</tr>
<tr>
<td>Vietnam</td>
<td>0.001 (11)</td>
</tr>
</tbody>
</table>
3.3.3 Distribution of Serotypes of FMDV in the Upper Mekong Region Countries

The serotypes isolated from the outbreaks are displayed in Figure 3.5. Many outbreaks had not been sampled (2113, 57%) and in some the isolates had not been typed (183, 5%) or there were no available details (30, 1%). Overall serotype O (914, 25%) was the most common followed by serotype A (414, 11%), with serotype Asia-1 confirmed in only 31 outbreaks (1%). Of those outbreaks with serotype information, 67.26% were due to serotype O, 30.46% serotype A and 2.28% serotype Asia-1.

**Figure 3.5 Distributions of FMDV Serotypes in Upper Mekong Region Countries (2000 - 2010)**

The serotypes were subdivided into the year of the outbreak and country of origin (Table 3.7). Data from this table were used to further analyse the outbreaks and generate a box and whisker plot (Table 3.8 and Figure 3.6). Two outlier extreme values “∗” were found in the serotype Asia-1 data. The most prevalent serotype was O with a median value of 73, followed by serotype A with a median of 29.
Table 3.7 Serotypes of FMDV Isolated from Outbreaks (2000 - 2010)

<table>
<thead>
<tr>
<th>Serotype</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>7</td>
<td>14</td>
<td>58</td>
<td>121</td>
<td>71</td>
<td>54</td>
<td>29</td>
<td>5</td>
<td>17</td>
<td>34</td>
<td>4</td>
<td>414</td>
</tr>
<tr>
<td>O</td>
<td>38</td>
<td>120</td>
<td>73</td>
<td>102</td>
<td>55</td>
<td>51</td>
<td>46</td>
<td>64</td>
<td>99</td>
<td>120</td>
<td>146</td>
<td>914</td>
</tr>
<tr>
<td>Asia-1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>2</td>
<td>17</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>31</td>
</tr>
</tbody>
</table>

Table 3.8 Descriptive Results of FMDV Serotypes (2000 - 2010)

<table>
<thead>
<tr>
<th>Serotype</th>
<th>Mean</th>
<th>95% CI</th>
<th>Median</th>
<th>Skewness</th>
<th>Std.Error</th>
<th>Kurtosis</th>
<th>Std.Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>38</td>
<td>14-62</td>
<td>29</td>
<td>1.324</td>
<td>0.661</td>
<td>1.688</td>
<td>1.279</td>
</tr>
<tr>
<td>O</td>
<td>83</td>
<td>59-107</td>
<td>73</td>
<td>0.403</td>
<td>0.661</td>
<td>-1.186</td>
<td>1.279</td>
</tr>
<tr>
<td>Asia-1</td>
<td>3</td>
<td>1-7</td>
<td>0</td>
<td>2.203</td>
<td>0.661</td>
<td>4.262</td>
<td>1.279</td>
</tr>
</tbody>
</table>

Figure 3.6 Box and Whisker Plots of the Distribution of FMDV Serotypes
Based on the skewness and kurtosis values (Table 3.8), none of the distributions for the three serotypes were normal and consequently the Kruskal-Wallis H test was applied to examine the statistical difference between the serotypes (Table 3.9). This analysis confirmed there was a statistically significant difference between the serotypes ($H^2=22.40$, $P=0.000$). The results indicated that the main serotype in the Upper Mekong Region was O and the least important was serotype Asia-1.

### Table 3.9 Nonparametric Test Results of the Distribution of FMDV Serotypes from Outbreaks (2000 - 2010)

<table>
<thead>
<tr>
<th>Serotype</th>
<th>Mean Rank</th>
<th>Chi-square</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>26</td>
<td>22.40</td>
<td>0.000</td>
</tr>
<tr>
<td>Asia-1</td>
<td>7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The results of the Mann-Whitney U Test indicated statistically significant differences between all serotypes (all $P$ values < 0.05) (Table 3.10).

### Table 3.10 Results of Comparison of Prevalence between Serotypes

<table>
<thead>
<tr>
<th>Serotype</th>
<th>Mann-Whitney U Test $P$ value (U value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>A</td>
<td>---</td>
</tr>
<tr>
<td>O</td>
<td>0.011 (22)</td>
</tr>
<tr>
<td>Asia-1</td>
<td>0.000 (8)</td>
</tr>
</tbody>
</table>

### 3.3.4 Results of the Genetic Analysis

Of the 3,685 outbreaks in South East Asia, Upper Mekong Region countries from 2000 to 2010, 47 FMDV isolates were sequenced and available from Genebank®. The strains...
were labelled with the country of origin, serotype and year of collection. The VP-1 gene (633 base pairs) of these strains were analysed through the neighbour joining tree method. In Figure 3.7 the results of the tree are displayed along with the bootstrap support (%) based on the neighbour-joining analysis of 1000 replications through Kimura 2-Parameter analysis.

The branches of three serotypes showed bootstrap values of 100 indicating that these serotypes were divided correctly. More than half (26) of the FMDV strains sequenced belonged to serotype O. The strain isolated from Vietnam in 2005 belonged to the Cathay topotype, while the other 25 serotype O lineages were clustered in the South East Asia (SEA) topotype. None of these 26 serotype O lineages was the Pan Asia topotype. The SEA topotypes found in the four Upper Mekong Countries were closely related indicating that these topotypes were widely distributed in the countries during the study period. Isolates from Thailand in 2007, 2008 and 2009 showed close genetic relationship and were also closely related to the Myanmar strain isolated in 2008 (similarity 99%, 99%, 97%, respectively), and Laos isolates from 2007 and 2009 (both 99% similarity). These strains, together with Myanmar strains found in 2004 and 2006, were all interleaved with Laos strains in 2001. Myanmar strains in 2004 and 2006 showed very close genetic relationships (similarity 100%), as did Vietnamese strains isolated in 2006 and 2007 (96%). Vietnamese strains from 2002, 2003, 2004 and 2006 were closely grouped together forming a ladder-shaped cluster; however these strains showed no temporal ordering.

Sixteen serotype A strains from Thailand, Vietnam and Laos were included in the
phylogenetic tree and all belonged to the Asia topotype. Serotype A isolates from 2008 to 2009 were clustered into the same genetic group. Strains from 2003 to 2007 were also clustered into the same genetic group which, other than for the 2005 Thai strain, had the same genetic source as the strains from 2008 and 2009. The Thai strain from 2005 showed a close genetic relationship with other Thai strains from 2001 (similarity 93%) and 2002 (similarity 92%).

Five strains were confirmed to be FMDV serotype Asia-1. All these strains originated from Myanmar and Vietnam. One isolate obtained from Myanmar in 1997 was added to examine if the source of the Vietnamese lineage might have originated from Myanmar. However, the Vietnamese isolate in 2007 was distinct to the others (only 81-82% similarity). The Vietnamese isolate in 2005 possessed 92% similarity to that of the Myanmar isolate in the same year and had 91% similarity to the 1997 Myanmar isolate. The isolate responsible for the outbreak in Myanmar in 2000 was genetically very similar to the strain isolated from that country in 1997 (94% similarity). The Asia-1 isolates in 2005 from Myanmar and Vietnam were genetically close and were also closely related to previous isolates from Myanmar in 1997 and 2000.
Figure 3.7 Neighbour-Joining Tree for the VP1 Gene of 47 FDMV Isolates from Upper Mekong Region Countries
3.4 Discussion

Foot and Mouth Disease is a notifiable disease in the Upper Mekong Region, and vaccination has been the main control strategy applied in the region. From 2000 to 2010, a total of 3,685 outbreaks were reported to the OIE SEAFMD online database. More (39%) outbreaks were reported in Vietnam followed by Thailand (34%). There was no specific trend in the number of outbreaks in the Upper Mekong Region over the 11 year period. However, FMD outbreaks occurred more frequently in December and January than in other months, but no evidence was found to explain this seasonal difference. Further research is required to study this seasonal trend. In 2005 the number of animals vaccinated against FMD was reduced, since some of the budget ear-marked for vaccination of FMD was transferred to the control of Avian Influenza and the upgrading of the capacity to diagnose FMD in Vietnam (Do 2005; Morrissy 2011b). This may have resulted in an increased proportion of susceptible animals and the subsequent epidemic in Vietnam in 2006. Consequently, the Vietnamese government approved the spending of US$ 12.5 million on FMD control in 2007, which was much higher than the US$4 million spent in the previous year (OIE 2006b; 2007b).

Although information was available on 3,685 outbreaks from the online database, most (63%) had no results for the relevant serotype. This was because either no samples had been collected (57%), the samples were not good enough/suitable for testing (5%) or because no details about the outbreak were provided (1%). It is important that these four countries pay more attention to their animal disease control and surveillance strategies and to facilitate this it is important to ensure more outbreaks are sampled and serotyped.
As only a small number of samples were sequenced the results found in this study may not necessarily be representative of the true situation in these countries.

Serotype O was the most prevalent (67%) serotype. The SEA topotype of serotype O poses a threat to each of these countries every year. The serotype A (31%) Asia topotype was prevalent in the Upper Mekong Region as a geographically restricted genotype (Knowles and Samuel 2003). In contrast serotype Asia-1 (2%) was infrequently isolated. All three serotypes showed close genetic relationships indicating the endemic nature of FMD in the Upper Mekong Region. The strains found in recent years (2007 to 2009) showed very close genetic relationships, as opposed to those isolated from earlier outbreaks. The circulation of FMDV in SEA is believed to be the result of livestock movements within and between countries (Parida 2011). Unofficial cross-boundary animal movements in SEA and subsequent disease are believed to be one of the main reasons that preclude the development of the livestock industry in this region (Fujita 2002).

International organisations have been concentrating on zoning and the control of animal movements in SEA to progressively control FMD in the Mekong Region (Abila 2005b; Bouchot 2009; Oketani 2006). However, it has been suggested that as SEA is an underdeveloped area, control of the disease may not be implemented widely or be effective (Ozawa 1993; Sasaki 1993). Most livestock are kept by small holders, and consequently there are low inputs into their health and low levels of biosecurity adopted (Gleeson 2002). Furthermore animal holders may either not notice disease outbreaks or
may fail to report an outbreak promptly. The improved control of FMD in the Upper Mekong Region primarily depends upon enhanced diagnostic services and heightened public awareness of the disease (Khounsy 2007; Ozawa 1993). One of the implementations adopted by the OIE for studying the disease and understanding the impact of the disease control programs adopted in SEA has been the online disease reporting system and database (Ben Jebara 2007; Blajan and Chillaud 1991).

It has been recommended and encouraged by the OIE that Upper Mekong Region countries should endeavour to promptly detect, report and diagnose outbreaks of FMD, and to increase cooperation on assessing cross-boundary animal movements (OIE 2006a). Research regarding animal movements in the region and the risks associated with these movements is presented in the following three chapters.
Chapter 4. Risk Analysis of the Movement of Cattle and Pigs to China from Myanmar
Chapter 4. Risk Analysis of the Movement of Cattle and Pigs to China from Myanmar

4.1 Animal Movement between Upper Mekong Region Countries

As outlined in the previous chapter, FMD is an endemic infectious disease in the Upper Mekong Region. One of the reasons that FMD is difficult to eradicate from this region is the continuous livestock movements within and between countries in this region. It is important to understand the pattern of livestock movements in the region to both determine the risk of FMD spreading and for the development of effective control strategies for the disease (Fujita 2005; Hawkins et al. 2012).

Trading of livestock along land and river routes has existed in the Upper Mekong Region for many centuries (Chapman 1995; Liao 2010). However since the 1990s the pattern of animal movement in the region has changed. At the beginning of the 1990s, Thailand was the main importing country and Yunnan Province in China, Myanmar and northern Laos were all exporting countries/regions (Figure 4.1). In the 1990s the animal movement route between China and Myanmar was from Yunnan Province to Kengtung Township and Tachilek Township. The major route between China and Thailand was from Yunnan Province, along the Mekong River, to Chiang Mai and Lampang provinces. There was also a route from China to Laos, involving movement from Yunnan Province to five northern provinces in Laos. All these livestock travelling routes were destined to Thailand (Chapman 1995). These animal movements increased from 1991 to 1993 and then decreased in 1994. The reasons for the initial increase were believed to be associated with population growth in Thailand and improved personal wealth of Thai nationals. The growth of the market for meat in Thailand resulted in an increase in the
price of meat and an associated increase in the unofficial importation of animals from neighbouring countries (Chapman 1995).

**Figure 4.1 Animal Movements towards Thailand in the Upper Mekong Region in the Early 1990s**

Recent studies in the upper Mekong countries have highlighted changes in the animal movement patterns and have demonstrated that most movements are concentrated in the border areas of the countries (Figure 4.2) (Oketani 2006). The main destination country had changed to China; however Chinese protocol requires that all animals and animal products imported into China need formal agreements approved at the national level. All stock should be provided with health certification and subjected to quarantine inspection.
Live ruminants (including embryos and semen) and ruminant products are prohibited from importation from Myanmar (MOA 1999), Thailand (C.I.Q 1998), Laos (MOA 1990) and Vietnam (MOA 1990) and can only be imported from countries with proven FMD free status. Border markets are required to be located near a quarantine office and are under the control of these quarantine offices. Animals and animal products imported from border markets are restricted and are required to be used only for local use. Live animals from border markets may be transported into inland China only after six months quarantine (MOA 1990).

Figure 4.2 Animal Movements in the Upper Mekong Region in the 2000s
4.1.1 Geographical Information of the National Border Region in Yunnan and Guangxi Provinces

The international border of Yunnan Province extends for 4,060 kilometres. It separates eight cities in Yunnan Province from three Southeast Asian countries (Myanmar, Lao PDR and Vietnam). Official entry to Yunnan Province can be via four airports, three seaports, one railway port and 15 highway points (eight at the national level and seven at the provincial level). There are also 108 international crossings and border markets which provide convenient passages and opportunities for local people to conduct business (Guo 2007).

To control animal disease outbreaks and transmission of disease in the border areas, 21 border surveillance stations were built prior to 2010 in Yunnan and Guangxi Provinces (MOA 2010a). Even though the number of official entry points has increased in the last few years, there are still a large number of unofficial (or informal) cross boundary animal movements between neighbouring countries and China. These movements pose a potential risk for the entry of diseases or strains of organisms, including FMDV, into China.

In the current and two following chapters, information on animal movement from the neighbouring Upper Mekong Region countries to China is described and the risk posed by these animal movements assessed. Two species of livestock are considered most important for the transmission of FMD in this region: cattle and pigs. This chapter focuses on movements from Myanmar to China, whilst the following chapters will focus on the movements from Thailand, Laos and Vietnam to China.
4.2 Materials and Methods

4.2.1 Sources of Data

The aim of this chapter was to analyse the risk of the informal movement of cattle and pigs from Myanmar to China. Several projects investigating animal movements among the Upper Mekong Region countries have already been conducted by ACIAR and OIE (Lüthi 2011; Scoizec 2009). However research from these projects was primarily restricted to the Upper Mekong Region countries but excluded China. The research described in this chapter was conducted in Yunnan Province, China and data reported were collected from China, and included published Chinese papers, Chinese government documents and informal talks with Chinese traders.

4.2.2 Survey Conducted in Yunnan Province

A field trip to Yunnan Province was organised and conducted by the Yunnan Tropical and Subtropical Animal Viral Disease Laboratory (YTSAVDL). The field trip was centred on the border area between the neighbouring South East Asian countries and Yunnan Province. The trip involved visiting three national level road entry ports into Yunnan Province, one dairy farm, one pig farm, one village that straddles the border, and one autonomous prefecture veterinary department. As this research was concerned with non-government approved animal businesses and business in the Golden Triangle (an area formed by the bordering regions of Myanmar, Laos and Thailand, and which is one of Asia’s main illicit opium-producing areas), to protect the responders’ safety and rights, no formal interviews or official talks were undertaken. To further protect the identities of the participants in this study, no definite location information, identities or
office/department names were recorded. The informal interviews/talks were organised through informal conversations conducted by YTSAVDL. The information and data obtained through these interviews/talks were summarised by YTSAVDL and provided for the research reported in this and the following chapters.

The information collected from the field trip included data on animal movements from Upper Mekong Region countries to Yunnan and Guangxi Provinces. In Yunnan and Guangxi Provinces informal animal businesses involving cattle, pigs, and sheep are undertaken and wild species such as wild boar (*S. scrofa*), muntjac (*Muntiacus* spp.), and Asian elephant (*Elephas maximus*) are present. These can all be infected with FMDV.

In this chapter, the potential risk for the transmission of FMD through the movement of cattle and pigs from Myanmar is discussed and in the following two chapters the risk posed by the movements from other Upper Mekong Region countries is outlined. The materials and methods used for the risk assessment reported in these three chapters were the same.

To describe the animal movements the geographical information system software Quantum GIS (version 1.7.0) (www.qgis.org) was used.

### 4.2.2.1 Route A. Cattle Movement from Sagaing Division, Myanmar to Western Yunnan Province

Sagaing Division is located in northern Myanmar and borders China and north-eastern India. It has a large number (more than three million) of cattle, buffalo and sheep/goats and several large animal markets (Naing Oo 2010). Cattle in the Sagaing Division are collected from different markets and then transported by ship along the Irrawaddy River.
or by railway to Myitkyina, Kachin State, in Myanmar. The livestock are then walked or trucked by local traders or farmers to Yunnan Province (Figure 4.3). The border between Kachin State and Yunnan Province is mountainous with peaks from 1000 to 3800 metres high. Most cattle movements occur in low altitude areas as this is less stressful than high altitude areas where the oxygen levels and temperatures are low. This route from Sagaing to Yunnan was identified as Route A.

**Figure 4.3 Route A - Cattle Movement from Northern Myanmar to Yunnan Province, China**

The survey results of Route-A provided by the YTSAVDL are displayed in Table 4.1. According to the survey, cross-border movements normally take two to three days either by truck or by walking. The similar time was due to the fact that animals which were walked were able to be taken on a shorter route compared with the longer route, with a gentler gradient, that was required for the roads used by trucks. According to the survey, some cattle could die during transport due to sickness or from an accident. The
carcasses of these dead animals could be contacted by wild animals living in the mountains which then may directly or indirectly spread FMDV to wild FMD-susceptible animals. Some cattle potentially could be lost during the cross-border walk, and might subsequently live in the mountains as wild or feral animals. These cattle were considered a potential risk as disease carriers and consequently may spread FMDV. Cattle that stayed with traders could also become infected through contact with other livestock living in the mountains. However, according to the survey, the majority of livestock in Yunnan Province were raised on the flat basin area, with only a few animals raised in the mountains or foothills. Notwithstanding this, these animals could pose a risk to livestock introduced from Myanmar into Yunnan. Although there had been no outbreaks of FMD reported in Yunnan over the past decade, there was a small chance that FMDV could be present in Yunnan but had not been detected.

Cattle from Myanmar could be detected by Chinese customs officers en route. In this case, detected animals were confiscated and destroyed. However, the confiscated and destroyed cattle may still pose a slight risk to local animals and this risk was estimated from the survey. When animals from Myanmar arrive at their destination in Yunnan Province, some are slaughtered immediately to avoid the risk of being detected by the Chinese customs officers. The slaughter houses in China are fully licensed and need to follow the quarantine and inspection laws in China. Nevertheless, there is a risk that the inspection procedure at the slaughter houses may fail to detect infected animals. Furthermore the offal and waste from slaughter could still contain viable FMDV and pose a disease risk to other livestock in Yunnan. The FMD risk from slaughter houses were estimated in this study and are summarised in Table 4.1.

Some cattle from Myanmar may be kept (fattened) by local farmers in Yunnan prior to slaughter. These cattle have the potential to mix with local cattle and, if infected,
introduce FMDV to other animals in the herd. Because the survey was conducted on the Chinese side of the border, the risk factors for dead, lost, destroyed, slaughtered and animals kept all refer to events in Yunnan Province.

Table 4.1 Details on the Movement of Cattle along Route A

<table>
<thead>
<tr>
<th>Possibility and numbers estimated by respondents in the survey</th>
<th>Minimum</th>
<th>Most likely</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Become infected from contact with infected wild/feral animals living in the mountains</td>
<td>0.01%</td>
<td>0.02%</td>
<td>0.04%</td>
</tr>
<tr>
<td>Died en route in the mountains</td>
<td>0.3%</td>
<td>0.4%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Carcasses spread disease to wild animals</td>
<td>0.01%</td>
<td>0.02%</td>
<td>0.04%</td>
</tr>
<tr>
<td>Animals lost in the mountain</td>
<td>0.1%</td>
<td>0.2%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Become infected from other livestock in the mountains near Chinese farms</td>
<td>0.04%</td>
<td>0.06%</td>
<td>0.08%</td>
</tr>
<tr>
<td>Detected by Chinese customs officers</td>
<td>3%</td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td>Virus survives and is disseminated from carcasses of animals destroyed by the Chinese customs</td>
<td>10%</td>
<td>15%</td>
<td>20%</td>
</tr>
<tr>
<td>Animals are kept on a Chinese farm for fattening</td>
<td>20%</td>
<td>25%</td>
<td>30%</td>
</tr>
<tr>
<td>FMDV is spread from slaughter houses to local animals</td>
<td>20%</td>
<td>25%</td>
<td>30%</td>
</tr>
<tr>
<td>Number of shipments each year</td>
<td>20</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>Number of cattle per shipment</td>
<td>Respondent</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Most Likely</td>
<td>40</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>60</td>
<td>80</td>
</tr>
</tbody>
</table>
4.2.2.2 Route B. Movement of Pigs from Shan state, Myanmar to Southern Yunnan Province along the Mekong River.

The fieldwork in Yunnan in 2010 indicated there was unofficial trade of pigs from Myanmar to China. This route, Route B, is from Shan State, Myanmar to Yunnan Province. Shan State is located in the eastern part of Myanmar and borders China to the north. Shan State is a large state making up nearly one quarter of the area of Myanmar. Pigs that are moved originated from the eastern part of Shan State which borders China and the Mekong River (Figure 4.4).

The pigs are transported to Yunnan Province by walking, via truck or through ship along the Mekong River. However, transport along the Mekong River is the main form of transportation of pigs from Shan State. Animals transported by truck or ship usually originated from the south east region of Shan State where there is a large population of pigs, compared with regions closer to the border.

**Figure 4.4 Route B – Movement of Pigs from Shan State, Myanmar to Yunnan Province, China**
The survey results for Route B provided by the YTSA VDL are displayed in Table 4.2. It may take one to three days for pigs to travel from Shan State to Yunnan. During this time pigs may die from disease, accident or hyperthermia prior to reaching their destination in China. The carcasses of these dead pigs may pose a risk of introducing FMDV to China if the animals are infected. Surviving pigs may be infected subclinically and subsequently shed FMDV to other susceptible animals in China. En route to their destination, the pigs could be detected by Chinese customs officers. According to Chinese law, any pigs detected by Customs should be destroyed; however even then there is a risk that virus could be shed during destruction and disposal. As these stock movements are not legal, traders are likely to choose the most covert way to transport their animals. Consequently it was difficult for Chinese customs to discover these informal movements of pigs. The survey indicated that up to 75% of pigs from Myanmar would be sold to slaughter houses for slaughter as soon as practical after entering China.

Table 4.2 Details on the Movement of Pigs along Route B

<table>
<thead>
<tr>
<th>Possibility and numbers estimated by respondents in the survey</th>
<th>Minimum</th>
<th>Most likely</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Died en route to China</td>
<td>1%</td>
<td>3%</td>
<td>4%</td>
</tr>
<tr>
<td>Carcasses spread disease to wild/feral animals</td>
<td>0.03%</td>
<td>0.05%</td>
<td>0.07%</td>
</tr>
<tr>
<td>Animals get infected after unloading in China</td>
<td>0.04%</td>
<td>0.06%</td>
<td>0.08%</td>
</tr>
<tr>
<td>Animals detected by Chinese customs</td>
<td>10%</td>
<td>15%</td>
<td>20%</td>
</tr>
<tr>
<td>Virus survives and is disseminated from carcasses of animals destroyed by the Chinese customs</td>
<td>10%</td>
<td>15%</td>
<td>20%</td>
</tr>
<tr>
<td>Animals are kept on a Chinese farm for fattening</td>
<td>5%</td>
<td>15%</td>
<td>25%</td>
</tr>
</tbody>
</table>
### Possibility and numbers estimated by respondents in the survey

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Most likely</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMDV is spread from slaughter houses to local animals</td>
<td>20%</td>
<td>25%</td>
<td>30%</td>
</tr>
<tr>
<td>Number of pigs imported each month from Myanmar during the peak season</td>
<td>2000</td>
<td>2200</td>
<td>2500</td>
</tr>
<tr>
<td>Number of pigs imported each month from Myanmar during the minor peak season</td>
<td>1000</td>
<td>1200</td>
<td>1500</td>
</tr>
</tbody>
</table>

The number of pigs entering China along Route B via the Mekong River was influenced by the season. In the peak movement season, from October to January, 2000 to 2500 pigs were moved along Route D each month. After the peak season (February to April and September), the number reduced to between 1000 and 1500 per month (minor peak). In the dry season (May to August) trading along the Mekong River stopped, although there were still small numbers of pigs transported via other routes. However as no information could be gathered on the movements during the dry season, the risk analysis only focused on the business during the peak and minor peak seasons, and it was assumed that the number of pigs transported from Myanmar to Yunnan during the dry season was negligible to zero.

#### 4.2.3 Scenario Trees

According to the route details from Tables 4.1 and 4.2, two scenario trees were constructed to reflect the two pathways (Routes A and B) of animal movements. Scenario tree A indicated the cattle movements along Route A from Sagaing Province, Myanmar to Yunnan Province, China (Figure 4.5) and Scenario Tree B displayed pig movements from Shan State, Myanmar to Yunnan Province, China (Figure 4.6). Each
branch of the tree was assigned a risk, based on the findings for Routes A and B.

**Figure 4.5 Scenario Tree A – Process of Cattle Movements along Route A**
Figure 4.6 Scenario Tree B – Process of Pigs Movements along Route B

- Pigs in Myanmar
  - Pigs from Myanmar infected with FMD ($P_{mp}$)
  - Pigs from Myanmar die en route on Mekong River ($P_{pd}$)
    - Dead pigs spread FMDV to China ($P_a$)
      - FMD risk from Myanmar pigs carcasses ($P_{mpd}$)
        - Myanmar pigs confiscated by Chinese customs ($P_{cm}$)
          - Confiscated pigs not destroyed properly ($P_{ca}$)
            - FMD risk confiscated Myanmar pigs ($P_{mpc}$)
              - Kept on Chinese farms for fattening ($P_{pf}$)
                - FMD risk from fattening pigs ($P_{mpfc}$)
      - Pigs stayed with traders ($1-P_{ca}$)
    - Myanmar pigs get infected in China ($P_e$)
      - Myanmar pigs transported to China become infected with FMD ($P_{pe}$)
    - Uninfected in China
  - Pigs initially not infected
    - Pigs sold to slaughter houses ($P_{ps}$)
      - Pigs not slaughtered properly ($P_n$)
        - FMD risk from slaughter houses ($P_{mpn}$)
4.2.4 Stochastic Models

4.2.4.1 Methods and Tools

To analyse the risk of the movement of cattle and pigs, two stochastic models were built to display the informal animal movements along Routes A and B, respectively. In order to develop the quantitative analysis of these models, data collected from field trips were organised to fit the parameters of the models. All parameters were estimated by various probability distributions which included the Pert, Discrete, Binomial and Beta distributions. The results of the distributions were simulated with Monte Carlo analyses and distribution curves generated. The details of the statistical methods used in this chapter are listed in Tables 4.4 to 4.6. Data displayed in these tables were collected during field trips by the YTSAVDL, at informal meetings, from government documents, published articles and meeting records. These data were entered into Excel® and the relevant distributions and formulas applied.

The add-in to Excel®, PopTools version 3.2.5, was the main risk assessment tool used for analysing stochastic processes (Hood 2010). The program @RISK 5.7 student version (Palisade Decision Tools, Palisade Corporation) was used to perform the sensitivity analyses. Basic calculations and data evaluation were undertaken in Microsoft® Excel® 2010.
I. Model of Route A

The parameters for the model of Route A are summarised in Table 4.3.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Distribution /Formula /Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_{(\text{Chaung-U})} )</td>
<td>Prevalence of FMD in Chaung-U animal market, Myanmar</td>
<td>5% of total cattle from Chaung-U</td>
</tr>
<tr>
<td>( P_{(\text{Sagaing})} )</td>
<td>Prevalence of FMD in Sagaing animal market, Myanmar</td>
<td>80% of total cattle from Sagaing</td>
</tr>
<tr>
<td>( P_{(\text{Kanbalu})} )</td>
<td>Prevalence of FMD in Kanbalu animal market, Myanmar</td>
<td>5% of total cattle from Kanbalu</td>
</tr>
<tr>
<td>( P_{(\text{Monywa})} )</td>
<td>Prevalence of FMD in Monywa animal market, Myanmar</td>
<td>5% of total cattle from Monywa</td>
</tr>
<tr>
<td>( P_{(\text{Myinmu})} )</td>
<td>Prevalence of FMD in Myinmu animal market, Myanmar</td>
<td>5% of total cattle from Myinmu</td>
</tr>
</tbody>
</table>
| \( P_{\text{mm}} \)          | Prevalence of FMD in Sagaing province, Myanmar                   | Discrete \( P_{(\text{Chaung-U})}, 5\% \)
|                           |                                                                 | \( P_{(\text{Sagaing})}, 80\% \)
|                           |                                                                 | \( P_{(\text{Kanbalu})}, 5\% \)
|                           |                                                                 | \( P_{(\text{Monywa})}, 5\% \)
<p>|                           |                                                                 | ( P_{(\text{Myinmu})}, 5% )                                                        |
| ( P_{\text{mi}} )          | Possibility of getting infection at the beginning of the shipment| Pert(0.01%, 0.02%, 0.04%, 4)                                                            |
| ( P_{\text{mm1}} )         | Possibility of Myanmar cattle being infected with FMD at the beginning of the shipment | ( P_{\text{mm1}} = P_{\text{mm}} + P_{\text{mi}} )                                   |
| ( P_{\text{md}} )          | Possibility of Myanmar cattle dying en route                     | Pert (0.3%, 0.4%, 0.5%, 4)                                                             |
| ( P_{\text{mdm}} )         | Possibility of disease spreading into animals resident in the Chinese mountains from infected carcasses of animals dying en route | Pert(0.01%, 0.02%, 0.04%, 4)                                                            |
| ( P_{\text{mr1}} )         | Risk of FMD from Myanmar cattle carcasses abandoned in the wild   | ( P_{\text{mr1}} = P_{\text{mm1}} \times P_{\text{md}} \times P_{\text{mdm}} )       |
| ( P_{\text{ml}} )          | Possibility of Myanmar cattle wandering off on the way to the final destination | Pert (0.1%, 0.2%, 0.3%, 4)                                                             |</p>
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Distribution /Formula /Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{mr2}$</td>
<td>Risk of FMD from infected Myanmar cattle wandering off on the way</td>
<td>$P_{mr2}=P_{mm1} \times P_{ml}$</td>
</tr>
<tr>
<td>$P_{mii}$</td>
<td>Possibility of Myanmar cattle getting infected from wild/feral animals in the mountain</td>
<td>Pert(0.04%,0.06%,0.08%, 4)</td>
</tr>
<tr>
<td>$P_{ms}$</td>
<td>Possibility of Myanmar cattle being infected with FMD during travel from the mountains to their final destination</td>
<td>$P_{ms} = P_{mm1} \times (1-P_{md} \times P_{ml}) + P_{mii}$</td>
</tr>
<tr>
<td>$P_{mc}$</td>
<td>Possibility of cattle being confiscated by Chinese customs officers</td>
<td>Pert (3%, 5%, 10%, 4)</td>
</tr>
<tr>
<td>$P_{mcr}$</td>
<td>Possibility of virus spreading from the carcasses of the confiscated animals</td>
<td>Pert (10%, 15%, 20%, 4)</td>
</tr>
<tr>
<td>$P_{mr3}$</td>
<td>FMD risk from confiscated Myanmar cattle</td>
<td>$P_{mr3} = P_{ms} \times P_{mc} \times P_{mcr}$</td>
</tr>
<tr>
<td>$P_{mk}$</td>
<td>Possibility of Myanmar cattle being kept for fattening on Yunnan farms</td>
<td>Pert (20%, 25%, 30%, 4)</td>
</tr>
<tr>
<td>$P_{mr4}$</td>
<td>Risk of FMD from the fattening Myanmar cattle</td>
<td>$P_{mr4} = P_{ms} \times P_{mk}$</td>
</tr>
<tr>
<td>$P_{mhr}$</td>
<td>Possibility of disease originating from slaughter houses</td>
<td>Pert (20%, 25%, 30%, 4)</td>
</tr>
<tr>
<td>$P_{mr5}$</td>
<td>FMD risk from Yunnan slaughter houses</td>
<td>$P_{mr5} = P_{ms} \times (1-P_{mc} \times P_{mk}) \times P_{mhr}$</td>
</tr>
<tr>
<td>$P_{route-A}$</td>
<td>FMD risk from Myanmar cattle</td>
<td>$P_{mr1} + P_{mr2} + P_{mr3} + P_{mr4} + P_{mr5}$</td>
</tr>
<tr>
<td>$N_{mp}$</td>
<td>Number of cattle shipments from Myanmar each year</td>
<td>Pert (20, 20, 30, 4)</td>
</tr>
<tr>
<td>$N_{ms1}$</td>
<td>Number of cattle coming from Myanmar per shipment according to Expert No. 1</td>
<td>Pert (5, 40, 60, 4)</td>
</tr>
<tr>
<td>$N_{ms2}$</td>
<td>Number of cattle coming from Myanmar per shipment according to Expert No. 2</td>
<td>Pert (10, 35, 80, 4)</td>
</tr>
<tr>
<td>$N_{ms2}$</td>
<td>Number of cattle coming from Myanmar per shipment according to Expert No. 3</td>
<td>Pert (3, 60, 100, 4)</td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
<td>Distribution /Formula /Note</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>$N_{ms}$</td>
<td>Number of cattle coming from Myanmar per shipment</td>
<td>Discrete ($N_{ms1}$, 1 $N_{ms2}$, 1 $N_{ms3}$, 1)</td>
</tr>
<tr>
<td>$N_{msy}$</td>
<td>Number of cattle coming from Myanmar per year</td>
<td>VLOOKUP($N_{mp}$,Table4.6, 3)</td>
</tr>
<tr>
<td>$N_{route-A}$</td>
<td>Number of Myanmar cattle each year posing a risk of introducing FMD to China through Route A</td>
<td>Binomial[$P_{route-A}$, $N_{msy}$]</td>
</tr>
</tbody>
</table>

a) **Prevalence of FMD in Sagaing province, Myanmar – $P_{mm}$**

Cattle travelling from Myanmar along Route A were first collected from the middle of the Sagaing Division (north-western Myanmar). According to Naing Oo (2010) the Sagaing Province has five main domestic animal markets located in Chaung-U, Sagaing (township), Kanbalu, Monywa and Myinmu. The probability a cow from one of the five animal markets in Sagaing Province is infected with FMDV was based on the research carried out by Naing Oo (2010) (Table 4.4).

**Table 4.4 Prevalence of FMD in Animals Markets in Sagaing Province, Myanmar (Naing Oo 2010)**

<table>
<thead>
<tr>
<th>Markets</th>
<th>Apparent Prevalence (%)</th>
<th>95% CI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chaung-U</td>
<td>43.8</td>
<td>29.7 - 57.8</td>
</tr>
<tr>
<td>Kanbalu</td>
<td>8.5</td>
<td>2.4 - 20.4</td>
</tr>
<tr>
<td>Sagaing</td>
<td>6.0</td>
<td>1.2 - 16.5</td>
</tr>
<tr>
<td>Myinmu</td>
<td>10.0</td>
<td>1.7 - 18.3</td>
</tr>
<tr>
<td>Monywa</td>
<td>4.3</td>
<td>0.5 - 14.5</td>
</tr>
</tbody>
</table>
The opinions of the respondents were that 80% of the cattle originated from the Sagaing township with the remaining 20% from the other 4 areas (Chaung-U, Kanbalu, Myinmu and Monywa). It was assumed that the prevalence of FMD in the Sagaing Division had not changed significantly since 2004 because there have been very limited use of FMD vaccine in this area, and that the townships of Chaung-U, Kanbalu, Myinmu and Monywa provided equal numbers of cattle to China. A discrete distribution was used to model the probability that an informally exported animal from Myanmar was infected with FMD ($P_{mm}$).

$$P_{mm} = \text{Discrete (} P_{(\text{Chaung-U})}, 5\% \) \quad P_{(\text{Sagaing})}, 80\% \) \quad P_{(\text{Kanbalu})}, 5\% \) \quad P_{(\text{Monywa})}, 5\% \) \quad P_{(\text{Myinmu})}, 5\% \)$$

b) Possibility of Myanmar cattle being infected with FMD at the beginning of the shipment - $P_{mm1}$

Cattle travelling from Myanmar needed to walk two to three days through forest and mountains to reach China. Some transport of cattle involved the use of vehicles (trucks). At the beginning of the shipment, except for cattle from Myanmar that were already infected with FMD ($P_{mm}$), uninfected cattle could pick up infection through fomites, primarily through a contaminated vehicle, or from having effective contact with infected local animals/carriers. However, the experts estimated that the possibility of an animal from Myanmar being infected at the start of the shipment ($P_{mi}$) was very low. The possibility of cattle from Myanmar being or becoming infected ($P_{mm1}$) is influenced by the prevalence of FMD in the Myanmar animal markets and the possibility of gaining infection during shipment ($P_{mi}$).
\[ P_{\text{mi}} = \text{Pert (0.01\%, 0.02\%, 0.04\%, 4)} \]
\[ P_{\text{mm1}} = P_{\text{mm}} + P_{\text{mi}} \]

**c) FMD risk from Myanmar cattle carcasses abandoned in the wild – \( P_{\text{mr1}} \)**

On the way to China, some cattle may die from illness or accidents, even though the healthiest animals would be preferentially selected in Myanmar. The mortality of cattle from Myanmar en route (\( P_{\text{md}} \)) was estimated to be between 0.3 and 0.5\%, with a most likely value of 0.4\%. Animals that died en route would be left where they die by traders. If these carcasses were eaten by wild pigs or there was contact with other livestock in the mountain, there was the chance of FMDV transmission, albeit low. This risk of disease spread through animal carcasses (\( P_{\text{mdm}} \)) was estimated to be from 0.01 to 0.04\%, with a most likely value of 0.02\%. \( P_{\text{mr1}} \) was assigned to the FMD risk from Myanmar cattle carcasses abandoned in the wild.

\[ P_{\text{md}} = \text{Pert (0.3\%, 0.4\%, 0.5\%, 4)} \]
\[ P_{\text{mdm}} = \text{Pert (0.01\%, 0.02\%, 0.04\%, 4)} \]
\[ P_{\text{mr1}} = P_{\text{mm1}} \times P_{\text{md}} \times P_{\text{mdm}} \]

**d) Possibility of FMD infected cattle wandering off on the way but surviving and living in China – \( P_{\text{mr2}} \)**

On the way to China, cattle could wander off into the forest and then live in the mountains as wild livestock. Even though the traders would try their best to keep all animals, the probability of an animal being lost (\( P_{\text{ml}} \)) was estimated to be between 0.1 and 0.3\%, with a most likely value of 0.2\%. These lost but surviving cattle from Myanmar had the potential to introduce FMDV to other livestock if they were infected with FMD. \( P_{\text{mr2}} \) was assigned to the possibility of an FMD infected cow wandering off on the way but surviving and living in China.

\[ P_{\text{ml}} = \text{Pert (0.1\%, 0.2\%, 0.3\%, 4)} \]
\[ P_{\text{mr2}} = P_{\text{mm1}} \times P_{\text{ml}} \]
e) Cattle staying with traders being FMD infected - $P_{ms}$

In Yunnan the population density of livestock increases as the altitude decreases, since most people live in the flat basin region of Yunnan and it is here that they keep and manage their livestock. In the mountaineous area there is a possibility that cattle from Myanmar may acquire FMD from local livestock; however this is likely to be low as there has been a high level of vaccination along the border of Yunnan Province, and no outbreak of FMD has been reported from Yunnan Province during the past decade. Experts estimated that the possibility of cattle from Myanmar being infected en route through contact with infected local livestock ($P_{mii}$) was from 0.04 to 0.08% with a most likely value of 0.06%. The probability of cattle from Myanmar that stayed with the traders but became infected with FMD, $P_{ms}$, was calculated with the following formula.

$$P_{mii} = \text{Pert (0.04\%, 0.06\%, 0.08\%, 4)}$$
$$P_{ms} = P_{mm1} \times (1 - P_{md} - P_{ml}) + P_{mii}$$

f) FMD risk from confiscated Myanmar cattle – $P_{mr3}$

An animal that was traded to China and was not lost or died could be detected by the Chinese customs ($P_{mc}$). Once found by the Chinese customs officers, according to Chinese law, animals would be destroyed immediately and then should pose minimal to no risk to local Chinese animals. However if the animals were not destroyed immediately and the carcasses disposed of correctly, or if the confiscated animals were not destroyed but sold, then there is a risk of infection. The experts estimated that the risk of FMDV existing after confiscation of the animals ($P_{mcr}$) was between 10 and 20%, with a most likely value of 15%. $P_{mr3}$ was assigned to be the FMD risk from confiscated Myanmar cattle.
\[
P_{\text{mc}} = \text{Pert (10\%, 15\%, 20\%, 4)}
\]
\[
P_{\text{mr3}} = P_{\text{ms}} \times P_{\text{mc}} \times P_{\text{mcr}}
\]

**g) FMD risk from Myanmar cattle kept on Yunnan farms – \( P_{\text{mr4}} \)**

Cattle shipments from Myanmar that had not been detected by Chinese customs would either be transported to farms for fattening or to slaughter houses for the meat market. Approximately 20 to 30% of the cattle (\( P_{\text{mk}} \)) were transported to farms for fattening for a period of weeks to months. These cattle are raised together with local animals and may transmit FMD to local animals. \( P_{\text{mr4}} \) was assigned to the risk of FMD being introduced from cattle originating from Myanmar and kept for fattening in Yunnan.

\[
P_{\text{mk}} = \text{Pert (20\%, 25\%, 30\%, 4)}
\]
\[
P_{\text{mr4}} = P_{\text{ms}} \times P_{\text{mk}}
\]

**h) FMD risk from Myanmar cattle sold to slaughter houses – \( P_{\text{mr5}} \)**

Most of the cattle transported from Myanmar were sold to slaughter houses in Yunnan and were slaughtered as soon as possible on arrival to avoid detection by Chinese customs and veterinary officers. Slaughter houses in Yunnan are fully licensed and need to follow the laws and regulations determined by the Chinese government. These laws stipulate the quarantine, inspection and waste processes, however it is possible that not all processes were undertaken correctly and diseased animals may be missed during the inspection process. Further risks for the escape of FMDV could arise from indirect spread of FMDV by staff, waste or vehicles. The experts estimated the possibility of disease being transmitted from slaughter houses (\( P_{\text{mhr}} \)) was 20 to 30%, with a most likely value of 25%. This estimation included all possible methods of FMDV escaping from the slaughter houses.

\[
P_{\text{mhr}} = \text{Pert (20\%, 25\%, 30\%, 4)}
\]
\[
P_{\text{mr5}} = P_{\text{ms}} \times (1 - P_{\text{mc}} - P_{\text{mk}}) \times P_{\text{mhr}}
\]
The number of cattle from Myanmar travelling via Route A which pose an FMD risk to Yunnan Province, China – \(N_{\text{route-A}}\)

The possibility of an infected cow from Myanmar staying in China after entering informally through Route A (\(P_{\text{route-A}}\)) was the sum of \(P_{\text{mr1}}\) to \(P_{\text{mr5}}\). \(N_{\text{msy}}\) was set as the total number of cattle traded from Myanmar to China each year. The number of shipments each year (\(N_{\text{mp}}\)) was between 20 and 30. The number of cattle per shipment (\(N_{\text{ms}}\)) was calculated from the opinions of three different experts and the discrete distribution used. \(N_{\text{ms}}\) was independently calculated 30 times, and each of these results was numbered one to 30. The sum of each \(N_{\text{ms}}\) and all of its prior \(N_{\text{ms}}\) was then calculated to show the total number of cattle shipped from one shipment to \(n\) shipments (\(n=N_{\text{mp}}\)). \(N_{\text{msy}}\) was the sum of the first \(N_{\text{ms}}\) to the \(nN_{\text{ms}}\). Table 4.5 was set to equal the range of the three columns: number one to 30, \(N_{\text{ms}}\), \(N_{\text{msy}}\). The formula used to calculate \(N_{\text{msy}}\) involved using a VLOOKUP function in Excel (Table 4.5). The VLOOKUP function was used to calculate the \(N_{\text{msy}}\) as the number of cattle in each shipment varied.

The total number of cattle from Myanmar that posed a risk of introducing FMD to China each year through Route A (\(N_{\text{route-A}}\)) was calculated using a binomial distribution.

\[
P_{\text{route-A}} = P_{\text{mr1}} + P_{\text{mr2}} + P_{\text{mr3}} + P_{\text{mr4}} + P_{\text{mr5}} \\
N_{\text{mp}} = \text{Pert (20, 20, 30, 4)} \\
N_{\text{ms1}} = \text{Pert (5, 40, 60, 4)} \\
N_{\text{ms2}} = \text{Pert (10, 35, 80, 4)} \\
N_{\text{ms2}} = \text{Pert (3, 60, 100, 4)} \\
N_{\text{ms}} = \text{Discrete (}N_{\text{ms1}}, 1) \\
N_{\text{ms}} = \text{Discrete (}N_{\text{ms2}}, 1) \\
N_{\text{ms}} = \text{Discrete (}N_{\text{ms3}}, 1) \\
N_{\text{msy}} = \text{VLOOKUP}(N_{\text{mp}}, \text{Table 4.5, 3)} \\
N_{\text{route-A}} = \text{Binomial}[P_{\text{route-A}}, N_{\text{msy}}] \\
\]
Table 4.5 Details of VLOOKUP

<table>
<thead>
<tr>
<th>nN_{mp}</th>
<th>N_{ms}</th>
<th>N_{msy}</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>54 ((n1))</td>
<td>54 ((N1=n1))</td>
</tr>
<tr>
<td>2</td>
<td>54 ((n2))</td>
<td>108 ((N2=n2+N1))</td>
</tr>
<tr>
<td>3</td>
<td>34 ((n3))</td>
<td>142 ((N3=n3+N2))</td>
</tr>
<tr>
<td>...</td>
<td>......</td>
<td>......</td>
</tr>
<tr>
<td>20</td>
<td>38 ((n20))</td>
<td>840 ((N20=n20+N19))</td>
</tr>
<tr>
<td>21</td>
<td>34 ((n21))</td>
<td>874 ((N21=n21+N20))</td>
</tr>
<tr>
<td>22</td>
<td>38 ((n22))</td>
<td>912 ((N22=n22+N21))</td>
</tr>
<tr>
<td>23</td>
<td>34 ((n23))</td>
<td>946 ((N23=n23+N22))</td>
</tr>
<tr>
<td>24</td>
<td>54 ((n24))</td>
<td>1000 ((N24=n24+N23))</td>
</tr>
<tr>
<td>25</td>
<td>34 ((n25))</td>
<td>1034 ((N25=n25+N24))</td>
</tr>
<tr>
<td>26</td>
<td>34 ((n26))</td>
<td>1068 ((N26=n26+N25))</td>
</tr>
<tr>
<td>27</td>
<td>38 ((n27))</td>
<td>1106 ((N27=n27+N26))</td>
</tr>
<tr>
<td>28</td>
<td>38 ((n28))</td>
<td>1144 ((N28=n28+N27))</td>
</tr>
<tr>
<td>29</td>
<td>38 ((n29))</td>
<td>1182 ((N29=n29+N28))</td>
</tr>
<tr>
<td>30</td>
<td>54 ((n30))</td>
<td>1236 ((N30=n30+N29))</td>
</tr>
</tbody>
</table>
II. Model of Route B

The parameters included in the model for Route B are summarised in Table 4.6.

Table 4.6 Details of the Parameters of Route B (highlighted lines needed inputs)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Distribution /Formula /Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>N_{fp}</td>
<td>False positive results of NSPs tests</td>
<td>Negbin [40, 88.89%]</td>
</tr>
<tr>
<td>P_{mp}</td>
<td>Prevalence of FMD in Myanmar</td>
<td>Beta[40 + N_{fp} + 11347 - (40 + N_{fp}) + 1]</td>
</tr>
<tr>
<td>P_{pd}</td>
<td>Possibility of Myanmar pigs dying during transport along the Mekong River</td>
<td>Pert (1%, 3%, 4%, 4)</td>
</tr>
<tr>
<td>P_{rd}</td>
<td>Possibility of pig carcasses from dead animals introducing FMDV to China</td>
<td>Pert(0.03%, 0.05%, 0.07%, 4)</td>
</tr>
<tr>
<td>P_{mpr1}</td>
<td>FMD risk from pigs that died during transport along the Mekong River</td>
<td>$P_{mpr1} = P_{mp} * P_{pd} * P_{rd}$</td>
</tr>
<tr>
<td>P_{sc}</td>
<td>Probability that pigs from Myanmar get infected after entry to China</td>
<td>Pert(0.04%, 0.06%, 0.08%, 4)</td>
</tr>
<tr>
<td>P_{pi}</td>
<td>Probability that pigs from Myanmar traveling via the Mekong River are infected with FMD</td>
<td>$P_{pi} = P_{mp} * (1 - P_{pi}) + P_{ic}$</td>
</tr>
<tr>
<td>P_{dc}</td>
<td>Possibility of a pig shipment being detected by Chinese customs</td>
<td>Pert (10%, 15%, 20%, 4)</td>
</tr>
<tr>
<td>P_{nd}</td>
<td>Possibility of confiscated animals not being destroyed properly to inactivate the virus</td>
<td>Pert (10%, 15%, 20%, 4)</td>
</tr>
<tr>
<td>P_{mpr2}</td>
<td>The risk of FMD from the pigs confiscated by customs</td>
<td>$P_{mpr2} = P_{pi} * P_{dc} * P_{nd}$</td>
</tr>
<tr>
<td>P_{pk}</td>
<td>Possibility of Myanmar pigs kept on Chinese farms for fattening</td>
<td>Pert (5%, 15%, 25%, 4)</td>
</tr>
<tr>
<td>P_{mpr3}</td>
<td>FMD risk from pigs from Myanmar kept</td>
<td>$P_{mpr3} = P_{pi} * (1 - P_{dc}) * P_{pk}$</td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
<td>Distribution /Formula /Note</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>$P_{ps}$</td>
<td>Possibility of pigs from Myanmar being sold to slaughter houses</td>
<td>$P_{ps}=1- P_{pk}$</td>
</tr>
<tr>
<td>$P_{rs}$</td>
<td>Possibility of FMDV escaping from slaughter houses</td>
<td>Pert (20%, 25%, 30%, 4)</td>
</tr>
<tr>
<td>$P_{mpr4}$</td>
<td>FMD risk from Chinese slaughter houses</td>
<td>$P_{mpr3}=P_{pi}<em>(1- P_{dc})</em> P_{ps} * P_{rs}$</td>
</tr>
<tr>
<td>$P_{route-B}$</td>
<td>FMD risk from pigs originating from Myanmar</td>
<td>$P_{mpr1}+P_{mpr2}+P_{mpr3}+P_{mpr4}$</td>
</tr>
<tr>
<td>$N_{pm}$</td>
<td>Number of pigs from Myanmar imported each month during the peak season</td>
<td>Pert (2500, 2700, 3000, 4)</td>
</tr>
<tr>
<td>$N_{hpm}$</td>
<td>Number of pigs from Myanmar each per month during the minor peak season</td>
<td>Pert (1000, 1300, 1500, 4)</td>
</tr>
<tr>
<td>$N_{pms}$</td>
<td>Number of pigs imported from Myanmar during the peak season</td>
<td>SUM[$N_{pm1}, N_{pm2}, N_{pm3}, N_{pm4}$]</td>
</tr>
<tr>
<td>$N_{hpms}$</td>
<td>Number of pigs imported from Myanmar during the minor peak season</td>
<td>SUM[$N_{hpms1}, N_{hpms2}, N_{hpms3}, N_{hpms4}$]</td>
</tr>
<tr>
<td>$N_{py}$</td>
<td>Number of pigs imported from Myanmar each year</td>
<td>$N_{py}= N_{pms}+ N_{hpms}$</td>
</tr>
<tr>
<td>$N_{pms-B}$</td>
<td>Number of pigs from Myanmar introducing FMD to China during the peak season</td>
<td>Binomial[$N_{pms}, P_{route-B}$]</td>
</tr>
<tr>
<td>$N_{hpms-B}$</td>
<td>Number of pigs from Myanmar introducing FMD to China during the minor peak season</td>
<td>Binomial[$N_{hpms}, P_{route-B}$]</td>
</tr>
<tr>
<td>$N_{route-B}$</td>
<td>Number of pigs from Myanmar introducing FMD to China each year</td>
<td>Binomial[$N_{py}, P_{route-B}$]</td>
</tr>
</tbody>
</table>
a) FMD prevalence in Myanmar - $P_{mp}$

Myanmar reports the number of FMD outbreaks to the OIE biannually, however these reports do not provide sufficient data to determine the prevalence of infection in the country. The prevalence of FMD used in this study was calculated through sero-surveillance conducted in Myanmar from 2009 to 2010. The surveillance indicated that using viral Nonstructural Proteins tests (NSPs), 40 of 1347 serum samples were positive (Sunn 2011). This test has a reported sensitivity of 88.89% and a specificity of 100% (Wongsathapornchai et al. 2008). The sensitivity less than a 100% would result in some false negative results ($N_{fp}$). The number of true positives was composed of the number of test positive results plus the number of false negative results. In 2010, the prevalence of FMD in Myanmar ($P_{mp}$) was determined with a Beta equation.

$$
N_{fp} = \text{Negbin}[40, 88.89\%]
$$

$$
P_{mp} = \text{Beta}[40 + N_{fp} + 1, 1347 - (40 + N_{fp}) + 1]
$$

b) FMD risk from pigs originating from Myanmar that die en route to China - $P_{mpr1}$

Pigs from Myanmar may die en route because of sickness or an accident. Carcasses of these animals are usually left where the animals die. Any FMDV in these carcasses has the potential to be transmitted to other animals, particularly local animals, through direct or indirect contact. The virus could also be dispersed if the carcasses are collected for human consumption or through aerosolisation. However, in the opinion of the respondents, the possibility of FMDV spreading from carcasses ($P_{rd}$) was low. The FMD risk from the carcasses of pigs dying en route from Myanmar via the Mekong River was $P_{mpr1}$.

$$
P_{pd} = \text{Pert}(1\%, 3\%, 4\%, 4)
$$

$$
P_{rd} = \text{Pert}(0.03\%, 0.05\%, 0.07\%, 4)
$$

$$
P_{mpr1} = P_{mp} \times P_{pd} \times P_{rd}
$$
c) The probability pigs travelling via the Mekong River to China being infected with FMD after entry to China - $P_{pi}$

Pigs from Myanmar, after being unloaded in China, are transported predominantly by vehicles; however some were walked to their destination. After unloading, these animals may be exposed to FMDV through contaminated vehicles or people. Even though Yunnan Province has not reported an outbreak of FMD for over a decade, it is possible that FMDV may be present, but undetected, in the Golden Triangle area. In this area the climate is humid and warm, and there is little government input or control. The probability that pigs from Myanmar could be infected after arrival in China ($P_{ic}$) was estimated by the respondents to be between 0.04 and 0.08%. $P_{pi}$ was assigned to the possibility of Myanmar pigs being infected with FMD after unloading in China.

$$P_{ic} = \text{Pert}(0.04\%, 0.06\%, 0.08\%, 4)$$

$$P_{pi} = P_{mp} \times (1 - P_{pd}) + P_{ic}$$

d) FMD risk from Myanmar pigs confiscated by customs – $P_{mpr2}$

According to Chinese laws and regulations, confiscated animals need to be destroyed and the carcasses disposed of. However, during this process, virus may be released through either ineffective destruction or disposal, or some animals may be sold or killed and the meat sold. The possibility of FMDV escaping from confiscated animals ($P_{nd}$) was estimated by three respondents. The possibility that pigs from Myanmar were confiscated by Chinese customs ($P_{dc}$) was also estimated by the respondents. $P_{mpr2}$ was assigned to the risk of FMD being introduced in pigs from Myanmar confiscated by custom officials.

$$P_{dc} = \text{Pert}(10\%, 15\%, 20\%, 4)$$

$$P_{nd} = \text{Pert}(10\%, 15\%, 20\%, 4)$$

$$P_{mpr2} = P_{pi} \times P_{dc} \times P_{nd}$$
e) FMD risk from Myanmar pigs kept on Chinese farms – $P_{mpr3}$

Pigs from Myanmar may be kept on Chinese farms for fattening and these represent a potential source of FMD. According to the survey, pigs from Myanmar are kept in the backyards of farmers if the pigs were not large enough to be slaughtered. These pigs were housed with local animals from Yunnan to avoid detection by Chinese customs officers. The probability of pigs being kept for fattening ($P_{pk}$) was estimated to be between 5 and 25%. The risk of FMD from these pigs from Myanmar was assigned the identity of $P_{mpr3}$.

$$P_{pk}=\text{Pert (5\%, 15\%, 25\%, 4)}$$
$$P_{mpr3}=P_{pl}*(1-P_{dc})*P_{pk}$$

f) FMD risk from Myanmar pigs sold to slaughter houses – $P_{mpr4}$

If pigs were not kept for fattening, they were sold to slaughter houses ($P_{rs}$). Most of these were slaughtered within 24 hours of arrival in China; however some were kept for longer periods. Foot and Mouth Disease virus could be transmitted to other animals waiting to be slaughtered or could be present in the carcasses after slaughter. Furthermore virus could be present in waste from the slaughter house including waste water. The experts estimated that the probability of virus escaping from the slaughter houses ($P_{rs}$) was between 20 and 30%. $P_{mpr4}$ was assigned as the FMD risk from slaughter houses.

$$P_{ps}=1-P_{pk}$$
$$P_{rs}=\text{Pert (20\%, 25\%, 30\%, 4)}$$
$$P_{mpr4}=P_{pl}*(1-P_{dc})*P_{ps}*P_{rs}$$
g) The number of Myanmar pigs posing a risk of introducing FMD to China through Route B – $N_{route-B}$

Animal movements along the river have notable seasonal variations as the weather and consequently water level of the river changes. During the peak time, from October to January, approximately 2500 to 3000 pigs were sold to Yunnan Province each month. From May to August, during the dry season, river transport is restricted and animal transport along the river stops. In February, March, April and September (minor peak season), between 1000 and 1500 pigs are moved each month. $N_{pm}$ and $N_{hpm}$ were assigned to the number of pigs from Myanmar that were transported each month to China along Route B in the peak and minor peak seasons, respectively. $N_{pms}$ and $N_{hpms}$ were assigned to the total number of Myanmar pigs sold to China during the peak and minor peak seasons, respectively. $N_{py}$ was assigned to the total number of pigs from Myanmar traded along the Mekong River in a one-year period. $N_{pms-B}$, $N_{hpms-B}$ and $N_{route-B}$ were allocated to the risk of pigs from Myanmar introducing FMD to China during the peak season, minor peak season and each year, respectively.

\[
\begin{align*}
N_{pm} &= \text{Pert (2500, 2700, 3000, 4)} \\
N_{hpm} &= \text{Pert (1000, 1300, 1500, 4)} \\
N_{pms} &= \text{SUM}[N_{pm1}, N_{pm2}, N_{pm3}, N_{pm4}] \\
N_{hpms} &= \text{SUM}[N_{hpm1}, N_{hpm2}, N_{hpm3}, N_{hpm4}] \\
N_{py} &= N_{pms} + N_{hpms} \\
N_{pms-B} &= \text{Binomial}[N_{pms}, P_{route-B}] \\
N_{hpms-B} &= \text{Binomial}[N_{hpms}, P_{route-B}] \\
N_{route-B} &= \text{Binomial}[N_{py}, P_{route-B}] 
\end{align*}
\]
4.3 Results

Two routes for the movement of cattle and pigs from Myanmar to China were found in this research and a large number of live animals were transported along these routes.

4.3.1 Results of Route A

4.3.1.1 The possibility of Myanmar cattle posing an FMD risk to China through Route A – $P_{route-A}$

The distribution of $P_{route-A}$ is displayed in Figure 4.7 to indicate the probability that cattle from Myanmar travelling along Route A may introduce FMD to China. After 2000 iterations using Monte Carlo analysis, the mean of $P_{route-A}$ was 3.54% (90% CI: 2.10 – 4.76%), indicating the risk of an FMD infected cow from Myanmar being traded to China through the informal trade. The median $P_{route-A}$ was 2.65% and the range 1.68 to 20.7%.

Figure 4.7 Histogram of $P_{route-A}$ and Cumulative Probability Distribution

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
<th>Std Dev</th>
<th>Skewness</th>
<th>Kurtosis</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.68%</td>
<td>20.7%</td>
<td>3.54%</td>
<td>2.65%</td>
<td>3.55%</td>
<td>4.0267</td>
<td>17.6301</td>
<td>2000</td>
</tr>
</tbody>
</table>
4.3.1.2 Sensitivity analysis result of $P_{\text{route-A}}$

The sensitivity of $P_{\text{route-A}}$ was calculated using regression coefficients to show the factors that influence $P_{\text{route-A}}$ (Figure 4.8). The regression results indicated that the prevalence of FMD in cattle markets in Myanmar had the highest coefficient value (1). Myanmar cattle kept in China for fattening can increase the risk of FMD from Myanmar to China with a coefficient value 0.03, which was the same as the possibility that disease might spread from slaughter houses. The detection of consignments of cattle by Chinese customs officers, but which subsequently shed virus, also increased slightly the risk of introducing FMD to China (0.002). In contrast the detection of consignments by Chinese customs officers slightly decreased the risk (-0.002).

**Figure 4.8 Regression Coefficients of Sensitivity Analysis of $P_{\text{route-A}}$**
4.3.1.3 Number of Myanmar cattle posing an FMD risk to China per year – $N_{\text{route-A}}$

A distribution of $N_{\text{route-A}}$ (Figure 4.9) indicates the total number of Myanmar cattle which could pose a risk to China each year through Route A. After 2000 iterations the mean value of $N_{\text{route-A}}$ was 39 (90% CI: 16–76) with a median of 29 and a range of 7 to 329.

**Figure 4.9 Histogram of $N_{\text{route-A}}$ and Cumulative Probability Distribution**

<table>
<thead>
<tr>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
<th>Std Dev</th>
<th>Skewness</th>
<th>Kurtosis</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>329</td>
<td>39</td>
<td>29</td>
<td>40.54</td>
<td>4.2815</td>
<td>22.1691</td>
<td>2000</td>
</tr>
</tbody>
</table>
4.3.1.4 Sensitivity analysis results of $N_{\text{route-A}}$

The regression coefficients were determined to estimate the sensitivity of factors affecting the number of infected cattle arriving from Myanmar that could potentially introduce FMD to China (Figure 4.10). The prevalence of FMD in the source of cattle had the biggest impact on $N_{\text{route-A}}$ (0.94). The opinions of the three experts also affected the results (0.14, 0.10 and 0.06). The number of shipments (0.07), the possibility of disease spread from cattle dying en route (0.04) and the potential for virus escaping from animals slaughtered in the slaughter houses (0.03) also had slight positive influences on $N_{\text{route-A}}$.

**Figure 4.10 Regression Coefficients of Sensitivity Analysis of $N_{\text{route-A}}$**

![Diagram showing regression coefficients for different factors affecting $N_{\text{route-A}}$.](image-url)
4.3.2 The Results for Pigs Travelling via Route B

4.3.2.1 Possibility of pigs from Myanmar introducing FMD to China after travelling along Route B – $P_{\text{route-B}}$

A probability density graph was produced to show the distribution of 2000 iterations of $P_{\text{route-B}}$ (Figure 4.11). $P_{\text{route-B}}$ varied from 0.558 to 1.98%, with a mean value of 1.11% (90% CI: 0.83 – 1.44%). The median value was also 1.11%.

Figure 4.11 Histogram of $P_{\text{route-B}}$ and Cumulative Probability Distribution

![Histogram of $P_{\text{route-B}}$ and Cumulative Probability Distribution](image)
4.3.2.2 Sensitivity analysis results of $P_{\text{route-B}}$

Based on the distribution of $P_{\text{route-B}}$, regression analysis was applied using @RISK and a tornado graph was produced to display the results (Figure 4.12). The factor with the highest sensitivity was the prevalence of FMD in Myanmar (0.88). The possibility of being kept in China for fattening also added risk of introducing FMD to China (0.43) as did the risk from slaughter houses (0.24) and confiscated animals (0.05). Detection by Chinese customs officials (-0.07) and pigs dying en route (-0.03) reduced the risk slightly.

Figure 4.12 Regression Coefficients of Sensitivity Analysis of $P_{\text{route-B}}$
4.3.2.3 Number of Myanmar pigs posing a risk of introducing FMD to China—\( N_{\text{route-B}} \)

In Figure 4.13 the distribution of \( N_{\text{route-B}} \) after 2000 iterations is displayed. The number of pigs from Myanmar that posed a risk of introducing FMD to China was between 81 and 318, with a mean of 178 (90% CI: 129-235). The median value of \( N_{\text{route-B}} \) was 177.

Figure 4.13 Histogram of \( N_{\text{route-B}} \) and Cumulative Probability Distribution
4.3.2.4 Sensitivity Analysis of $N_{route-B}$

The sensitivity of $N_{route-B}$ was analysed and the results displayed in a tornado diagram (Figure 4.14). The results for this analysis were similar to those of $P_{route-B}$. The prevalence of FMD in pigs from Myanmar had the highest sensitivity (0.82), which was followed by the possibility of pigs from Myanmar being kept on Chinese farms for fattening (0.39). Detection of consignments by Chinese customs officers decreased the risk of FMD entering China.

Figure 4.14 Regression Coefficients of Sensitivity Analysis of $N_{route-B}$
4.4 Discussion

This is the first quantitative assessment of the risk of the introduction of FMDV from Myanmar to south-east China through the informal movement of cattle and pigs. For the purpose of understanding the cross-border movement of large ruminants and pigs several studies have been conducted in the Greater Mekong Sub-region during the past few years (Cocks et al. 2009; Lüthi 2011; Scoizec 2009). These studies all indicate that China is becoming the main destination for large ruminants and pigs originating from the Upper Mekong Region. These findings differ dramatically from research conducted more than ten years ago (Chapman 1995) when the majority of animal movements were directed towards to Thailand. However, recently other studies have highlighted that livestock movements from Myanmar to China followed the same two routes as those found in this study (OIE 1998; Sasaki 1993).

In Myanmar, the livestock industries are not the main source of income for the country, however they do generate most of the income for agriculture (OIE 1998). Foot and Mouth Disease is a frequently occurring animal disease that has a negative effect on livestock health, as well as the economy of Myanmar (OIE 1998; 1999). It is likely that the disease has been present in Myanmar for a long-time and has spread within the region through the movement of livestock.

In the current study, the probability that cattle from Myanmar could introduce FMD into China travelling along Route A was 2.65%, and each year approximately 29 cattle had the potential to introduce FMD into Yunnan Province. The probability that infection
could enter through the movement of pigs from Myanmar travelling along Route B was 1.11%, and each year approximately 177 pigs could introduce FMD into Yunnan Province. According to the sensitivity analysis conducted in this study, reducing the prevalence of FMD in Myanmar should result in a reduced risk of FMD being introduced into China through the movement of livestock from Myanmar. Other studies have reported similar findings with the risk of FMDV to an importing country being dependent upon the prevalence in the exporting country (Martinez-Lopez et al. 2008; Yu et al. 1997).

Although in Myanmar there are restrictions on livestock movements, vaccination campaigns against FMD and serosurveillance activities are not carried out widely due to a lack of funds (OIE 1998; 2000; 2001; 2010a). It has been recommended that in Myanmar a country-wide systematic control strategy be implemented with a key component being the execution of a comprehensive vaccination program to decrease the prevalence of FMD (Doel 2003; OIE 2007a). This strategy would decrease the prevalence of FMD within Myanmar and also decrease the risk to countries receiving animals from Myanmar, including China.

The models built in this study indicated that several factors, including the detection by customs officers, could reduce the risk of FMD entering China through the movement of animals from Myanmar. However, the sensitivity analysis also indicated that if the confiscated animals were not destroyed and disposed of in a suitable manner, the risk of FMD could actually be increased. In China, two methods are widely recommended for the disposal of confiscated animals, incineration and deep burial (Li and Xu 2004;
Zhang et al. (2009). However both of these methods require specialised expensive equipment, including large incinerators and mechanical diggers, and unless conducted correctly FMDV may survive the process (Zhang et al. 2009). An effective customs department can reduce the risk of FMD entering from Myanmar but it cannot eliminate the risk completely.

The risk of FMDV being released from an infected animal is significantly reduced after slaughter (Panina et al. 1989). Deboned beef has a very low risk of spreading FMDV and the OIE permits the transport of frozen deboned beef from FMD endemic areas to FMD free areas (Paton et al. 2010; Pharo 2002). In contrast, live pigs can exhale large quantities of virus (Leon 2012). It is recommended that China should alter its present policy of prohibiting the importation of live animals from south-eastern Asian countries into one of allowing the importation of frozen deboned meat, which has been processed under suitable inspection conditions in the exporting countries. Even though this change may not totally eliminate the threat of FMD to China, it could minimise the risk to a negligible or acceptable level (Paton et al. 2010).

Recently the informal entry of live animals to China has increased. These animals originate from a range of neighbouring countries and enter via several main pathways. In the following chapter the risk of introducing FMDV through the movement of live cattle from Thailand and Laos is analysed and discussed.
Chapter 5. Risk Analysis of the Movement of Cattle from Thailand and Laos to China
Chapter 5. Risk Analysis of the Movement of Cattle from Thailand and Laos to China

5.1 Background

As described in Chapter 4, livestock are moved from four Upper Mekong Region countries to China. One of the major routes for transporting livestock found in the Yunnan field surveys was along the Mekong River. In this chapter the risk of introducing FMDV to China from the movement of cattle which are transported along the Mekong River from Thailand and Laos is discussed.

5.2 Materials and Methods

5.2.1 Sources of Data

The data reported in this chapter were collected using the same methods and sources as that reported in Chapter 4, including the field surveys conducted in Yunnan Province, published papers, and government reports submitted to the OIE.

5.2.2 Route C. Movement of Cattle from Thailand and Laos to Southern Yunnan Province along the Mekong River

The Mekong River is a main passageway and hub for economic development in south-eastern Asia (Zhou 2011). The river rises in the Tibetan Plateau, runs through Myanmar, and forms the border between Myanmar and Laos and between Laos and Thailand (Figure 5.1). The Mekong River, as the natural border between Myanmar, Laos and Thailand, also runs through Yunnan Province (Jiang and Zhou 2005).
Along Route C, beef cattle are the main animal traded, with most originating from Thailand. In Laos and Thailand, buffalo, which are used for work, are rarely traded across the border to China. Few dairy cattle are present in Laos and Thailand, and consequently very few are traded internationally. To enhance the survival of the cattle that are moved, traders in Laos and Thailand normally choose the healthiest animals for trade. According to the traders informally interviewed (Table 5.1), the mortality along the Mekong river was usually below 5% per shipment. The main reasons given for losses include hyperthermia and disease.
Table 5.1 Details on the Movement of Cattle along Route C

<table>
<thead>
<tr>
<th>Possibility and numbers estimated by experts in the survey</th>
<th>Minimum</th>
<th>Most likely</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Died en route</td>
<td>2%</td>
<td>2.5%</td>
<td>5%</td>
</tr>
<tr>
<td>Disease spread from carcasses to China</td>
<td>40%</td>
<td>50%</td>
<td>60%</td>
</tr>
<tr>
<td>Animals lost en route</td>
<td>0.1%</td>
<td>0.2%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Animals infected en route from local animals in China</td>
<td>0.01%</td>
<td>0.02%</td>
<td>0.03%</td>
</tr>
<tr>
<td>Detected by Chinese customs</td>
<td>5%</td>
<td>7%</td>
<td>10%</td>
</tr>
<tr>
<td>Animals not destroyed properly by the Chinese customs officers</td>
<td>10%</td>
<td>15%</td>
<td>20%</td>
</tr>
<tr>
<td>Animals are kept for fattening on Chinese farms</td>
<td>Responder</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Minimum</td>
<td>20%</td>
<td>25%</td>
<td>30%</td>
</tr>
<tr>
<td>Most Likely</td>
<td>15%</td>
<td>20%</td>
<td>25%</td>
</tr>
<tr>
<td>Maximum</td>
<td>10%</td>
<td>15%</td>
<td>20%</td>
</tr>
<tr>
<td>Disease spreads from slaughter houses</td>
<td>20%</td>
<td>25%</td>
<td>30%</td>
</tr>
<tr>
<td>Number of cattle transported along Mekong River (per month in peak season)</td>
<td>10000</td>
<td>15000</td>
<td>20000</td>
</tr>
<tr>
<td>The percentage of cattle transported along the Mekong River each month during the post peak season compared with the peak season</td>
<td>20%</td>
<td>25%</td>
<td>30%</td>
</tr>
</tbody>
</table>

After arrival in China, live animals are transported by vehicles to their destination. In contrast cattle that die en route are usually abandoned on the shore. These abandoned carcasses could introduce FMDV into China either through other animals having contact with the carcasses or from the carcasses being removed and on-sold. Respondents considered that there was a high possibility that virus could spread from cattle carcasses. As FMDV can survive for several months in cattle carcasses (Henderson and Brooksby 1948) and the livestock population in the Mekong area is higher than that in the mountains, there was considered to be an increased likelihood of
contact between live animals and the carcasses. Respondents provided their opinions on the likelihood of this happening (Table 5.1). After unloading at the dock vehicles/traders can transmit FMDV and spread the infection. Cattle could also be detected and confiscated by Chinese customs officers. Most of these confiscated animals would be destroyed and then would pose negligible risk to China. However, there is a small risk from animals if they are not disposed of appropriately (Table 5.1). Animals which are not detected by customs officers are either slaughtered in slaughter houses or sold to local farmers for fattening. Both groups pose a potential risk of introducing FMDV; however the respondents considered that cattle distributed to farms for fattening posed a higher risk than those slaughtered promptly.

The number of animals transported along the river varies with season as the water level of the river changes. During the peak time, from October to January, approximately 10,000 to 20,000 beef cattle arrive in Yunnan Province each month. Of these 60% to 70% are from Lao PDR and the remainder are from Thailand. From May to August, during the dry season, animal transport along the river stops. In February, March, April and September (post-Peak season), only 20% to 30% of the animals moved during the peak time are transported along this route.

5.2.3 Scenario Tree

Using details from Table 5.1, a scenario tree was constructed to reflect the pathway of cattle moving from Thailand and Laos along the Upper Mekong River to China (Figure 5.2).
Figure 5.2 Scenario Tree C – Process of Animal Movement along Route C

- Cattle transported along Mekong River
- Cattle from Mekong river are FMD infected ($P_{w1}$)
- Cattle infected with FMD die during transportation ($P_{w2}$)
- Dead cattle spread FMDV to China ($P_{w3}$)
- Risk from cattle dying along the Mekong Route ($P_{w4}$)
- Cattle stayed with traders ($P_{w5}$)
- Cattle confiscated by Chinese customs ($P_{w6}$)
- Confiscated cattle not be destroyed properly ($P_{w7}$)
- Risk from confiscated cattle ($P_{w8}$)
- Cattle kept on farms for fattening ($P_{w9}$)
- Slaughter houses spread FMDV to China ($P_{w10}$)
- Risk from slaughter houses ($P_{w11}$)
- Risk from fattening cattle ($P_{w12}$)

Legend:
- ◻ Risk category node
- ➔ Infection node
- ◆ Risk node
- ❌ Safe node
5.2.4 Stochastic Model

Using the scenario tree displayed in Figure 5.2, a stochastic model was built to represent the informal animal movements along Route C. Data collected from field trips were organised to fit the parameters of the model to develop the quantitative analysis. As in Chapter 4, Pert, Discrete, Binomial and Beta distributions were used in this chapter to estimate various probability distributions of the Route C model. The results of the distributions were simulated with Monte Carlo analyses and distribution curves generated.

Basic calculations and data evaluation were undertaken in Microsoft® Excel® 2010. The add-in, PopTools version 3.2, was the main risk assessment tool used for analysing stochastic processes (Hood 2010). The program @RISK 5.7, student version (Palisade Decision Tools, Palisade Corporation) was used to perform the sensitivity analyses.

The parameters for the model of Route C are summarised in Table 5.2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Distribution/Formula/Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{tm}$</td>
<td>Prevalence of FMD in northern Thailand</td>
<td>Beta [13+1, 702383-13+1]</td>
</tr>
<tr>
<td>$P_{lm}$</td>
<td>Prevalence of FMD in northern Laos</td>
<td>Beta [125+1, 2178-125+1]</td>
</tr>
<tr>
<td>$P_{mc}$</td>
<td>Possibility of cattle traded along the Mekong River to China are infected with FMD</td>
<td>$P_{mc}=0.65 * P_{tm}+ 0.35 * P_{lm}$</td>
</tr>
<tr>
<td>$P_{dm}$</td>
<td>Possibility of cattle dying en route</td>
<td>Pert (2%, 2.5%, 5%, 4)</td>
</tr>
<tr>
<td>$P_{dms}$</td>
<td>Possibility of FMDV spreading to Chinese animals from abandoned carcasses</td>
<td>Pert (40%, 50%, 60%, 4)</td>
</tr>
<tr>
<td>$P_{mcr1}$</td>
<td>The risk of FMD from abandoned cattle carcasses</td>
<td>$P_{mcr1}= P_{mc} * P_{dm} * P_{dms}$</td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
<td>Distribution/Formula/Note</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>$P_{ci}$</td>
<td>Possibility of animals acquiring infection from Chinese animals during transport</td>
<td>Pert (0.01%, 0.02%, 0.03%, 4)</td>
</tr>
<tr>
<td>$P_{sm1}$</td>
<td>Possibility of cattle travelling along Route C becoming infected after unloading</td>
<td>$P_{sm1} = P_{mc1} * (1 - P_{dm}) + P_{ci}$</td>
</tr>
<tr>
<td>$P_{md}$</td>
<td>Possibility of cattle being confiscated by the Chinese customs</td>
<td>Pert (5%, 7%, 10%, 4)</td>
</tr>
<tr>
<td>$P_{cc}$</td>
<td>Possibility of customs not properly destroying confiscated animals</td>
<td>Pert (10%, 15%, 20%, 4)</td>
</tr>
<tr>
<td>$P_{mcr2}$</td>
<td>FMD risk from confiscated cattle</td>
<td>$P_{mcr2} = P_{sm1} * P_{md} * P_{cc}$</td>
</tr>
<tr>
<td>$P_{sm2}$</td>
<td>Possibility of cattle not being detected by Chinese customs officers</td>
<td>$P_{sm2} = 1 - P_{md}$</td>
</tr>
<tr>
<td>$P_{kf}$</td>
<td>Possibility of cattle being kept for fattening on Yunnan farms</td>
<td>Discrete[Pert(20%, 25%, 30%, 4), 1, Pert(15%, 20%, 25%, 4), 1, Pert(10%, 15%, 20%, 4), 1]</td>
</tr>
<tr>
<td>$P_{mcr3}$</td>
<td>FMD risk from the fattening cattle</td>
<td>$P_{mcr3} = P_{sm1} * P_{sm2} * P_{kf}$</td>
</tr>
<tr>
<td>$P_{rs}$</td>
<td>Possibility of FMDV spreading from the slaughter houses</td>
<td>Pert (20%, 25%, 30%, 4)</td>
</tr>
<tr>
<td>$P_{mcr4}$</td>
<td>FMD risk from Yunnan slaughter houses</td>
<td>$P_{mcr4} = P_{sm1} * P_{sm2} * (1 - P_{kf}) * P_{rs}$</td>
</tr>
<tr>
<td>$P_{route-B}$</td>
<td>Possibility of FMD risk from cattle transported along the Mekong River</td>
<td>$P_{route-B} = P_{mcr1} + P_{mcr2} + P_{mcr3} + P_{mcr4}$</td>
</tr>
<tr>
<td>$N_{pms}$</td>
<td>Number of cattle travelling along the Mekong River which are sold each month to China during the peak season</td>
<td>Pert(10000, 15000, 20000, 4)</td>
</tr>
<tr>
<td>$N_{pm}$</td>
<td>Total number of cattle sold to China during the peak season</td>
<td>SUM[$N_{pms1}$, $N_{pms2}$, $N_{pms3}$, $N_{pms4}$]</td>
</tr>
<tr>
<td>$N_{hms}$</td>
<td>Number of cattle sold to China per month during the minor peak season</td>
<td>Binomial[Pert(2%, 25%, 30%, 4), $N_{pms}$]</td>
</tr>
<tr>
<td>$N_{hm}$</td>
<td>Total number of cattle sold to China and transported along the Mekong River in the minor-peak season</td>
<td>SUM[$N_{hms1}$, $N_{hms2}$, $N_{hms3}$, $N_{hms4}$]</td>
</tr>
<tr>
<td>$N_{mc}$</td>
<td>Number of cattle sold to China and transported along the Mekong River each year</td>
<td>$N_{mc} = N_{pm} + N_{hm}$</td>
</tr>
<tr>
<td>$N_{route-B}$</td>
<td>Number of cattle transported along the Mekong River that pose an FMD risk to China each year</td>
<td>Binomial[$P_{route-B}$, $N_{mc}$]</td>
</tr>
<tr>
<td>$P_{thai}$</td>
<td>Possibility of FMD risk from cattle originating from Thailand</td>
<td>Use $P_{tm}$ replace $P_{mc}$</td>
</tr>
<tr>
<td>$P_{laos}$</td>
<td>Possibility of FMD risk from cattle originating from Laos</td>
<td>Use $P_{tm}$ replace $P_{mc}$</td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
<td>Distribution/Formula/Note</td>
</tr>
<tr>
<td>------------</td>
<td>------------------------------------------------------------------------------</td>
<td>------------------------------------</td>
</tr>
<tr>
<td>$P_{ft}$</td>
<td>Possibility of cattle being transported to China along the Mekong River being sourced from Thailand</td>
<td>Pert (60%, 65%, 70%, 4)</td>
</tr>
<tr>
<td>$N_{ft}$</td>
<td>Number of cattle travelling along the Mekong River from Thailand to China each year</td>
<td>Binomial[$P_{ft}$, $N_{mc}$]</td>
</tr>
<tr>
<td>$N_{fl}$</td>
<td>Number of cattle travelling along the Mekong River from Laos to China each year</td>
<td>$N_{fl} = N_{mc} - N_{ft}$</td>
</tr>
<tr>
<td>$N_{thai}$</td>
<td>Number of cattle from Thailand posing a risk of FMD to China each year</td>
<td>Binomial[$P_{thai}$, $N_{fl}$]</td>
</tr>
<tr>
<td>$N_{laos}$</td>
<td>Number of cattle from Laos which pose a risk of FMD to China each year</td>
<td>Binomial[$P_{laos}$, $N_{fl}$]</td>
</tr>
</tbody>
</table>

a) **Possibility cattle traded along the Mekong River to China are FMD infected - $P_{mc}$**

Cattle traded along the Mekong River were collected from and loaded in northern Laos and northern Thailand. The prevalence of FMD in northern Laos ($P_{lm}$) and northern Thailand ($P_{tm}$) were used to calculate the possibility of cattle traded along Route C to China being infected with FMD ($P_{mc}$). To help the control of animal diseases, Thailand is divided into nine administrative regions (OIE 2005). Region five is the region near the Mekong River in northern Thailand. In this region in 2010, 13 cattle were reported to have FMD out of a population of 702,383 (Tritsadee 2011). No information on the number of cases of FMD in cattle was available for northern Laos; however in 2010, 125 of 2178 villages in northern Laos had outbreaks of FMD (Nampanya et al. 2012). Experts from China estimated that about 65% cattle were sourced from Thailand and the others were sourced from Laos.

\[
P_{tm} = \text{Beta}[13+1, 702383-13+1]
\]

\[
P_{lm} = \text{Beta}[125+1, 2178-125+1]
\]

\[
P_{mc} = 0.65 \times P_{tm} + 0.35 \times P_{lm}
\]
b) Risk of FMD being introduced to China through the carcasses of cattle which died en route - $P_{mcr1}$

Cattle traded along the Mekong River are unloaded at unofficial Chinese Mekong River docks. Although these were not visited, according to the respondents 2 to 5% (most likely 2.5%) of the cattle transported along the Mekong River died and the carcasses were abandoned after unloading. These carcasses could have been collected by local people for meat or they could have been eaten or had contact with wild animals. Virus could be transmitted to China through these direct and indirect means. The experts estimated the probability of cattle carcasses transmitting FMDV to China ($P_{dms}$). $P_{dm}$ was allocated to the probability of cattle transported along the Mekong River dying en route and $P_{mcr1}$ was set as the risk of FMD from cattle which died during transport on the Mekong River.

$$P_{dm} = Pert (2\%, 2.5\%, 5\%, 4)$$
$$P_{dms} = Pert (40\%, 50\%, 60\%, 4)$$
$$P_{mcr1} = P_{mc} \times P_{dm} \times P_{dms}$$

c) Possibility of cattle transported along Route C being infected after unloading - $P_{sm1}$

Cattle transported along the Mekong River were purchased by Chinese buyers and usually transported by vehicles to their destination. These vehicles may have been contaminated with virus resulting in transmission of infection to the newly imported disease-free stock. As there was no information on the prevalence of FMD in the Golden Triangle, the experts estimated the probability of the cattle becoming infected after unloading as between 0.01 and 0.03%, with a most likely value of 0.02%. $P_{sm1}$ was assigned to be the possibility of a cattle transported along Route C being infected after unloading and before being transported further into China.

$$P_{ei} = Pert (0.01\%, 0.02\%, 0.03\%, 4)$$
$$P_{sm1} = P_{mc} \times (1 - P_{dm}) + P_{ei}$$
d) Risk of FMD from cattle confiscated by customs – $P_{mcr2}$

Cattle transported to China along Route C may be detected by Chinese customs officers. Based on the results of the survey, the likelihood of detection ($P_{md}$) was between 5 and 10% with a most likely value of 7%. After detection it was estimated that between 10 and 20% ($P_{cc}$) of the cattle could still spread FMDV through unsatisfactory disposal of the carcasses, on-selling rather than destruction of the cattle and survival of FMDV in fomites, vehicles and clothing of the customs officers.

$$
P_{md} = \text{Pert (5%, 7%, 10%, 4)}
$$

$$
P_{cc} = \text{Pert (10%, 15%, 20%, 4)}
$$

$$
P_{mcr2} = P_{sm1} \times P_{md} \times P_{cc}
$$

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e) Risk of FMD from cattle transported along Route C being kept for fattening - $P_{mcr3}$

Cattle transported along Route C that were not detected by customs would either be sent to slaughter houses for processing or be kept on Chinese farms for fattening. The three experts estimated that between 15 and 30% of the cattle were kept for fattening. The mixing of these cattle with local cattle, to minimise the detection by veterinary officers, increased the risk of introducing FMD into this region. $P_{sm2}$ was allocated as the possibility that cattle were not confiscated by customs and $P_{kf}$ as the likelihood they were kept for fattening prior to being slaughtered. $P_{mcr3}$ was calculated as the risk of FMD being introduced to China through cattle transported along the Mekong River which were kept for fattening.

$$
P_{sm2} = 1 - P_{md}
$$

Discrete[ Pert (20%, 25%, 30%, 4), 1]

$$
P_{kf} = \begin{cases} \text{Pert (15%, 20%, 25%, 4), 1} \\
\text{Pert (10%, 15%, 20%, 4), 1} \end{cases}
$$

$$
P_{mcr3} = P_{sm1} \times P_{sm2} \times P_{kf}
$$

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</table>

113
f) Risk of FMD from slaughter houses – $P_{mcr4}$

Most cattle entering China via Route C were transported directly to slaughter houses for processing. Most of these animals were killed within 24 hours to minimise the likelihood of detection by Chinese customs and veterinary officers. However, it is possible for FMDV to be released from the slaughter houses through direct transmission from animal products or through indirect transmission by fomites, vehicles or workers. The possibility that FMD might spread from slaughter houses ($P_{rs}$) was evaluated to be between 20 and 30%.

$$P_{rs} = \text{Pert (20%, 25%, 30%, 4)}$$

$$P_{mcr4} = P_{sm1} * P_{sm2} * (1 - P_{kf}) * P_{rs}$$

g) The number of cattle transported along the Mekong River that pose a risk of introducing FMD to Yunnan, China – $N_{route-C}$

The probability of cattle transported along the Mekong River introducing FMD to Yunnan Province ($P_{route-C}$) was the sum of $P_{mcr1}$, $P_{mcr2}$, $P_{mcr3}$, and $P_{mcr4}$. The number of animals traded varied with the season due to the impact of precipitation on the water level of the Upper Mekong River. Data on the number of cattle moved in different seasons were collected from Chinese slaughter houses. More animals were transported in the months of October to January. In contrast the number of livestock transported in the months of February, March, April and September was only 20 to 30% of the number transported at the peak time. In the dry season, few boats travelled along the Mekong River, and consequently the number of animals transported was very small and considered by the experts to be negligible.

$N_{pms}$ was assigned to the number of cattle traded each month along the Mekong River.
during the peak season (October to January) and \( N_{pm} \) to the total number of cattle traded during the four month minor peak season. The opinions of the experts on \( N_{pms} \) were the same. \( N_{pms} \) was run separately four times to account for the four months of the peak season. These values were then summed to determine \( N_{pm} \). \( N_{hms} \) was assigned to the number of cattle traded along the Mekong River in each month during the minor peak season (February, March, April, and September). \( N_{hm} \) was assigned to the total number of cattle in the post-peak season and a Pert distribution used to calculate \( N_{pms} \). \( N_{hm} \) was calculated by summing the results from each month for the separately calculated \( N_{hms} \). \( N_{mc} \) was set as the number of cattle transported each year to China along the Mekong River. \( N_{route-C} \) was assigned to the number of cattle infected with FMD that had been transported via Route C to China each year.

\[
P_{route-C} = P_{mcr1} + P_{mcr2} + P_{mcr3} + P_{mcr4}
\]

\[
N_{pms} = \text{Pert}(10000, 15000, 20000, 4)
\]

\[
N_{pm} = \text{SUM}\[N_{pms1}, N_{pms2}, N_{pms3}, N_{pms4}\]
\]

\[
N_{hms} = \text{Binomial}[\text{Pert}(2\%, 25\%, 30\%, 4)\times N_{pms}]
\]

\[
N_{hm} = \text{SUM}\[N_{hms1}, N_{hms2}, N_{hms3}, N_{hms4}\]
\]

\[
N_{mc} = N_{pm} + N_{hm}
\]

\[
N_{route-B} = \text{Binomial}[P_{route-C}, N_{mc}]
\]

h) The number of cattle from Thailand and Laos which are transported to China along the Mekong River and pose a risk of introducing FMD - \( N_{\text{thai}} \) and \( N_{\text{laos}} \)

Cattle from Thailand and Laos followed the same route to China and also the same parameters were included in the model. \( P_{\text{thai}} \) and \( P_{\text{laos}} \) were assigned to the possibility of FMD being introduced to China by cattle from Thailand and Laos, respectively. \( P_{\text{tm}} \) and \( P_{\text{lm}} \) were used to replace \( P_{mc} \) in the stochastic risk model. \( P_{\text{thai}} \) and \( P_{\text{laos}} \) were two results
obtained from the $P_{tm}$ and $P_{mc}$ models. $P_{ft}$ was assigned to the possibility of cattle travelling along the Mekong River being sourced from Thailand (60 to 70%). $N_{ft}$ and $N_{fl}$ were set as the number of cattle from Thailand and Laos, respectively, transported to China along the Mekong River each year. $N_{thai}$ and $N_{laos}$ were the number of cattle from Thailand and Laos which posed a risk of introducing FMD to China each year.

$$
P_{thai} = \text{Use } P_{tm} \text{ replace } P_{mc}
$$

$$
P_{laos} = \text{Use } P_{tm} \text{ replace } P_{mc}
$$

$$
P_{ft} = \text{Pert (60\%, 65\%, 70\%, 4)}
$$

$$
N_{ft} = \text{Binomial}[P_{ft}, N_{mc}]
$$

$$
N_{fl} = N_{mc} - N_{ft}
$$

$$
N_{thai} = \text{Binomial}[P_{thai}, N_{ft}]
$$

$$
N_{laos} = \text{Binomial}[P_{laos}, N_{ft}]
$$
5.3 Results

5.3.1 The Possibility of FMD Entering China from Cattle Originating from Thailand and Laos Transported along the Mekong River – $P_{route-C}$

After modelling $P_{route-C}$ for 2000 iterations, a mean value of 0.79% was revealed. Ninety percent of the iterations were between 0.64 and 0.95% (Figure 5.3).

![Figure 5.3 Histogram of $P_{route-C}$ and Cumulative Probability Distribution](image)
5.3.2 Sensitivity Analysis Result of $P_{route-C}$

The results of the sensitivity analysis for $P_{route-C}$ are displayed in Figure 5.4. The FMD prevalence in northern Laos presented the highest regression coefficient value (0.71), followed by the possibility of cattle being kept for fattening (0.65). The spread of disease from slaughter houses also contributed to the risk of spreading FMD (0.29). The risk from virus escaping from confiscated animals or the carcasses of animals dying en route, the chance of animals dying en route and the probability of animals becoming infected in China all had small positive impacts. The only factor that reduced risk was the detection of shipments by customs officers (-0.05).

![Figure 5.4 Regression Coefficients of Sensitivity Analysis of $P_{route-C}$](image)
5.3.3 Number of Cattle from Thailand and Laos Posing a Risk of Introducing FMD into China after Travelling along Route C - $N_{route-C}$

After modelling $N_{route-C}$ for 2000 iterations, a mean value of 592 was found (Figure 5.5), with a 90% CI of 458 to 739. The median number of cattle travelling along the Mekong River which could introduce FMD to Yunnan Province was 588 with a range of 347 to 877.

Figure 5.5 Histogram of $N_{route-C}$ and Cumulative Probability Distribution

![Histogram and cumulative probability distribution](image-url)
5.3.4 Sensitivity Analysis Results of $N_{\text{route-C}}$

Similar to the sensitivity results of $P_{\text{route-C}}$, factors that significantly increased the risk of FMD being introduced to China were the prevalence in Laos, the keeping of cattle for fattening and the spread of disease from slaughter houses (Figure 5.6). Being detected by Chinese customs slightly reduced the risk of the incursion of FMD (-0.06).

![Figure 5.6 Regression Coefficients of Sensitivity Analysis of $N_{\text{route-C}}$](image)
5.3.5 Possibility of FMD being Introduced from Cattle Travelling from Thailand to China along the Mekong River \(- P_{\text{thai}}\)

After 2000 replications of \(P_{\text{thai}}\) the average possibility of FMD being introduced was 0.0083\% (90\% CI: 0.0058 - 0.011\%).

![Histogram of \(P_{\text{thai}}\) and Cumulative Probability Distribution](image-url)
5.3.6 Sensitivity Analysis Results of $P_{\text{thai}}$

The most sensitive factor found in the $P_{\text{thai}}$ model was cattle becoming infected in China after disembarkation (0.87). The prevalence of disease in Thailand also increased the risk (0.12). However this was not as important as the risk from Chinese farms (0.42) or escape from slaughter houses (0.19). Detection by customs officers slightly reduced the risk of disease incursion (-0.03), however, if the confiscated animals were not destroyed and disposed of properly, the risk of FMD incursion was a small positive value.

![Figure 5.8 Regression Coefficients of Sensitivity Analysis of $P_{\text{thai}}$](image)
5.3.7 Number of Cattle Travelling along the Mekong River from Thailand which Pose a Risk of Introducing FMD to China – $N_{\text{thai}}$

The number of cattle from Thailand that posed a risk of introducing FMD into China ($N_{\text{thai}}$) was small (range 0 to 14, with a mean/median of 4).

Figure 5.9 Histogram of $N_{\text{thai}}$ and Cumulative Probability Distribution

![Histogram of $N_{\text{thai}}$ and Cumulative Probability Distribution](image)

- Minimum: 0
- Maximum: 14
- Mean: 4
- Median: 4
- Std Dev: 2.18
- Skewness: 0.5756
- Kurtosis: 3.3541
- Values: 2000
5.3.8 Sensitivity Analysis Results of $N_{\text{thai}}$

The number of cattle from Thailand travelling along Route C which posed a risk of introducing FMD to China was most influenced by the likelihood of becoming infected after arrival in China (0.30). The possibility of cattle being kept for fattening (0.16), the possibility of the disease escaping from slaughter houses (0.08), the prevalence in Thailand (0.05) and the percentage of cattle from Thailand (0.04) also had a positive influence on $N_{\text{thai}}$.

**Figure 5.10 Regression Coefficients of Sensitivity Analysis of $N_{\text{thai}}$**
5.3.9 Probability of FMD being Introduced into China by Cattle Originating from Laos – $P_{laos}$

The risk of FMD being introduced to China by cattle from Laos was much higher (2.23%) than that for cattle from Thailand (0.0083%). The range of $P_{laos}$ was 1.49 to 3.18%, with a 90% CI of 1.816 to 2.694%.

Figure 5.11 Histogram of $P_{laos}$ and Cumulative Probability Distribution

<table>
<thead>
<tr>
<th>Risk from Laos cattle</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>1.49%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>3.18%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>2.24%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>2.23%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std Dev</td>
<td>0.271%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skewness</td>
<td>0.2738</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kurtosis</td>
<td>3.0345</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Values</td>
<td>2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.3.10 Sensitivity Analysis Results of $P_{laos}$

The prevalence of FMD at the source (northern Laos) was the most sensitive contributor in the regression coefficient analysis of $P_{laos}$ (0.71). This was followed by the possibility of the cattle being kept on Chinese farms for fattening (0.66) and the possibility of virus escape from slaughter houses (0.29). Detection of consignments by customs officials reduced the risk of FMD entering China.

**Figure 5.12 Regression Coefficients of Sensitivity Analysis of $P_{laos}$**
5.3.11 The Number of Cattle from Laos which Pose a Risk of Introducing FMD to Yunnan Province – $N_{laos}$

The range for $N_{laos}$ was 337 to 891 each year, with a median of 580 and a mean of 586 (Figure 5.13) which were much higher than the numbers of cattle posing a risk from Thailand.

**Figure 5.13 Histogram of $N_{laos}$ and Cumulative Probability Distribution**

<table>
<thead>
<tr>
<th>No of cattle from Laos pose</th>
<th>FMD risk to China</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>337</td>
</tr>
<tr>
<td>Maximum</td>
<td>891</td>
</tr>
<tr>
<td>Mean</td>
<td>586</td>
</tr>
<tr>
<td>Median</td>
<td>580</td>
</tr>
<tr>
<td>Std Dev</td>
<td>87.84</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.3537</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>3.0688</td>
</tr>
<tr>
<td>Values</td>
<td>2000</td>
</tr>
</tbody>
</table>
5.3.12 Sensitivity Analysis Results of $N_{\text{laos}}$

The prevalence of FMD in the exporting country (Laos) was the most sensitive contributor (0.56) to the model (Figure 5.14). However, if the cattle were from Thailand, where the prevalence of FMD was much lower than Laos, the risk of FMD was reduced dramatically (-0.36). Cattle kept for fattening or virus escape from slaughter houses also posed a risk (0.53 and 0.23, respectively). As with previous analyses detection by customs officials reduced the risk of disease entry.

**Figure 5.14 Regression Coefficients of Sensitivity Analysis of $N_{\text{laos}}$**
5.4 Discussion

This is the first quantitative assessment of the risk of the introduction of FMDV from Thailand and Laos to Yunnan Province through the informal movement of cattle. These cattle were transported along the Mekong River (Route C) and the probability of FMD being introduced into China by these cattle was 0.79%, with nearly 600 cattle (mean value of $N_{route-C}=592$ and median of 588) potentially introducing FMDV to Yunnan each year via this route.

In contrast to Laos (580), the number of cattle with the potential to introduce FMD to China from Thailand was low (4). This difference is primarily due to the lower prevalence of FMD in Thailand compared with Laos. In northern Thailand, disease surveillance and routine vaccination are actively undertaken and animals are raised in a manner that reduces risk factors for FMD, such as by not sharing pasture or water sources between farms/villages (Baldock et al. 1993; OIE 1998b; Rojanasthien et al. 2006).

Thailand has the highest Gross Domestic Product (GDP) of the countries in the Greater Mekong Sub-region (Zhang and Zhao 2011) and commenced its disease control plan for FMD in 1958. The control plan now involves multiple strategies including mass vaccination, control of national and international animal movements, disease surveillance, public awareness campaigns and a national livestock identification system (Chaisrisongkram 1993; OIE 2010a; 2011b). In addition, another important measure to help control FMD in Thailand is through actively contributing to the regional international control program for this disease (OIE 2009b; 2010a; Wacharapon 2008).

Foot and Mouth Disease has been present in Laos since the 1980s (OIE 1998a). Initially outbreaks were believed to have been caused by informal cross-boundary animal
movements and these were exacerbated by the husbandry methods adopted in the country which allows animals to graze freely (OIE 1998a; 1999). Livestock movements between China and Laos were in both directions in the 1990s (Mekbagnomdara and Vongthilath 1993); however the current research has highlighted that with the increasing demand for meat in China, livestock movements are now directed predominantly towards China and Vietnam. In Laos, the government has undertaken sero-surveillance programmes, developed regulations on the movements of animals and animal products movements and established public awareness campaigns (OIE 2000; 2001). However the success of these has been limited due to insufficient funding and a lack of skilled workers, resulting in a low vaccination coverage and a failure to investigate FMD outbreaks in a timely manner (Inthavong 2009; 2011). The Laos government has also developed cooperation with other countries to aid in the control of FMD in the region (Inthavong 2010; OIE 2009a); however the prevalence in some parts of the country is still likely to be higher than that in neighbouring countries.

In addition to the situation of FMD in the exporting countries, another factor correlated with the introduction of FMD was the spread of disease from slaughter houses. Slaughter houses are a potential source of FMDV, particularly if waste is not disposed of properly or inspection practices not undertaken thoroughly. The Chinese government has implemented regulations to ensure the production of safe meat. These regulations include “Measures for the Implementation of the Regulations on the Domestic Animal Slaughter” and “Slaughter House Meat Inspection Specification”. According to these safeguards, animals with infectious or parasitic diseases cannot be slaughtered and dead
animals cannot be processed (Lin 2010). These activities should decrease the risk of FMDV escaping from the slaughter houses. However the Chinese slaughter industry still has several problems. Firstly, contaminants from the slaughter houses are not always treated effectively (Yang and Zhao 2010). Secondly, animals are often not inspected prior to slaughter or the inspection process is not effective (Cao 2012; Hu and Xu 2010). To ensure meat safety, many provinces in China are applying and promoting ‘Livestock Slaughtering in Appointed Places and Quarantine Inspection in a Centralized Way’ policy on livestock and poultry, as recommended by the Chinese government (Li and Ren 2008; Liu et al. 2009; Tang and Su 2005; Zhang et al. 2005). This policy has been effective in preventing transmission of infectious diseases, reducing environmental pollution and guaranteeing the safety and quality of meat in areas where it is adopted thoroughly (Zhang 2004). However the policy is not adopted in all slaughter houses in China, and the management of approved slaughter houses needs to be improved to prevent them being a source and distributor of infectious animal diseases including FMD (Sun et al. 2003; Wang 2002).

Previous studies indicated that the higher price of meat in China is the main factor driving the informal animal movements towards China (Cocks et al. 2009; Lüthi 2011; Scoizec 2009). Consequently it is difficult to prevent this trade unless the gap in the price of animals and the demand for meat is reduced. Furthermore, the dangerous and complex business routes found within the Golden Triangle region makes the control of livestock movement challenging. People living in the Golden Triangle area and other undeveloped areas may not consider that cross-border animal movements are serious
illegal activities, since more serious crimes are commonly found in these regions, including weapon smuggling and drug dealing (Liang et al. 2002).

To reduce the continued threat of FMD to China from animals travelling along the Mekong River from neighbouring countries, it is recommended that an intensive vaccination programs be strengthened and evaluated in the Upper Mekong Region countries and that the unregulated movement of live animals be replaced by controlled formal trading of animal product (meat).

In the following chapter the movement routes of cattle and pigs from Vietnam to Guangxi Province in China, and their associated risk are assessed.
Chapter 6. Risk Analysis of the Movement of Cattle and Pigs from Vietnam to China
Chapter 6. Risk Analysis of the Movement of Cattle and Pigs from Vietnam to China

6.1 Background

As described in Chapters 4 and 5, the field survey conducted by the Yunnan Tropical and Subtropical Animal Viral Disease Laboratory (YTSAVDL) identified informal livestock movements from four Upper Mekong Region countries. This chapter focuses on the movement of pigs and cattle from Vietnam to Guangxi Province, China and assesses the risk of these movements.

The international land border of China and Vietnam is approximately 1350 kilometres long separating two provinces (Yunnan and Guangxi) in China from seven provinces in Vietnam (He 2009). The international boundary between Guangxi Province and Vietnam is 637 kilometres long on land and 1595 kilometres long on water (Liang and Shang 2009; Nong 2004). Guangxi Province has eight border cities (and counties) contacting with three border provinces in Vietnam. Currently, there are 25 cross border entry points and 25 border markets along this border (Guo 2007; Lai et al. 2011).

Although total trade between Vietnam and China is worth millions of dollars, there is no official trade in cloven hoofed animals between the two countries (Li 2010a). However, informal trade in livestock and animal products occurs through hundreds of cross-boundary trails (Huang and Tang 2009).
6.2 Materials and Methods

6.2.1 Sources of Data

The data reported in this chapter were collected using the same methods and sources as that reported in Chapters 4 and 5. The research described in this chapter was conducted in Yunnan Province and relates to the risk of FMDV introduction to Guangxi Province from Vietnam. All data reported were collected from China.

Foot and Mouth Disease is endemic in Vietnam (Le et al. 2010), and susceptible species of livestock are officially prohibited from importation into China. However according to data collected during the field research, informal movements of animals occur and these are expanding, particular with respect to pigs and beef cattle. Informal animal transport from Vietnam to Guangxi Province is either by walking or through the use of vehicles (Figure 6.1). The livestock movement route from Northern Vietnam to Guangxi Province in China was called Route D in this study.
The journey from Vietnam to China via Route D takes one half to a full day of travelling time. Since the journey is not long, the majority of animals can cross safely without any impact on their health. It is estimated that less than 0.2% die on the journey through sickness or accidents. Animals that die en route are normally left where they die. Their carcasses may be eaten by wild animals or be collected by local farmers for meat. It is possible that FMDV could be spread from infected carcasses and respondents estimated the probability of virus escape from these carcasses to be 30 to 40%, since the population density, as well as domestic livestock density, along Route D was much higher than along Routes A to C. Vietnamese cattle could acquire infection from contact with other livestock grazing along the route or from interaction with wild animals. Foot and mouth disease has previously been diagnosed in Guangxi Province (Figure 2.14).
The likelihood of animals acquiring infection during the journey was estimated by the experts (Table 6.1). It was believed that 20 to 30% of the informal shipments would be detected by Chinese customs. If these confiscated animals were not destroyed immediately or properly, virus could still be released and potentially infect other livestock in China. However, most cattle arrive in Guangxi Province undetected because of the long border and the mountainous and heavily forested trails followed.

After reaching China, most animals were killed by local Chinese traders on the day of arrival to avoid the risk of being detected by customs and veterinary officers. The risk of virus escape from slaughter houses was estimated in the survey by experts (Table 6.1). No more than 10% of cattle were believed to be retained for fattening with the aim of ultimately receiving a higher price. These animals kept for fattening were considered to be a potential risk for introducing FMDV into China since they would be mixed with local livestock.

**Table 6.1 Details of the Movements of Cattle and Pigs along Route D**

<table>
<thead>
<tr>
<th>Possibility and numbers estimated by experts in the survey</th>
<th>Minimum</th>
<th>Most likely</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Died on the way to Guangxi</td>
<td>0.05%</td>
<td>0.15%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Carcasses spread FMDV to China</td>
<td>30%</td>
<td>35%</td>
<td>40%</td>
</tr>
<tr>
<td>Animals become infected in Guangxi</td>
<td>0.1%</td>
<td>0.5%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Animals detected by Chinese customs</td>
<td>10%</td>
<td>15%</td>
<td>20%</td>
</tr>
<tr>
<td>Animals detected by Chinese customs not destroyed/disposed of properly</td>
<td>10%</td>
<td>15%</td>
<td>20%</td>
</tr>
<tr>
<td>Sold to farms for fattening</td>
<td>5%</td>
<td>7%</td>
<td>10%</td>
</tr>
<tr>
<td>FMDV escapes from slaughter houses</td>
<td>20%</td>
<td>25%</td>
<td>30%</td>
</tr>
<tr>
<td>Number of cattle shipments each year</td>
<td>50</td>
<td>55</td>
<td>60</td>
</tr>
<tr>
<td>Possibility and numbers estimated by experts in the survey</td>
<td>Minimum</td>
<td>Most likely</td>
<td>Maximum</td>
</tr>
<tr>
<td>----------------------------------------------------------</td>
<td>---------</td>
<td>-------------</td>
<td>---------</td>
</tr>
<tr>
<td>Number of cattle from Vietnam per shipment</td>
<td>15</td>
<td>60</td>
<td>120</td>
</tr>
<tr>
<td>Number of shipments of pigs each year</td>
<td>40</td>
<td>45</td>
<td>50</td>
</tr>
<tr>
<td>Number of pigs from Vietnam per shipment</td>
<td>2</td>
<td>25</td>
<td>102</td>
</tr>
</tbody>
</table>
6.2.2 Scenario Tree

Using details from Table 6.1, a scenario tree was constructed to reflect the risk pathways of cattle and pigs movements from northern Vietnam to Guangxi Province (Figure 6.2).

**Figure 6.2 Scenario Tree D – Process of Animal Movement along Route D**
6.2.3 Stochastic Model

The stochastic model built for Route D followed the same methods as that described in Chapters 4 and 5. The details of the distributions used in this chapter are listed in Table 6.2.

Table 6.2 Details of Parameters Used in Route D (highlighted lines required values to be input)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description of the parameter</th>
<th>Distribution/Formula/Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{vc}$</td>
<td>Prevalence of FMD in cattle from northern Vietnam</td>
<td>Beta[1030+1,4088129-1030 +1]</td>
</tr>
<tr>
<td>$P_{vp}$</td>
<td>Prevalence of FMD in pigs from northern Vietnam</td>
<td>Beta[1188+1, 19462203-1188+1]</td>
</tr>
<tr>
<td>$P_{vd}$</td>
<td>Prevalence of FMD in northern Vietnam</td>
<td>$P_{vd}=P_{vc}$ or $P_{vp}$</td>
</tr>
<tr>
<td>$P_{ad}$</td>
<td>Possibility of animals dying en route</td>
<td>Pert(0.05%,0.15%,0.2%,4)</td>
</tr>
<tr>
<td>$P_{cr}$</td>
<td>Possibility of animal carcasses releasing virus</td>
<td>Pert (30%, 35%, 40%, 4)</td>
</tr>
<tr>
<td>$P_{v1}$</td>
<td>Risk of FMDV escaping from the carcasses of livestock originating from Vietnam that were abandoned en route</td>
<td>$P_{v1}=P_{vd}P_{ad}P_{cr}$</td>
</tr>
<tr>
<td>$P_{vg}$</td>
<td>Possibility of acquiring infection in China</td>
<td>Pert(0.1%,0.5%,0.7%,4)</td>
</tr>
<tr>
<td>$P_{vdc}$</td>
<td>Possibility of livestock from Vietnam becoming infected en route to China</td>
<td>$P_{vdc}=P_{vg}P_{vd}(1-P_{ad})+P_{vg}$</td>
</tr>
<tr>
<td>$P_{vcc}$</td>
<td>Possibility of cattle from Vietnam being confiscated by Chinese customs</td>
<td>Pert (10%, 15%, 20%, 4)</td>
</tr>
<tr>
<td>$P_{vcd}$</td>
<td>Possibility of confiscated animals not being destroyed/disposed properly</td>
<td>Pert (10%, 15%, 20%, 4)</td>
</tr>
<tr>
<td>$P_{v2}$</td>
<td>Risk of FMD from confiscated Vietnamese livestock</td>
<td>$P_{v2}=P_{vdc}P_{vcc}P_{vcd}$</td>
</tr>
<tr>
<td>$P_{vs}$</td>
<td>Possibility of livestock being kept by the traders</td>
<td>$P_{vs}=1-P_{vcc}$</td>
</tr>
<tr>
<td>$P_{vck}$</td>
<td>Possibility of Vietnamese cattle being kept for fattening on Guangxi farms</td>
<td>Pert (5%, 7%, 10%, 4)</td>
</tr>
<tr>
<td>$P_{v3}$</td>
<td>Risk of FMD from livestock from Vietnam kept for fattening</td>
<td>$P_{v3}=P_{vg}P_{vs}P_{vck}$</td>
</tr>
<tr>
<td>Parameter</td>
<td>Description of the parameter</td>
<td>Distribution/Formula/Note</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>$P_{\text{vcs}}$</td>
<td>Possibility of FMDV spreading from slaughter houses</td>
<td>Pert (20%, 25%, 30%, 4)</td>
</tr>
<tr>
<td>$P_{\text{vr4}}$</td>
<td>Risk of FMD from Chinese slaughter houses</td>
<td>$P_{\text{vr4}} = P_{\text{vdc}} * P_{\text{vs}} * (1 - P_{\text{vck}}) * P_{\text{vcs}}$</td>
</tr>
</tbody>
</table>
| $P_{\text{vcr}}$ | Possibility of cattle from Vietnam introducing FMD into Guangxi Province | $P_{\text{vd}} = P_{\text{vc}}$  
$P_{\text{vcr}} = P_{\text{v}\text{r1}} + P_{\text{v}\text{r2}} + P_{\text{v}\text{r3}} + P_{\text{v}\text{r4}}$ |
| $P_{\text{vpr}}$ | Possibility of pigs from Vietnam introducing FMD into Guangxi Province | $P_{\text{vd}} = P_{\text{vp}}$  
$P_{\text{vpr}} = P_{\text{v}\text{r1}} + P_{\text{v}\text{r2}} + P_{\text{v}\text{r3}} + P_{\text{v}\text{r4}}$ |
| $P_{\text{route-D}}$ | Possibility of livestock from northern Vietnam introducing FMD into Guangxi Province | $P_{\text{route-D}} = P_{\text{vcr}} + P_{\text{vpr}}$ |
| $N_{\text{vc}}$ | Number of cattle travelling from Vietnam to China per shipment | Pert(15, 60, 120, 4) |
| $N_{\text{vcs}}$ | Number of cattle shipments from Vietnam to China each year | Pert (50, 55, 60, 4) |
| $N_{\text{vp}}$ | Number of pigs travelling from Vietnam to China per shipment | Pert(2, 25, 102, 4) |
| $N_{\text{vps}}$ | Number of pig shipments from Vietnam to China each year | Pert (40, 45, 50, 4) |
| $N_{\text{vcy}}$ | Number of cattle traded from Vietnam to China each year | VLOOKUP($N_{\text{vcs}}$, Table 6.3, 3) |
| $N_{\text{vpy}}$ | Number of pigs traded from Vietnam to China each year | VLOOKUP($N_{\text{vps}}$, Table 6.4, 3) |
| $N_{\text{vcr}}$ | Number of cattle from Vietnam that pose a risk of introducing FMD to China each year | Binomial[$P_{\text{vcr}}$, $N_{\text{vcy}}$] |
| $N_{\text{vpr}}$ | Number of pigs from Vietnam that pose a risk of introducing FMD to China each year | Binomial[$P_{\text{vpr}}$, $N_{\text{vpy}}$] |
a) Possibility of cattle traded from Vietnam to China being infected with FMD – \( P_{vd} \)

In 2010, FMD was reported to the OIE in 1,030 cattle and 1,188 pigs from northern Vietnam (Minh 2011). In that year the cattle and pig population in Vietnam was 5,916,250 and 27,373,000, respectively of which 69.1% and 71.1% were from northern Vietnam, respectively (Dinh and Nguyen 2005) (4,088,129 cattle and 19,462,203 pigs). The Beta distribution was used to calculate the prevalence of FMD in cattle from northern Vietnam in 2010. \( P_{vc} \) and \( P_{vp} \) were assigned to the cattle and pig prevalence in northern Vietnam and \( P_{vd} \) was set as the cattle/pig FMD prevalence in northern Vietnam. As the field survey indicated that the models of cattle and pig movements along the border were similar, parameters described in this model can be applied to both cattle and pig movements.

\[
P_{vc} = \text{Beta}[1030, 4088129] \\
P_{vp} = \text{Beta}[1188, 19462203] \\
P_{vd} = P_{vc} \text{ or } P_{vp}
\]

b) Risk of FMD from the carcasses of cattle travelling from Vietnam that have been abandoned in the wild - \( P_{vr1} \)

The short travelling time from Vietnam to China meant that few cattle died en route (range 0.05 to 0.2% with a most likely value of 0.15% - \( P_{ad} \)). The possibility of FMDV being released from cattle that died en route was estimated to be between 30 and 40%, with a most likely value of 35% (\( P_{cr} \)). \( P_{vr1} \) was assigned to the risk of FMD from carcasses from cattle from Vietnam that had been abandoned in the wild.

\[
P_{ad} = \text{Pert}(0.05\%, 0.15\%, 0.2\%, 4) \\
P_{cr} = \text{Pert}(30\%, 35\%, 40\%, 4) \\
P_{vr1} = P_{vd} \times P_{ad} \times P_{cr}
\]
c) Possibility of livestock from Vietnam being infected with FMD en route to China - $P_{vdc}$

As some animals from Vietnam to China were walked along mountainous paths there was the potential to have interaction with other livestock or wild animals and becoming infected with FMD if these in-contact animals were infected. The likelihood of infection en route to China ($P_{vg}$) was estimated to be from 0.1 to 0.7% with a most likely value of 0.5%. $P_{vdc}$ was assigned as the probability of cattle from Vietnam becoming infected with FMD en route to China.

$$P_{vg} = \text{Pert}(0.1\%, 0.5\%, 0.7\%, 4)$$

$$P_{vdc} = P_{vd} * (1 - P_{ad}) + P_{vg}$$

d) Risk of FMD from confiscated Vietnamese cattle – $P_{vr2}$

Informal animal movements can be detected by Chinese customs especially when animals are descending from the mountains. Detected shipments should be confiscated and destroyed as per the national/local policies, laws and regulations. $P_{vcc}$ was assigned to the possibility of cattle from Vietnam being detected by Chinese customs and $P_{vcd}$ as the likelihood of FMDV escaping from the confiscated animals. $P_{vr2}$ was set as the risk of FMD from the confiscated Vietnam cattle.

$$P_{vcc} = \text{Pert} (10\%, 15\%, 20\%, 4)$$

$$P_{vcd} = \text{Pert} (10\%, 15\%, 20\%, 4)$$

$$P_{vr2} = P_{vdc} * P_{vcc} * P_{vcd}$$

e) Risk of FMD from fattening cattle – $P_{vr3}$

The experts estimated that the possibility of cattle from Vietnam being kept in Guangxi for fattening ($P_{vck}$) was 5 to 10% with a most likely value of 7%. $P_{vr3}$ was assigned to the FMD risk from Vietnam cattle kept for fattening and $P_{vs}$ as the possibility of cattle from Vietnam not being detected by Chinese customs.
\[ P_{vs} = 1 - P_{vcc} \]
\[ P_{vck} = \text{Pert}(5\%, 7\%, 10\%, 4) \]
\[ P_{vr3} = P_{vpg} \times P_{vs} \times P_{vck} \]

**f) Risk of FMD escaping from Guangxi slaughter houses – \( P_{vr4} \)**

Up to 90\% of animals from Vietnam that did not die or were confiscated en route were sold to slaughter houses. The experts estimated that the possibility of FMD being transmitted from slaughter houses (\( P_{vcs} \)) to livestock was 20 to 30\%.

\[ P_{vcs} = \text{Pert}(20\%, 25\%, 30\%, 4) \]
\[ P_{vr4} = P_{vdc} \times P_{vs} \times (1 - P_{vck}) \times P_{vcs} \]

**g) Possibility of livestock from northern Vietnam introducing FMD to Guangxi Province - \( P_{route-D} \)**

\( P_{vc} \) and \( P_{vp} \) were substituted into the model separately, and the risk from cattle and pigs from Vietnam calculated. \( P_{vcr} \) and \( P_{vpr} \) were assigned to the possibility that cattle and pigs from Vietnam, respectively, introduced FMD into Guangxi Province. \( P_{route-D} \) was set as the possibility of livestock from northern Vietnam introducing FMD to Guangxi Province.

\[ P_{vcr} = P_{vr1} + P_{vr2} + P_{vr3} + P_{vr4} \text{ (when } P_{vd} = P_{vc}) \]
\[ P_{vpr} = P_{vr1} + P_{vr2} + P_{vr3} + P_{vr4} \text{ (when } P_{vd} = P_{vp}) \]
\[ P_{route-D} = P_{vcr} + P_{vpr} \]

**h) Number of cattle imported each year from Vietnam that pose a risk of introducing FMD to China - \( N_{vcr} \)**

The number of cattle from Vietnam to China per shipment (\( N_{vc} \)) was estimated to be from 15 to 120 with 50 to 60 shipments a year (\( N_{vcs} \)). \( N_{vc} \) was separately calculated 60 times and summed (Table 6.3). The number of cattle traded from Vietnam to China each year (\( N_{vcy} \)) was calculated using the VLOOKUP function and \( N_{vcr} \) was assigned to the number of cattle from Vietnam which posed a risk of introducing FMD to China each year.
\[ N_{vcs} = \text{Pert}(50, 55, 60, 4) \]
\[ N_{vcy} = \text{VLOOKUP}(N_{vcs}, \text{Table 6.3}, 3) \]
\[ N_{vcy} = \text{Binomial}[P_{vcy}, N_{vcy}] \]

Table 6.3 Random Results of the Number of Cattle per Shipment Imported Informally from Vietnam to China

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>72</td>
<td>72 = n1</td>
</tr>
<tr>
<td>2</td>
<td>69</td>
<td>141 = N1+n2</td>
</tr>
<tr>
<td>3</td>
<td>67</td>
<td>208 = N2+n3</td>
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<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>50</td>
<td>97</td>
<td>3351 = N49+n50</td>
</tr>
<tr>
<td>51</td>
<td>75</td>
<td>3425 = N50+n51</td>
</tr>
<tr>
<td>52</td>
<td>65</td>
<td>3490 = N51+n52</td>
</tr>
<tr>
<td>53</td>
<td>75</td>
<td>3565 = N52+n53</td>
</tr>
<tr>
<td>54</td>
<td>48</td>
<td>3613 = N53+n54</td>
</tr>
<tr>
<td>55</td>
<td>34</td>
<td>3647 = N54+n55</td>
</tr>
<tr>
<td>56</td>
<td>46</td>
<td>3693 = N55+n56</td>
</tr>
<tr>
<td>57</td>
<td>24</td>
<td>3717 = N56+n57</td>
</tr>
<tr>
<td>58</td>
<td>71</td>
<td>3788 = N57+n58</td>
</tr>
<tr>
<td>59</td>
<td>49</td>
<td>3837 = N58+n59</td>
</tr>
<tr>
<td>60</td>
<td>40</td>
<td>3877 = N50+n60</td>
</tr>
</tbody>
</table>

i) The number of pigs imported each year from Vietnam that pose a risk of introducing FMD to China - \( N_{vpr} \)

The number of pigs from Vietnam to China per shipment \( (N_{vp}) \) was between two and 102 with 40 to 50 shipments per year \( (N_{vps}) \). \( N_{vp} \) was calculated separately 50 times and summed (Table 6.4). The number of pigs traded from Vietnam to China each year \( (N_{vpy}) \) was calculated using a VLOOKUP function and \( N_{vpr} \) set as the number of pigs from Vietnam that posed a risk of FMD to China each year.

\[ N_{vp} = \text{Pert}(2, 25, 102, 4) \]
\[ N_{vps} = \text{Pert}(40, 45, 50, 4) \]
\[ N_{vpy} = \text{VLOOKUP}(N_{vps}, \text{Table 6.4}, 3) \]
\[ N_{vpr} = \text{Binomial}[P_{vpr}, N_{vpy}] \]
Table 6.4 Random Results of the Number of Pigs Imported from Vietnam to China
Each Shipment

<table>
<thead>
<tr>
<th></th>
<th>$n$</th>
<th>$N$</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14</td>
<td>14</td>
<td>= $n_1$</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>74</td>
<td>= $N_1+n_2$</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>81</td>
<td>= $N_2+n_3$</td>
</tr>
</tbody>
</table>
| ... | ... | ...   | ... ... \ ...
| 40 | 37  | 1392  | = $N_{39}+n_{40}$ |
| 41 | 19  | 1411  | = $N_{40}+n_{41}$ |
| 42 | 64  | 1475  | = $N_{41}+n_{42}$ |
| 43 | 54  | 1529  | = $N_{42}+n_{43}$ |
| 44 | 24  | 1553  | = $N_{43}+n_{44}$ |
| 45 | 35  | 1587  | = $N_{44}+n_{45}$ |
| 46 | 59  | 1647  | = $N_{45}+n_{46}$ |
| 47 | 42  | 1689  | = $N_{46}+n_{47}$ |
| 48 | 48  | 1737  | = $N_{47}+n_{48}$ |
| 49 | 25  | 1762  | = $N_{48}+n_{49}$ |
| 50 | 11  | 1773  | = $N_{49}+n_{50}$ |
6.3 Results

6.3.1 The Possibility of FMD Spreading from Vietnam to China through Informal Livestock Movements – $P_{route-D}$

The results of 2000 iterations for $P_{route-D}$ are displayed in Figure 6.3. The mean value of $P_{route-D}$ was 0.27% with a range of 0.112 to 0.391%.

Figure 6.3 Histogram of $P_{route-D}$ and Cumulative Probability Distribution
6.3.2 Sensitivity Analysis Results of $P_{\text{route-D}}$

The results of the sensitivity analysis for $P_{\text{route-D}}$ are displayed in Figure 6.4. The factor that had the greatest influence on $P_{\text{route-D}}$ was the possibility that cattle from Vietnam were infected en route in China (0.68). Release from slaughter houses (0.16) and keeping animals on Chinese farms (0.07) also increased the risk of FMD. The detection by Chinese customs (-0.03) slightly reduced the risk. Surprisingly the prevalence of FMD in northern Vietnam only posed a small risk to the introduction of the disease (0.01).

**Figure 6.4 Regression Coefficients of Sensitivity Analysis of $P_{\text{route-D}}$**
6.3.3 The Possibility of FMD Spreading from Vietnam to China through the Informal Movement of Cattle– $P_{ver}$

The distribution of 2000 iterations for $P_{ver}$ are summarised in Figure 6.5. The mean value of the possibility of FMD entering China from Vietnam through informal cattle movements was 0.138%, with a range from 0.04 to 0.22%. The median value was 0.14% with 90% CI of 0.083 to 0.188%.

![Figure 6.5 Histogram of $P_{ver}$ and Cumulative Probability Distribution](image_url)
6.3.4 Sensitivity Analysis Results of $P_{\text{ver}}$

Regression analysis (Figure 6.6) identified that there were several factors contributing positively to $P_{\text{ver}}$. The greatest impact was the possibility that cattle from Vietnam became infected en route to China (0.97). The other contributors all had small impacts on the result of $P_{\text{ver}}$, including escape from slaughter houses in China (0.23), possibility of cattle being kept for fattening (0.09), cattle confiscated by Chinese customs but not destroyed properly (0.04) and the prevalence of FMD in the exporting country (0.01). Detection by Chinese customs slightly reduced the risk of FMD entering China (-0.04).

![Figure 6.6 Regression Coefficients of Sensitivity Analysis of $P_{\text{ver}}$](image_url)
6.3.5 The Number of Vietnamese Cattle Imported to Guangxi Province Each Year Posing a Risk of FMD – $N_{\text{ver}}$

The mean number of the distribution of $N_{\text{ver}}$ was five, and the median four with a range from 0 to 16 (Figure 6.7).

**Figure 6.7 Histogram of $N_{\text{ver}}$ and Cumulative Probability Distribution**

- Minimum: 0
- Maximum: 16
- Mean: 5
- Median: 4
- Std Dev: 2
- Skewness: 0.5033
- Kurtosis: 3.3485
- Values: 2000
6.3.6 Sensitivity Analysis Results of $N_{vcr}$

The results of $N_{vcr}$ after 2000 iterations are displayed in Figure 6.8. The biggest effect on the sensitivity of $N_{vcr}$ was the possibility of cattle from Vietnam becoming infected en route to China (0.44). Other positive, but small, effects on the result of $N_{vcr}$ were found from the escape of virus from slaughter houses (0.11), the number of shipments each year (0.07) and the possibility of cattle from Vietnam being kept on Chinese farms for fattening (0.05). Detection and confiscation of customs could slightly decrease the risk of FMD entering China from Vietnam (-0.04).

Figure 6.8 Regression Coefficients of Sensitivity Analysis of $N_{vcr}$
6.3.7 The Possibility of FMD Spreading from Vietnam to China through the Informal Movement of Pigs – $P_{\text{vpr}}$

The distribution of 2000 iterations for $P_{\text{vpr}}$ are summarised in Figure 6.9. The mean value of the possibility of FMD spreading from Vietnam to China through the informal movement of pigs was 0.133\%, with a range of 0.04 to 0.21\% and a median of 0.134\%.

**Figure 6.9 Histogram of $P_{\text{vpr}}$ and Cumulative Probability Distribution**
6.3.8 Sensitivity Analysis Results of $P_{vpr}$

Regression analysis (Figure 6.10) identified that there were several factors contributing positively to $P_{vpr}$. The greatest impact was the possibility that pigs from Vietnam acquired FMD en route to China (0.98). Other contributors with small impacts on the result of $P_{vpr}$ were escape of virus from slaughter houses (0.22), possibility of pigs being kept for fattening (0.09), and pigs being confiscated by Chinese customs but not being destroyed properly (0.04). The detection of consignments by Chinese customs slightly reduced the risk (-0.04).

Figure 6.10 Regression Coefficients of Sensitivity Analysis of $P_{vpr}$

![Figure 6.10 Regression Coefficients of Sensitivity Analysis of $P_{vpr}$]
6.3.9 The Number of Pigs from Vietnam that Pose a Risk of Introducing FMD to Guangxi Province Each Year – $N_{vpr}$

The mean number of pigs posing a risk of introducing FMD to Guangxi Province ($N_{vpr}$) from Vietnam was 2 with a range of 0 to 9.

Figure 6.11 Histogram of $N_{vpr}$ and Cumulative Probability Distribution
6.3.10 Sensitivity Analysis Results of $N_{vpr}$

The results of $N_{vpr}$ after 2000 iterations are displayed in Figure 6.12. The biggest effect on the sensitivity of $N_{vpr}$ was the possibility of pigs from Vietnam acquiring FMD en route to their destination (0.34). Factors with a slight positive effect included escape of virus from slaughter houses (0.10), confiscated pigs not being destroyed properly (0.04) and the prevalence of FMD in pigs from Vietnam (0.04).

**Figure 6.12 Regression Coefficients of Sensitivity Analysis of $N_{vpr}$**
6.4 Discussion

This is the first quantitative assessment of the risk of introducing FMDV from northern Vietnam to Guangxi Province through the informal movement of livestock (cattle and pigs).

Livestock movements between Vietnam and China have been documented since the 1990s (Bouchot 2009; Le 1999; Ozawa 1993; Sasaki 1993). Practices to control FMD adopted by the Vietnamese government since the 1990s have included training programs on the diagnosis of the disease, improvement in the control and surveillance reporting systems, an expanded vaccination program and control of animal movements (OIE 1998c; Sasaki 1993). Initially the vaccination and movement control strategies implemented did not work effectively (OIE 1998c; Sasaki 1993). With the implementation of a nation-wide vaccination programme from 2006 to 2010 the disease has been more effectively controlled (Pham 2011a). It has been recommended that to reduce the risk of FMDV in the Upper Mekong Region countries, the primary strategy applied should be intensive vaccination (Doel 2003; OIE 2007). In recent years, the Vietnamese government has taken an active part in international cooperation against FMD and has administered more than seven million doses of FMD vaccine each year to animals across the country (Do 2011; Hoang 2010; Van 2010).

The model built in this chapter indicated that the most sensitive factor influencing the spread of FMD from Vietnam to Guangxi Province was the possibility that livestock from Vietnam acquired infection en route to their destination in China. In the border
In areas there are many small villages scattered throughout the mountains (Xiang et al. 2012). The consignments of unofficial livestock need to move through this area prior to arriving at the slaughter houses or fattening farms in Guangxi Province. There is the potential for infectious animal diseases, including FMD, to enter and spread into this area through these unofficial livestock movements (Ou 1999). There are several reasons which make the control of infectious diseases in the border area challenging. Firstly, the animal keepers have low levels of education and consequently their understanding of animal disease and how to prevent them is likely to be low. Secondly the low level of compensation paid for animals dying from the side effects of vaccination results in a low level of vaccination uptake and coverage in the mountainous area (Lu et al. 2009). Thirdly there are insufficient veterinary personnel because of low salaries and the difficulties in working in remote areas (Lu et al. 2009; Ou 1999; Wang 2009). Finally the diagnostic equipment in the local veterinary stations and the cold-chain facilities to maintain the FMD vaccine is often limited (Deng et al. 2011; Ou 1999).

Some counties in the Guangxi Province have employed people to prevent and/or report informal livestock cross-boundary trade (Deng et al. 2011; Huang 2012). However, the existing regulations/measures in China may actually promote the informal animal trade (Kitching 1999). It is recommended that the Chinese Government should change the current policy prohibiting the importation of live animals from its neighbouring countries to allow the legal importation of animals which can then be traced and examined under a suitable surveillance system. Others have highlighted the fact that the disease risk through legal trade is easier to manage (Bronsvoort et al. 2008). An
alternative to live animal movement is the movement of animal product, in particular boned-out meat, which has a lower risk of introducing FMD than live animals (Garland and de Clercq 2011; Paton et al. 2010; Thomson et al. 2009).

It is evident that control of FMD in China requires implementation of an effective and well-resourced control strategy. In the following chapter the efficacy of vaccination against FMD in China using Meta-Analysis is assessed and the opinions of Chinese government veterinary workers on the current control strategy for FMD in China are obtained.
Chapter 7. Meta-Analysis on the Efficacy of FMD Vaccine in China and the Opinions of Experts on the Control of FMD in China
Chapter 7. Meta-Analysis on the Efficacy of FMD Vaccine in China and the Opinions of Experts on the Control of FMD in China

7.1 Background

The results of Chapters 4, 5 and 6 indicated that China faces a risk of FMD incursion from neighbouring South East Asian countries. For example, from 2005 to 2011, in Guangxi Province, a total of 2,000 tonnes of unofficially imported livestock product were detected and destroyed by Guangxi customs, and 13,000 live pigs were imported informally (Ji 2011). The risk of FMD due to livestock movement entering into China is not only from Southeast Asia but also from other countries including Russia, Mongolia, Japan and Korea (Wang 2000), as well as movement of animals and animal product from other regions of China. In Figure 7.1 outbreaks of FMD in China and its neighbouring countries for the period from 2005 to 2011 are displayed.
For the purpose of controlling infectious animal diseases in China, the China National Animal Epidemic Prevention Law was proclaimed on the 1\textsuperscript{st} January 1998 and was revised in 2008 (Ye 2008b). In this law, Article 13 states that China applies compulsory immunisation to epidemic animal disease which causes serious damage to the breeding and production potential or to human health. These epidemic diseases includes highly pathogenic avian influenza (HPAI), Porcine Reproductive and Respiratory Syndrome (PRRS), Foot and Mouth Disease (FMD), Classical Swine Fever (CSF) and Peste des Petits Ruminants (PPR) (MOA 2010b).
As well as the compulsory immunisation strategy, to control animal disease the Chinese government also uses various veterinary administrative organisations, law enforcement agencies, and technology support institutes to cooperate with a range of animal disease control and veterinary services such as the China Animal Health and Epidemiology Center, China Animal Disease Control Center, National Veterinary Reference Laboratories, and China Institute of Veterinary Drug Control (MOA 2010a).

China has also established an animal disease reporting system and a surveillance system to evaluate the control of animal diseases (Figure 7.2). People (farmers or veterinarians) who detect a suspected case/outbreak either call their local veterinary service office or send a letter to them. The reporting system and flow of data to related government organisations is displayed in Figure 7.2.
In this chapter the control strategy adopted in China against FMD is evaluated through analysis of information provided by Chinese veterinary workers. The efficacy of vaccination against FMD in China is also assessed through a meta-analysis. Meta-analysis is a statistical method designed to estimate the effectiveness of clinical interventions (Crombie and Davies 2009). Publication bias is an uncertainty which
exists in meta-analysis (Ahmed et al. 2012) and this is also assessed and estimated in this chapter (Halasa et al. 2011).

7.2 Materials and Methods

7.2.1 Compulsory Immunisation against FMD in China

In China it is compulsory to immunise: pigs against FMD serotype O virus; cattle, sheep (and goats), camels and deer against serotypes O and Asia-1; dairy and breeding cows against serotype A; and cattle and sheep (and goats) from Guangxi Zhuang Autonomous Region (Guangxi Province), Yunnan Province, Tibet Autonomous Region (Tibet), and Xinjiang Province against serotype A. In large scale livestock farms, piglets and lambs should initially be immunised at 28 to 35 days of age and calves at approximately 90 days of age. After one month, animals should receive a secondary booster immunisation and then should be immunised at four to six monthly intervals. Backyard livestock are immunised biannually (in spring and autumn) by staff from local veterinary stations. However when outbreaks of FMD occur, emergency vaccination is implemented to prevent the disease spreading. These emergency procedures involve vaccination of all susceptible animals in the outbreak and buffer zones that are set by the government. The vaccines adopted by the Chinese government for cattle, sheep and goats, camels and deer include serotypes O and Asia-1 bivalent inactivated vaccines, serotype O plus serotype A bivalent inactivated vaccine and serotype A inactivated vaccine. The vaccines used in pigs are inactivated and synthetic peptide serotype O vaccines. Empty capsid vaccines of serotype O are also administered to pigs in
approved regions (MOA 2010b).

The vaccine used in compulsory immunisation programs is procured and distributed by the government (Zhang and Guo 2011). The vaccine is free to farmers and the supply chain is displayed in Figure 7.3. The vaccine is funded by the central government (50%), provincial financial department (20%), municipal financial department (10%) and county financial department (20%). Poverty-stricken counties can obtain a financial difficulty allowance from higher level financial departments to fund the vaccination program (Lin 2008).

**Figure 7.3 The Supply Chain for FMD Vaccine in China (Zhang and Guo 2011)**
After a compulsory vaccination program is completed, a surveillance program is required to be implemented. The surveillance is designed to assess the vaccine coverage and its effectiveness. The liquid phase blocking ELISA (LPB-ELISA) is used for testing antibody to serotype Asia-1, with a titre greater to or equal to 64 required to demonstrate protection. For serotype O the indirect haemagglutination assay (IHA) and the LPB-ELISA are used with effective titres assessed at greater or equal to 32 or 64, respectively. For serotype A a titre greater or equal to 64 on the LPB-ELISA is required. The indirect ELISA is also used for diagnosing antibody to VP-1 structural protein (titre greater or equal to 32 required). This structural protein is used in synthetic peptides vaccine to protect pigs against serotype O (MOA 2010b).

7.2.2 Efficacy of FMD Vaccine Used in the Compulsory Vaccination Program

Meta-Analysis was used to evaluate the efficacy of the compulsory vaccination program against FMD adopted in China. Published papers were collected and evaluated from three main sources: databases of Chinese academic journals, academic theses, and conference papers. These were sourced from Wan Fang Data (www.wanfangdata.com.cn), Wei Pu Information Network (www.cqvip.com) and China National Knowledge Infrastructure (CNKI) (www.cnki.net).

A total of 500 papers were detected using the key word search of “Foot and Mouth Disease”, “immune”, “efficacy”, “antibody” and “monitoring” (in Chinese). After restricting these 500 papers those published from 1998 to 2011, 122 papers remained. These papers were then reviewed in the meta-analysis.
Research studies included in the analysis were required to fulfil the following conditions:

a) The aim of the study was to evaluate antibody titre to FMD after compulsory immunisation.

b) The antibody test methods used in the study were required to be the standard methods described in Section 7.2.1.

c) The study clearly indicated the species of animals tested.

d) The species of tested animals included at least one domestic livestock animal (pigs, cattle and sheep).

e) The study clearly indicated the breeding condition of the tested animals, farms or households.

f) If the animals tested included cattle and/or sheep, then the study needed to clearly indicate the serotype tested for.

g) The study must have clearly shown the number of animals with sufficient immunity and the total number of samples tested.

Research studies included in the meta-analysis should not be evaluating:

a) Field trials aimed to test the efficacy of an FMD vaccine using comparative field trials.

b) Studies designed to test the dynamics of antibody to FMD.

After this screening only 23 studies fulfilled all of the criteria (Figure 7.4). The proportion of animals with sufficient antibody level to be protective in these papers
were analysed with the free software R© version 2.13.1 provided by The R Foundation for Statistical Computing (www.r-project.org). The inverse variance method, LOGIT transformation, was used to combine the results from the different papers. If the combined results of the test for heterogeneity had a $P > 0.05$, then the studies were considered homogeneous. In this case the fixed effect model was followed. If the studies were not homogeneous then the random effect model was followed (He et al. 2011). After analysing the overall success rate of the 23 papers, details on the target animal species, breeding conditions and vaccine types were collected and analysed separately.

**Figure 7.4 The Screening Procedure for the Studies**

![Diagram showing the screening procedure for studies](image)
This chapter was designed to analyse published papers on the efficacy of immunity to FMD induced by vaccination. However studies which result in positive and significant findings are more likely to be published than those which produce negative or non-significant findings (Halasa et al. 2011). This publication bias was described and discussed after the meta-analysis was conducted. In recent years, the popular methods of detecting publication bias have included funnel graphs, Egger’s method, rank correlation test, Begg’s method, truncated sampling, weighted distribution theory, maximum likelihood, fail-safe N, Hackshaw’s method, Sugita’s method, and Givens’ method (Thornton and Lee 2000). However none of these methods is perfect, with each having advantages and disadvantages. This chapter used funnel graphs to show the bias of the published papers collected, followed by a rank correlation test to show the statistical asymmetry of funnel graphs. In the Begg and Mazumdar’s rank correlation test, the test accesses the interdependence of test variances and test accuracy estimates (Song et al. 2002).

There were two values produced to show the statistical results of the funnel graphs: the Z-value and the P-value. The Z-value of the Rank Correlation Test indicated the presence of a relationship between effect size and precision (Borenstein 2006). A positive value means a tendency leaning to high level of test accuracy in a small size study. The P value of the result of the rank correlation test was the measurement used to determine if publication bias existed among the trials from the different studies.
7.2.3 The Attitudes of Government Veterinary Workers towards the Control of FMD in China

In August 2011, a five day course “Training to Improve Control and Prevention of Foot and Mouth Disease (FMD)” was held in Lanzhou City, China for 66 veterinary workers from animal disease control organisations from 28 of the 31 Provinces (including municipality cities and autonomous regions) of China. The training course was conducted by Development Solutions (DS), a European consultancy company and funded by the European Union.

In the training course, trainees were asked to give their opinion on “the most important things for the control of FMD in China”. Responders were allowed to submit as many opinions or comments as they liked. Among these 66 middle-level administrators in the field of Chinese animal disease control, 53 responses (80.3%) were received.

7.3 Results

7.3.1 Results of the Meta-Analysis of Immunity against FMD in China

The study number, published year and the first author of the 23 studies which met the selection criteria are displayed in Figure 7.5. The meta-analysis results of these 23 studies and the combined results are also displayed in Figure 7.5. In this figure the Events column indicates the number of animals that had antibody titres at, or above, the national requirement (seroprotective success). The column labelled Total was the total number of animals tested. The number of seroprotective successes divided by the total number of animals tested was analysed and represented the immunity success. The grey areas (when this was too small it became a black dot) on the horizontal lines indicate the
proportion of the study in all of the studies included in the meta-analysis.

The heterogeneity test result for these data had a P value < 0.0001. This indicated that the differences between the studies were very large, and consequently the random effects model was employed (StatsDirectSupport 2011). The overall proportion that was seroprotective after immunisation was 73% (95% CI: 66 – 79%).

Figure 7.5 The Forest Plot of the Meta-Analysis on the Seroprotective Success Rate of Compulsory Vaccination against FMD in China

<table>
<thead>
<tr>
<th>Study</th>
<th>Events</th>
<th>Total</th>
<th>Proportion</th>
<th>95%-CI W(fixed)</th>
<th>W(random)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2004 Lin L</td>
<td>159 332</td>
<td>=</td>
<td>0.48 [0.42; 0.53]</td>
<td>1.4%</td>
<td>4.4%</td>
</tr>
<tr>
<td>2 2007 Ren G</td>
<td>1890 2541</td>
<td>=</td>
<td>0.74 [0.72; 0.76]</td>
<td>8.0%</td>
<td>4.4%</td>
</tr>
<tr>
<td>3 2009 Wu J</td>
<td>4897 9087</td>
<td>=</td>
<td>0.50 [0.46; 0.51]</td>
<td>40.5%</td>
<td>4.4%</td>
</tr>
<tr>
<td>4 2011 Wei Z</td>
<td>379 456</td>
<td>=</td>
<td>0.83 [0.79; 0.86]</td>
<td>1.1%</td>
<td>4.3%</td>
</tr>
<tr>
<td>5 2008 Liu Y</td>
<td>1394 1850</td>
<td>=</td>
<td>0.75 [0.73; 0.77]</td>
<td>5.7%</td>
<td>4.4%</td>
</tr>
<tr>
<td>6 2009 Liu H</td>
<td>205 239</td>
<td>=</td>
<td>0.86 [0.81; 0.90]</td>
<td>0.5%</td>
<td>4.2%</td>
</tr>
<tr>
<td>7 2009 Zhang C</td>
<td>71 315</td>
<td>=</td>
<td>0.23 [0.18; 0.28]</td>
<td>0.9%</td>
<td>4.3%</td>
</tr>
<tr>
<td>8 2008 Ye W</td>
<td>563 694</td>
<td>=</td>
<td>0.64 [0.61; 0.67]</td>
<td>1.5%</td>
<td>4.4%</td>
</tr>
<tr>
<td>9 2000 He Q</td>
<td>67 243</td>
<td>=</td>
<td>0.26 [0.22; 0.34]</td>
<td>0.8%</td>
<td>4.3%</td>
</tr>
<tr>
<td>10 2009 Xiao C</td>
<td>1044 1617</td>
<td>=</td>
<td>0.65 [0.62; 0.67]</td>
<td>6.1%</td>
<td>4.4%</td>
</tr>
<tr>
<td>11 2007 Wen M</td>
<td>539 575</td>
<td>=</td>
<td>0.63 [0.59; 0.66]</td>
<td>1.3%</td>
<td>4.3%</td>
</tr>
<tr>
<td>12 2008 Zhang D</td>
<td>430 530</td>
<td>=</td>
<td>0.73 [0.69; 0.77]</td>
<td>1.3%</td>
<td>4.2%</td>
</tr>
<tr>
<td>13 2010 Fang X</td>
<td>830 921</td>
<td>=</td>
<td>0.88 [0.83; 0.91]</td>
<td>0.5%</td>
<td>4.2%</td>
</tr>
<tr>
<td>14 2011 Zhao C</td>
<td>493 1000</td>
<td>=</td>
<td>0.49 [0.46; 0.52]</td>
<td>4.1%</td>
<td>4.4%</td>
</tr>
<tr>
<td>15 2010 Liu B</td>
<td>143 200</td>
<td>=</td>
<td>0.72 [0.65; 0.78]</td>
<td>0.7%</td>
<td>4.3%</td>
</tr>
<tr>
<td>16 2010 Quan Y</td>
<td>365 510</td>
<td>=</td>
<td>0.72 [0.68; 0.76]</td>
<td>1.7%</td>
<td>4.4%</td>
</tr>
<tr>
<td>17 2009 Xue B</td>
<td>306 359</td>
<td>=</td>
<td>0.85 [0.81; 0.89]</td>
<td>0.7%</td>
<td>4.3%</td>
</tr>
<tr>
<td>18 2009 Zhang Y</td>
<td>1680 1947</td>
<td>=</td>
<td>0.86 [0.85; 0.88]</td>
<td>3.0%</td>
<td>4.4%</td>
</tr>
<tr>
<td>19 2011 Su C</td>
<td>306 409</td>
<td>=</td>
<td>0.65 [0.61; 0.70]</td>
<td>1.7%</td>
<td>4.4%</td>
</tr>
<tr>
<td>20 2008 Long W</td>
<td>397 673</td>
<td>=</td>
<td>0.59 [0.55; 0.63]</td>
<td>2.7%</td>
<td>4.4%</td>
</tr>
<tr>
<td>21 2008 Yuan L</td>
<td>3488 4279</td>
<td>=</td>
<td>0.81 [0.80; 0.82]</td>
<td>10.8%</td>
<td>4.4%</td>
</tr>
<tr>
<td>22 2011 Gan Y</td>
<td>952 1252</td>
<td>=</td>
<td>0.76 [0.74; 0.78]</td>
<td>3.7%</td>
<td>4.4%</td>
</tr>
</tbody>
</table>

7.3.2 Results of the Meta-Analysis of Immunity against FMD in Different Groups

The details, such as the animal species tested, livestock breeding modes and the type of vaccine, of the 23 studies are displayed in Table 7.1. As some studies had multiple
results, the data were reorganised into livestock breeds, breeding models and antibody types. Meta-analysis was applied to all of these recombined groups to show the difference of vaccine efficacy between species, breeding models and antibody types.

<table>
<thead>
<tr>
<th>Study No.</th>
<th>Publish Year</th>
<th>First Author</th>
<th>Species</th>
<th>Breeding Model</th>
<th>No. of Seroprotective Successes</th>
<th>No. of Samples</th>
<th>Antibody Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2004</td>
<td>Lin L</td>
<td>pigs</td>
<td>Farm</td>
<td>159</td>
<td>332</td>
<td>O</td>
</tr>
<tr>
<td>2</td>
<td>2007</td>
<td>Ren G</td>
<td>pigs</td>
<td>Farm</td>
<td>622</td>
<td>854</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>cattle</td>
<td>Farm</td>
<td>421</td>
<td>475</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>pigs</td>
<td>Household</td>
<td>237</td>
<td>356</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>cattle</td>
<td>Farm</td>
<td>119</td>
<td>181</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>cattle</td>
<td>Farm</td>
<td>257</td>
<td>312</td>
<td>Asia-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>cattle</td>
<td>Household</td>
<td>54</td>
<td>91</td>
<td>Asia-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>sheep</td>
<td>Farm</td>
<td>63</td>
<td>118</td>
<td>Asia-1</td>
</tr>
<tr>
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<td>2009</td>
<td>Wu J</td>
<td>pigs</td>
<td>Farm</td>
<td>4897</td>
<td>9887</td>
<td>O</td>
</tr>
<tr>
<td>4</td>
<td>2011</td>
<td>Wei Z</td>
<td>pigs</td>
<td>Farm</td>
<td>215</td>
<td>270</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>pigs</td>
<td>Household</td>
<td>73</td>
<td>94</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>cattle</td>
<td>Household</td>
<td>91</td>
<td>94</td>
<td>O</td>
</tr>
<tr>
<td>5</td>
<td>2008</td>
<td>Liu Y</td>
<td>pigs</td>
<td>Farm</td>
<td>100</td>
<td>168</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>cattle</td>
<td>Farm</td>
<td>649</td>
<td>849</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>sheep</td>
<td>Farm</td>
<td>635</td>
<td>833</td>
<td>O</td>
</tr>
<tr>
<td>6</td>
<td>2009</td>
<td>Liu H</td>
<td>pigs</td>
<td>Household</td>
<td>38</td>
<td>48</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>pigs</td>
<td>Farm</td>
<td>76</td>
<td>84</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>cattle</td>
<td>Household</td>
<td>7</td>
<td>9</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>cattle</td>
<td>Farm</td>
<td>16</td>
<td>16</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>sheep</td>
<td>Household</td>
<td>23</td>
<td>29</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>sheep</td>
<td>Farm</td>
<td>45</td>
<td>53</td>
<td>O</td>
</tr>
<tr>
<td>7</td>
<td>2009</td>
<td>Zhang C</td>
<td>pigs</td>
<td>Farm</td>
<td>71</td>
<td>315</td>
<td>O</td>
</tr>
<tr>
<td>8</td>
<td>2008</td>
<td>Ye W</td>
<td>pigs</td>
<td>Farm</td>
<td>583</td>
<td>694</td>
<td>O</td>
</tr>
<tr>
<td>9</td>
<td>2000</td>
<td>He Q</td>
<td>pigs</td>
<td>Farm</td>
<td>67</td>
<td>243</td>
<td>O</td>
</tr>
<tr>
<td>10</td>
<td>2009</td>
<td>Xiao G</td>
<td>pigs</td>
<td>Farm</td>
<td>1044</td>
<td>1617</td>
<td>O</td>
</tr>
<tr>
<td>11</td>
<td>2007</td>
<td>Wen M</td>
<td>pigs</td>
<td>Farm</td>
<td>394</td>
<td>407</td>
<td>O</td>
</tr>
</tbody>
</table>

Table 7.1 Details of 23 Published Papers Meeting the Selection Criteria
<table>
<thead>
<tr>
<th>Study No.</th>
<th>Publish Year</th>
<th>First Author</th>
<th>Species</th>
<th>Breeding Model</th>
<th>No. of Seroprotective Successes</th>
<th>No. of Samples</th>
<th>Antibody Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>2008</td>
<td>Zhang D</td>
<td>pigs</td>
<td>Farm</td>
<td>135</td>
<td>170</td>
<td>O</td>
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<tr>
<td>13</td>
<td>2010</td>
<td>Fang X</td>
<td>pigs</td>
<td>Farm</td>
<td>830</td>
<td>921</td>
<td>O</td>
</tr>
<tr>
<td>14</td>
<td>2011</td>
<td>Zhao C</td>
<td>pigs</td>
<td>Farm</td>
<td>124</td>
<td>145</td>
<td>O</td>
</tr>
<tr>
<td>15</td>
<td>2010</td>
<td>Liu B</td>
<td>pigs</td>
<td>Farm</td>
<td>147</td>
<td>200</td>
<td>O</td>
</tr>
<tr>
<td>16</td>
<td>2010</td>
<td>Quan Y</td>
<td>cattle</td>
<td>Farm</td>
<td>112</td>
<td>140</td>
<td>O</td>
</tr>
<tr>
<td>17</td>
<td>2009</td>
<td>Xie B</td>
<td>pigs</td>
<td>Farm</td>
<td>237</td>
<td>300</td>
<td>O</td>
</tr>
<tr>
<td>18</td>
<td>2009</td>
<td>Zhang Y</td>
<td>pigs</td>
<td>Farm</td>
<td>81</td>
<td>105</td>
<td>O</td>
</tr>
<tr>
<td>19</td>
<td>2011</td>
<td>Su C</td>
<td>pigs</td>
<td>Farm</td>
<td>285</td>
<td>332</td>
<td>O</td>
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<tr>
<td>20</td>
<td>2008</td>
<td>Long W</td>
<td>pigs</td>
<td>Farm</td>
<td>306</td>
<td>469</td>
<td>O</td>
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<tr>
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<td>2008</td>
<td>Yuan L</td>
<td>pigs</td>
<td>Farm</td>
<td>397</td>
<td>673</td>
<td>O</td>
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<td>2011</td>
<td>Gan Y</td>
<td>pigs</td>
<td>Farm</td>
<td>2214</td>
<td>2509</td>
<td>O</td>
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<tr>
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<td>2004</td>
<td>Li M</td>
<td>pigs</td>
<td>Farm</td>
<td>952</td>
<td>1252</td>
<td>O</td>
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</tbody>
</table>
The details reported in Table 7.1 are divided into eight groups: pigs, cattle, sheep, farms, households, antibody Asia-1 and antibody type O. The recombined results are displayed in Table 7.2. The tests for heterogeneity of the eight groups all had P values less than 0.0001; consequently the random effect models were used for these eight groups. The lowest level of protective immunity was found against serotype Asia 1 (71%; 95% CI: 61–79%). However this was still slightly higher than the national standard set for China (70%) (MOA 2010b). Overall the highest level of protection was in cattle (83%; 95% CI: 77-87%), followed by sheep (80%; 95% CI: 72-86%). The proportion of protected animals was lowest in pigs (73%; 95% CI: 67-79%), but this was still higher than the national standard. The proportion of protected animals was similar in the two different breeding models, although livestock raised under the farm model had a slightly higher proportion of protected animals than in household breeding animals (78%; 95% CI: 73-83% and 76%; 95% CI: 67-82%, respectively).
Table 7.2 Recombined Results of Details of the 23 Studies

<table>
<thead>
<tr>
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<th>Livestock Type</th>
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<tbody>
<tr>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>Number of studies</td>
<td>23</td>
</tr>
<tr>
<td>Number of trials</td>
<td>60</td>
</tr>
<tr>
<td>Number of animals protected</td>
<td>20826</td>
</tr>
<tr>
<td>Total number of samples</td>
<td>31173</td>
</tr>
<tr>
<td>Test of Heterogeneity</td>
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<tr>
<td>Q Value</td>
<td>3241.24</td>
</tr>
<tr>
<td>P Value</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Percent of animals protected</td>
<td>73</td>
</tr>
<tr>
<td>95% CI (%)</td>
<td>66-79</td>
</tr>
<tr>
<td>Rank Correlation Test</td>
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</tr>
<tr>
<td>Z Value</td>
<td>-0.34</td>
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<tr>
<td>P Value</td>
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</table>

<table>
<thead>
<tr>
<th>Breeding Model</th>
<th>Antibody Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Farm</td>
</tr>
<tr>
<td>Number of studies</td>
<td>23</td>
</tr>
<tr>
<td>Number of trials</td>
<td>40</td>
</tr>
<tr>
<td>Number of animals protected</td>
<td>17062</td>
</tr>
<tr>
<td>Total number of samples</td>
<td>25849</td>
</tr>
<tr>
<td>Test of Heterogeneity</td>
<td></td>
</tr>
<tr>
<td>Q Value</td>
<td>2939.09</td>
</tr>
<tr>
<td>P Value</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Percent of animals protected</td>
<td>78</td>
</tr>
<tr>
<td>95% CI (%)</td>
<td>73-83</td>
</tr>
<tr>
<td>Rank Correlation Test</td>
<td></td>
</tr>
<tr>
<td>Z Value</td>
<td>-0.42</td>
</tr>
<tr>
<td>P Value</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Eight funnel plots were produced after data were Logit transformed to display the publication bias of the total group and the seven sub-groups (Figure 7.6). In these charts the abscissa (X) axis was the odds ratio and the ordinate (Y) axis was the standard error.
The scatter distribution displayed the bias of the trials which were analysed and reported in this chapter. The statistical results of the eight funnel plots are displayed in Table 7.2 (Rank Correlation Test). In this table all $P$ values were greater than 0.05 on the Begg’s rank correlation test, indicating that there was no evidence of publication bias in the subgroups or the total group.
Figure 7.6 Funnel Graphs of the Eight Groups
7.3.3 Results of the Opinion Survey

Of the 66 trainees asked the question “What are the most important things for the control of FMD in China?”, 53 responded (80% response rate). Of these 53 responders, 48 properly answered the question, and were considered effective responses (effective rate 91%). These 48 were used as the denominator in the calculations reported in this chapter. Within these 48 responders, 37 provided more than one response (70%).
Twenty eight responders (58%) mentioned the importance of the FMD vaccine for the control of FMD. Comments were made about the need for the vaccine used to control FMD in China to be more effective and to provide longer protection and that the compulsory and emergency vaccination procedures needed to be adjusted between different provinces.

Forty percent of responders (n=19) mentioned the importance of the surveillance system for FMD. These suggestions included that: information on FMD in different provinces needed to be collected through surveillance before any immunity/vaccination procedure was applied; data from surveillance (both routine and after an outbreak) needed to be analysed scientifically; and the strategy/program selected to control FMD should be made after evaluating the surveillance results from the different regions.

Fifteen responders (31%) mentioned the importance of funds used on FMD control. These suggestions included: that the Government should provide higher salaries and allowances and better equipment to veterinarians working at the “grassroots” level; and that the compensation mechanism after outbreaks of FMD are detected needs to be improved.

Fourteen responders (29%) mentioned the importance of the management system. These suggestions included that: the Government should apply more reasonable policies for FMD control (different strategies in different regions) and should ensure that these policies are carried out; the breeding skills on farms and ranches should be improved; and the technology and awareness of FMD control by veterinarians and animal owners.
should be improved.

Twelve responders (25%) mentioned the importance of the information system in controlling FMD. These suggestions included that: new outbreaks of FMD should be reported and published immediately; outbreaks of FMD need to be diagnosed accurately; and a database was needed to record the most recent outbreaks of FMD in both China and other countries.

Seventeen percent of responders (n=8) mentioned the importance of stamping out procedures in the control of FMD. These suggestions included: the culling procedure in China needs to be strictly enforced; and the disposal of carcasses and disinfection procedures after outbreaks also needs to be carried out correctly.

7.4 Discussion

To the best of the writer’s knowledge, this is the first study that was designed to evaluate the effectiveness of the compulsory vaccination strategy against FMD in China that used meta-analysis for single proportions. This method is used for pooling and comparing several single-arm studies (Schwarzer 2011; StatsDirectSupport 2011).

Compulsory vaccination is one of the steps adopted by the Chinese government to achieve the goal of eradication of FMD from China. This, combined with other strategies, has already reduced the number of provinces affected by outbreaks of Asia-1 from seven in 2005 to three in 2008. Similarly the number of provinces with reported outbreaks from serotype O has reduced from 10 in 2010 to four in 2011 (MOA 1999-2011). The level of protective immunity detected in the different species of
cloven-hoofed livestock, raised under different conditions and against different FMDV serotypes all reached the Chinese national standard (70%). The percentage of animals protected against FMD through vaccination in China is higher than that of other Upper Mekong Region countries. For example, in northern Laos in 2011, there were 41% NSP ELISA positive animals on the vaccination day but 0% 30 and 90 days post vaccination (Khounsy 2012). The protective immunity induced by vaccination in Vietnam ranged from 52 to 76% in 2009 but vaccination coverage was low in that country (Do 2011; Van 2010). Myanmar only applies vaccination in areas with a high prevalence and in emergency outbreaks areas, and consequently insufficient doses are available (Khin 2009; Sunn 2012). As outlined in Chapters 4, 5 and 6, control of FMD by vaccination has been recommended as an important control strategy to adopt in neighbouring Upper Mekong Region countries.

The Thai government has implemented a large routine FMD vaccination program. This is undertaken biannually and achieved approximately 80% coverage in herds. An epidemiological study indicated that in southern Thailand vaccination against FMD can reduce the annual cumulative incidence by 85% (Wacharapon 2008; Wongsathapornchai et al. 2008), however, the level of seroconversion is heavily reliant upon the efficacy of the vaccine (Wongsathapornchai et al. 2008). These observations parallel the findings described in the current study.

The ideal FMD vaccine needs to fulfil several conditions including safety, efficacy, inducing a long period of seroprotection, being easily used and stored, and allow differentiation of infected from vaccinated animals (DIVA) (Domenech et al. 2010;
Morrissy 2011). According to the Chinese veterinary workers interviewed as part of this chapter’s study the principal need in China was a vaccine that induced a longer period of seroprotectivity.

Published Chinese papers have reported that anaphylactic reactions to FMD vaccines have included raised body temperature, decreased appetite, convulsions and asphyxiation (Liu et al. 2011a; Liu and Wang 2008; Zhang 2012). Studies in other countries have also reported occasional adverse reactions to vaccination including collapse, and apnoea (Black and Francis 1988; Black et al. 1975; Black and Pay 1975; Doel 2003). However these reported complications have predominantly been in the 1970’s and since then alternative techniques have been adopted for vaccine production including the purification of antigens and inactivation of the virus with BEI (Doel 2003). As well as these measures, avoiding the vaccination of sick, weak or peri-parturient livestock, disinfecting the vaccine bottle prior to use, and using single-use disposable needles can reduce the incidence of adverse reactions (Liu 2010; Sun 2011; Zhao 2010). Observing animals for one to two hours after vaccination, testing new vaccines in small herds before applying them to larger herds and adding immunity stimulating agents to feed or water can all assist in reducing the likelihood and severity of any untoward reactions to vaccination (Che 2007; Yu and Wang 2011; Zhao 2010). However the restriction on the international trade of animals and animal products which have been vaccinated against FMD has the greatest potential impact on the use of vaccine (Scudamore 2004). Although there can be significant disadvantages to the use of vaccines against FMD, the use of modern, serotype-specific vaccines in endemic areas
is still regarded as the key to disease control (Cox et al. 2005; Hunter 1998; Kahn et al. 2002).

The targeted population involved in the opinion survey was limited to the middle-level veterinary workers in China and did not include academic experts or high-level government officers. Consequently the survey result may not necessarily reflect the demand of the Chinese veterinary service. According to the middle-level veterinary officers opinion survey, the involvement of field veterinarians is critical in a vaccination program in China and it is important that these veterinarians are aware of the importance of administering vaccine to livestock and the correct method of application (Ye 2008a; Yu and Jin 2007). A challenge with the involvement of Chinese field veterinarians is insufficient funding and insufficient training. It is likely that increased salaries would increase the enthusiasm of the village level veterinary workers for their work and improve vaccination coverage. Funding is also required to improve: the cold-chain of the FMD vaccine; the skills and knowledge of the veterinary workers; the understanding and awareness of FMD by animal workers and owners; and the reporting of disease outbreaks by farmers and livestock workers (Liang 2006; Zhang et al. 2006).

Finally adoption of regional and national FMD control strategies, effective disease surveillance programs based on scientific approaches and education of farmers and vaccinators are needed to achieve the ultimate objective of China becoming free from FMD.
Chapter 8. General Discussion
Chapter 8. General Discussion

Foot and Mouth Disease is a severe infectious disease of animals that can result in serious economic consequences for individual farmers, as well as for a country or region (Carpenter et al. 2011; Garner et al. 2002). Although the People’s Republic of China was officially founded in 1949, China has one of the oldest cultures in the world. It has been adopting methods and strategies to control animal diseases for thousands of years, although a large amount of the literature has been difficult to access by researchers outside of the country (Wei 1992; Yu and Zhang 1995). China has, however, been officially reporting outbreaks of FMD to the OIE since 2007 and since then a series of strategies have been undertaken by the Chinese Government to cooperate with other countries and international organisations to control the disease within the region (Jia 2005; OIE 2008).

The study reported in this thesis systematically reviewed the historical records of outbreaks of FMD and hypothesised and evaluated the potential source of FMD for China. After analysing the situation of FMD in the Upper Mekong Region countries, data on the informal cross boundary livestock movements from these countries to China was collected and the risk of disease introduction to China analysed. The current control program against FMD in China was also evaluated and a meta-analysis conducted to appraise the effectiveness of the vaccination campaign adopted in China.

The source of foot and mouth disease in China

The ancient Chinese words Kouchuang (canker) and Tihuang (hoof jaundice) were
widely believed to be alternative names for FMD (Koutiyi in Chinese) (Anonymous 2012; Chen and Chen 2006; Li 2010b; Wikipedia 2012) and in this study these terms were used when searching databases in China for information on the disease. However, in Chinese traditional medicine, Kouchuang was also the collective name for oral mucosal diseases in humans and animals with symptoms/signs of aphthous stomatitis, ulcers and pain (Ma 2011; Zhao et al. 2007; Zhou 2003). Tihuang was also the collective name for hoof diseases with signs of swelling, suppurative, inflammation and fluid effusion (Bao 2008; Chen 2000; He 2001; Yang 1986). These descriptions mean that references reported in Chinese studies or documents to Kouchuang and Tihuang may not necessarily be referring to FMD. The results of this thesis indicate that FMD was most likely introduced into China from Europe in the Late Qing Dynasty (1840-1912). Subsequent to this initial report FMD was reported in different provinces of China. The chronological order and distribution of these outbreaks indicates disease spread occurred most likely through livestock movement. Restricting or prohibiting the movement of animals is now widely used throughout the world to minimise the spread of FMD (Hayama et al. 2012; Leforban 1999; MOA 2008b; OIE 2012; Velthuis and Mourits 2007).

**Upper Mekong Region countries**

In addition to the historical risk of FMD from South East Asian countries, China still faces the risk of new strains of FMDV entering from neighbouring SEA countries (Luo and Wei 2002; Wei 2005; Xiong et al. 2008). The disease is endemic with periodic epidemics occurring in the Upper Mekong Region countries (Cocks et al. 2009;
Morrissy and Hammond 2011; OIE 2000-2010). The risk of disease entry through the movement of animals, which are usually not inspected or quarantined, in the region has been reported previously (Ozawa 1993; Sasaki 1993). In undeveloped countries, such as Myanmar and Laos, the control of animal movements has previously not received sufficient attention from livestock traders and official departments (Sasaki 1993). In contrast, Thailand, as a more developed nation, has a better reporting system and control program for FMD (Chaisrisongkram 1993; Meephuch 1993). However unapproved animal movements can still occur leading to outbreaks of FMD (Ballock et al. 1993).

The Progressive Control Pathway for Foot and Mouth Disease (PCP-FMD) was developed in 2008 by the FAO and jointly adopted by the FAO, OIE and the European Commission for the control of Foot and Mouth Disease (EuFMD). It can be used as a country’s self-assessment tool, as well as an approach to achieve the OIE recognised FMD free status (with/without vaccination) (FAO 2009; 2011; Leeuw 2012). It is recommended that South East Asia countries and China should actively use the PCP-FMD as their FMD control tool and follow the stages described in the PCP-FMD to achieve the goal of FMD freedom.

The risk of FMD to China and the control strategies adopted for this disease in China

This study was initially designed to locate and analyse the risk of FMD entering China from neighbouring Upper Mekong Region countries. Although FMD is already present in China, there remains a risk of introducing new strains/serotypes of FMDV or the
reintroduction of disease if China is successful in eradicating the disease from specific regions. Five cross-boundary routes (three for cattle and two for pigs) were discovered and the risks of FMD entering via these routes assessed. According to the models developed in Chapters 4, 5 and 6, nearly 16,000 pigs were exported unofficially (informally) from Myanmar to China and around 1,500 pigs from Vietnam to China each year. In addition, over 1,000 cattle were exported unofficially from Myanmar to China, along with nearly 50,000 from Thailand, over 25,000 from Laos and 3,400 from Vietnam each year. These imported livestock were not inspected or quarantined, and thus could potentially pose a risk of introducing FMDV, as well as other infectious agents, to livestock in China (Wang 2000).

To improve the health and well-being of both livestock and the human population, China has adopted strategies to control and eradicate several severe animal diseases including cooperating with international agencies in these endeavours (OIE 2008). From 2004 to 2008, the Chinese government invested 18.4 billion Yuan (approximately 3.1 billion USD) to control animal disease in the country. Until 2010, there were a total of 304 national animal disease detection stations, 146 national border area animal disease detection stations, and 37,446 village level veterinary stations (Figure 8.1). There were also 645,000 veterinary workers in villages who were responsible for undertaking vaccination and disease detection (MOA 2010a).
Although over the past decade the animal disease control system in China has developed rapidly, there are still many challenges if eradication of FMD from China is to be achieved. To achieve the long-term goal of eradicating FMD from China and to reduce the economic impact of the disease, China has recently applied a regionalisation approach (Liu et al. 2011b; Zhang et al. 2009). This is designed to establish five zones that are free from FMD through vaccination (Pu and Wang 2007; Zheng 2010) (Figure 8.2). At present, Hainan Province has been certified by the Chinese Government to be the first “disease-free zone” in China, and this certification has enhanced business opportunities to the province (Luo et al. 2012; Zheng and Wang 2010). In the future it is planned to expand these five FMD free zones so that eventually FMD will be eradicated from China (Liu et al. 2011b).
Apart from the zoning approach, China is also adopting a compulsory vaccination program and post immunity surveillance system to control FMD and to reduce the spread of the disease. In 2010 2.81 billion doses of vaccine against FMD were used in China through the compulsory vaccination strategy and 2.99 million samples were collected and tested for the disease (MOA 2008a) at a cost of 1.5 billion Yuan (approximately USD 238 million). However, even with these significant expenditures, outbreaks of FMD have still occurred frequently in China (MOA 2005-2012). Based on the results of the meta-analysis in the current study (Chapter 7), the compulsory vaccination program in China has been successful in attaining the desired level of at least 70% seroprotective immunity in at-risk livestock. However as vaccines are serotype specific (Rodriguez and Grubman 2009), adoption of an integrated control...
strategy that also considers risk from animal movements is essential if the disease and the risk of new strains entering are to be controlled.

In spite of the millions of dollars spent on establishing the control and eradication program for FMD, the long-term benefit of this is considerable. From 2004 to 2008, the cost-benefit ratio (CBR) of the construction of the disease free zones was 1:8.54 – 1:14.78 annually (Pu 2009). From 2002 to 2011, it has been estimated that the control strategy adopted in China had a accumulative net present value of 1,680 million Yuan (approximately 280 million USD) (Pu 2009).

**Constraints and limitations of this study**

The historical literature review was mainly based on the available and accessible journal papers/reports/books. Unfortunately many old books have been lost or destroyed. The difficulty in accessing material from the 19th century and earlier is a constraint of this study when determining the potential source and time of introduction of FMD to China. Furthermore the use of official government reports introduces another potential bias. Reporting bias can be present due to missing or overlapping data or incomplete reporting (Pham 2011b). Although from 1999, a standardised FMD outbreak reporting system has been adopted in South East Asia, there is still room for improvement in disease reporting and collation of the results (OIE 2010b).

The field work conducted in Yunnan Province involved the informal interview of people working in the field of animal disease control or management and the risk modelling used data collected from the opinions of the respondents. Bias potentially
was introduced through the interviewed people being reluctant to provide correct information. For example, the FMD risk from livestock carcasses to China was as high as 60% in the model of Route C, and also was estimated to be very high in other models. According to the respondents’ opinion, this was because FMDV could survive for months in animal carcasses, and furthermore most carcasses were collected by local Chinese farmers soon after the animals died. These carcasses were then either sold to Chinese markets or were consumed by the collectors. The high level of risk reported by the respondents may be an overestimate. However the data used in the models generated as part of this thesis was that provided by the respondents. Therefore it is recommended that further research is required on the routes and the estimates of risk used in these models.

In the risk models the prevalence of FMD in the exporting countries was generally the most important factor influencing the likelihood of disease entering China. However the prevalence used in the models was either the test prevalence from previous studies or an estimated value from outbreak data sourced from official reports. This may have introduced a bias in the model generation and information on the real prevalence of disease in the exporting regions would enhance the validity of the risk models generated.

**Suggestions for further research**

The risk analysis conducted in this thesis should be extended to other neighbouring countries of China to determine if livestock movements from northern and western neighbours also pose a risk to the Chinese herd. Data used in the model, such as
survival in animal carcasses, confiscated animals and slaughter houses, should also be validated through the use of suitable diagnostic tests.

This study concentrated on livestock entering China from neighbouring countries; however internal movement of infected livestock may be playing as important or even a more important role in the spread of FMD within China. Data are required on internal movement of livestock and the risk of these movements also should be assessed.

The methods/models used in this study could also be applied to other diseases which pose a risk to China including HPAI as well as diseases of humans and wildlife.

The risk from formally imported frozen meat/animal products is likely to be less than the risk from the importation of live animals, particularly those entering informally. However there is the need for the development of practical measures, which are acceptable to the importers, to reduce the risk of disease entry from the importation of live animals. These might include suitable periods of quarantine, vaccination protocols, movement control measures and permanent animal identification. Such measures should reduce the risk of introducing FMD to China and could also be evaluated through a quantitative risk assessment similar to that used in this study. Studies are also needed to determine the economic and social benefits of disease control to the nation.

**Conclusions**

As the first quantitative assessment of the cross-boundary risk of FMD to China from SEA countries, this study has identified the routes by which cattle and pigs enter China informally. The impact of different factors on the risk of FMD entering China was
evaluated and the number of potentially infected cattle/pigs that enter China informally each year was determined. The results of the study indicated that FMD probably entered China late in the 19th Century through livestock movements/transport. The vaccination strategy adopted in China was found to be relatively effective; however it was concluded that the control and eradication of FMD from China and SEA required focusing on several approaches and required cooperation between the countries located in the region. Alternative methods to the importation of live animals to meet the high demand for animal protein by Chinese residents need to be considered. It is suggested that the importation of meat, which has been processed in licensed meat works located in neighbouring countries, would reduce the risk of FMD entering China.
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