An outbreak of a serious animal disease, such as classical swine fever (CSF), classified as a List A disease by the Office International des Epizooties (OIE) can have severe consequences for animal welfare, livestock production, exports of animals and animal products and the environment. Furthermore, the costs of control and eradication of the disease and loss of export value may have a significant impact on the national economy of a country. In the case of the 1997-1998 epidemic of CSF in the Netherlands, the total financial consequences were estimated at US$2.3 billion (18), with an estimated negative effect of 0.75% on the total annual national economic productivity. Rapid identification and response mechanisms are therefore of paramount importance when such an outbreak occurs.
Experience shows that early detection and response to a suspected disease outbreak will maximise the effectiveness of the emergency response actions and minimise the social, economic and environmental costs associated with the repercussions of the outbreak (22). A classic documented example of an early outbreak investigation was the work by John Snow during a cholera outbreak in London in 1860, in which Snow traced the source of the outbreak to a water pump in Broad Street (35). This was achieved long before bacteria were recognised as pathogens.

The development and implementation of measures designed to minimise the risk of diseases entering a country or region has been the predominant animal health management strategy in most countries. However, even the strongest preventive management systems do not guarantee that outbreaks of animal diseases will not occur (22). After five years of absence of CSF from the country and ten years of absence from the region concerned, a pig farm in the municipality of Venhorst in the southern part of the Netherlands was diagnosed as infected on 4 February 1997 (5). This herd was located in an area which has one of the highest pig and herd densities in Europe (26). A total of 429 outbreaks were observed in the Netherlands and approximately 625,000 pigs from these herds were slaughtered. A pandemic followed this introduction into the Netherlands from Germany, and the subsequent spread from the Netherlands to Italy, Spain and Belgium (5).

The emergency management of the 1997-1998 epidemic of CSF in the Netherlands will be described as a case study to identify the tracing systems applied during the eradication campaign.

Tracing

Tracing, a procedure that begins with a known infected individual, herd or flock and which traces all possible locational and interactive exposures in both directions, back towards the source and forward to contacts, is the fundamental basis of emergency disease management. From the standpoint of disease control and eradication, rapid tracing will clearly produce greater benefit, due to rapid identification of sources and contacts, compared to a leisurely approach that permits a longer period of spread whilst such sources are being located. Success in such situations requires the mobilisation of a sufficient number of qualified personnel to follow each lead without delay. This requires multiple teams of people in the field simultaneously, and also requires a well organised tracing unit within the field organisation to assemble and analyse data and to direct investigators (32).

Backward tracing

Backward tracing, towards the source of infection, commences with an estimation of the date of introduction of the disease agent into the holding. The starting point in this investigation can be the date of onset of clinical disease in animals or the date of onset of elevated mortality rates within the herd. When the date of onset and incubation period of a disease are relatively easy to determine, as is the case for foot and mouth disease or acute CSF; a rough estimate of the date of introduction of the pathogen into the herd is relatively easy to obtain (32). However, in the case of less clinically evident diseases such as brucellosis, tuberculosis or infection by moderate or mildly virulent strains of CSF virus (CSFV), sub-clinical infections are more common and estimation of the date of introduction is often very difficult. In such cases, careful interview of the owner and/or the person who takes care of the animals on a daily basis – with attention to such factors as possible modes of transmission, an estimate of affected animals within the herd, location of the affected animals within the herd and intra-herd movements of animals – will provide rough clues as to the length of time the agent has been present.

According to the European Union (EU) Directive 80/217/CEE, which details the procedures to be taken during an outbreak of CSF; a selection of animals is sampled serologically and virologically for epidemiological evaluation according to a standard protocol shortly before depopulation of the infected herd (26). During this operation, the location of animals sampled within the infected herd in different compartments, pig-units and barns is drawn on a schematic map. Upon return of the results from the laboratory testing of the samples, the location of infected animals within the herd can be determined. When no pigs with antibodies to CSFV are detected in the samples, this is an indication that CSFV was introduced into the herd less than eighteen to twenty-one days before sampling (+3). When one or more pigs with antibodies to CSFV are detected in the samples, one can deduce that introduction of CSFV into the herd occurred more than eighteen to twenty-one days before sampling. Furthermore, the higher the number of pigs with antibodies to CSFV in the sample, the longer the period between introduction of CSFV into the herd and detection of the outbreak. Using the results of the laboratory testing of the samples and mathematical models that simulate the dynamics of CSFV infection within pig herds, has allowed quantitative estimates – with an accessory confidence interval – of the date of introduction of CSFV into herds (16, 39). This is an important step forward for tracing activities, because the tracing unit is provided with a much more precise and focused list of:

- contacts that could have introduced CSFV into the herd
- contacts of the infected herd during the infectious period, which must be followed up.

However, before the estimate of the date of introduction of CSFV into the herd is available to the outbreak investigators, sometimes several weeks after the detection of the outbreak, an outbreak investigation begins with a careful interview of the owner and/or the person who takes care of the affected animals on a daily basis.
Forward tracing

Forward tracing, from the infected herd to all contacts during the infectious period, commences with a personal interview of the farmer of the infected herd. Potential contacts that must be checked in forward tracing are as follows:

- sale of pigs to other herds
- routing of transport lorries that were used to transport pigs from the infected herd
- tracing of meat from slaughter pigs of the infected herd, including that exported to other countries
- professional and non-professional visitors in contact with the pigs
- route taken by the carcass collection service of the rendering plant
- transport of pig slurry from the farm
- sharing of farm equipment with other pig farmers
- pig farms in the vicinity of the infected herd (possibility of neighbourhood infections: secondary outbreaks, without a clear origin of infection, concentrated in the close vicinity [<1,000 m] of a primary outbreak).

A precise estimate of the infectious period of the infected herd is extremely important for backward tracing to the source of infection. This estimate is equally as important for forward tracing, as this enables the tracing unit to focus on the relevant contacts of an infected herd. Among others, a crucial requirement for obtaining a precise estimate is the sampling of a sufficient number of pigs at the farm (serologically and virologically) before depopulation of the infected herd (36).

Organisational structure and responsibility for tracing within the disease emergency organisation

A separate unit within the field organisation of a disease emergency investigation is responsible for tracing (1). In Figure 1, an organisational chart illustrates the location of the tracing unit within the disease emergency organisation implemented to deal with the CSF epidemic in the Netherlands in 1997-1998. The tracing unit is responsible for inspection of suspect farms, sampling of pigs on farms for epidemiological evaluation before depopulation, backward tracing of the source of infection, nomination of farms that have had contact with an infected herd and are eligible for pre-emptive slaughter, forward tracing of contacts, identification of herds within a 1-km radius of an infected herd for pre-emptive slaughter, and epidemiological evaluation. This unit was headed by a director and a deputy director, and consisted of several sections (Fig. 2) with specific responsibilities (Table I).

The positions of director and deputy director of the tracing unit were filled by veterinary staff of the National Inspection Service for Livestock and Meat (RVV). The ‘infected herds’ section was staffed by veterinarians from RVV and the National Animal Health Service (NAHS). The ‘pre-emptive slaughter’ section was staffed by veterinarians from RVV, NAHS, part-time local practitioners, and in the early stages of the epidemic by veterinarians from the Governmental Veterinary Service of Belgium. The ‘epidemiology’ section was staffed by two

---

AID: General Inspection Service of the Ministry of Agriculture of the Netherlands
LASER: Implementation Service for Agricultural Regulations
RVV: National Inspection Service for Livestock and Meat

Fig. 1
Source: after Pluimers et al. [26]
veterinary epidemiologists (Institute for Animal Science and Health [ID-Lelystad] and the NAHS). The other sections were staffed by veterinarians (RVV, part-time local practitioners), veterinary students and non-veterinarians (hired on a contract basis).

Tracing methods and tools

Herd registration

A basic requirement for tracing is the registration of all pig herds in the country. In the Netherlands, the Agricultural Board Regulation ‘registration of pig farms’ came into force on 1 April 1990. This regulation stipulates that an owner of one or more pigs has the obligation to register the pig herd with the NAHS. The NAHS maintains and updates the pig herd registration database. Each pig herd has a unique herd registration number. Herd data, such as ownership, farm address, herd type (multiplier, finishing or mixed herd, artificial insemination centre, hobby farm or children’s zoo), number of pigs that can be accommodated on a given farm, and information on several key associations such as the veterinarian and breeding organisation, are available in the national herd registration database.

Table I
Responsibilities of different sections within the tracing unit during the epidemic of classical swine fever in the Netherlands, 1997-1998

<table>
<thead>
<tr>
<th>Section</th>
<th>Responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Director and deputy-director</td>
<td>General management, reporting, communication with infected herds, contact with management of LCO</td>
</tr>
<tr>
<td>Co-ordination</td>
<td>General co-ordination, quality assurance, personnel, efficiency control</td>
</tr>
<tr>
<td>Infected farms</td>
<td>Visiting infected farms, personal interview with pig farmer of infected farm, forward and backward tracing of contacts, keeping records of suspect farms, collecting data and information for epidemiologic investigations, maintaining up-to-date dossiers on infected farms, preparation of reports for LCO and standing veterinary committee of the EU, processing of laboratory diagnostic results, analysis of farms eligible for pre-emptive slaughter, communication with General Inspection Service of the Ministry of Agriculture</td>
</tr>
<tr>
<td>Infected farms – subsection infection routes</td>
<td>Requesting daily routes of specific contacts such as veterinary practitioner, collection service of the rendering plant, vermin control consultant, etc.</td>
</tr>
<tr>
<td>Pre-emptive slaughter</td>
<td>Selection and proposal of farms eligible for pre-emptive slaughter</td>
</tr>
<tr>
<td>Epidemiology</td>
<td>Support of tracing activities, evaluation of the efficacy of eradication measures taken by the disease emergency organisation and advising on additional measures to be taken in order to halt the epidemic</td>
</tr>
<tr>
<td>Farm visits</td>
<td>Declaration/lifting of the suspect status of pig farms, planning of farm visits, processing of routes of contacts, processing of reports of suspect situation by veterinary practitioners, planning of weekend service</td>
</tr>
<tr>
<td>Farm visits – subsection administration</td>
<td>Printing inspection reports, importation of data in computer, management of database, management of archives</td>
</tr>
<tr>
<td>Farm visits – subsection briefing</td>
<td>Briefing/debriefing of tracing and blood sampling teams, planning of personnel for tracing teams, execution of tracing visits, execution of blood sampling on infected farms, farms to be slaughtered pre-emptively and other tracing farms</td>
</tr>
<tr>
<td>Farm visits – subsection blood sampling</td>
<td>Planning of blood sampling on infected farms, farms to be slaughtered pre-emptively and other tracing farms, contacts with dispatch-unit of Reference Laboratory, contacts with depopulation teams</td>
</tr>
</tbody>
</table>

Fig. 2
An organisational chart of the tracing unit within the field organisation of the disease emergency investigation during the classical swine fever epidemic in the Netherlands, 1997-1998
Identification and registration system

The purpose of an identification and registration system (IRS) is to rapidly and efficiently trace the origin and movement of animals. In most countries, tracing of CSF is hampered because pigs are not identified and registration of movements does not occur (44). The identification and registration of movements of pigs is of utmost importance because in the case of notifiable diseases, Member States of the EU and third countries outside the EU will demand transparency with respect to the origin of the animals. The costs of tracing when animal identification is absent are very high, thus an obvious efficiency would result if marketed animals were routinely identified for future tracing. Permanent identification of domestic animals has been a goal for several thousands of years, in ancient times, Egyptians, Romans, Greeks and Chinese practised branding of livestock, used coded patterns of notches cut in ears, horns and wattles and paint marks for identification purposes (33). In the current context of rapid and long distance movement of animals, increased attention to animal disease prevention and compulsory documentation of genetic lines, animal identification is of importance to livestock culture world-wide (32). However, mandatory identification has met opposition in several countries, including the United States of America (USA). One indication of the importance and difficulties of comprehensive animal identification is that the United States Animal Health Association (USAHA) has maintained a special committee on livestock identification, which reports on the various technical methods and implementation systems studied (45). Some obstacles to national identification systems described by this committee include: apprehension over government interference and penalties, and negative connotations of the term ‘mandatory’. Although many livestock owners are resistant to mass identification, the fact remains that increased and improved identification is a prerequisite for future progress in animal disease control.

In 1988, initiatives were taken to develop a comprehensive IRS for cattle and pigs in the Netherlands (49). This programme took a full eight years to complete. The same resistance by pig farmers was met when the fully computerised IRS was introduced in the Netherlands in 1996. Registration of transactions became obligatory from January 1997 (12). The IRS database is maintained and updated by the NAHS. In this mandatory system, pig farmers must inform a computerised database when live animals are purchased. The registration of the removal of pigs from the farm is voluntary. In the case of occurrence of outbreaks of a notifiable disease within the country, the sale of pigs to other pig farmers, and the transport of pigs to a slaughterhouse, export-collection centre or livestock market, must be registered with the IRS within two days of the transaction. Furthermore, carcasses that are collected by the rendering service must also be registered with the central IRS database, either by the farmer or by the rendering plant if the farmer has authorised the rendering service to do so. Pigs are labelled with an individual animal identification device upon leaving the farm or at a maximum age of six months. For slaughter pigs, two possibilities existed until 1 July 2000: a metal ear tag or a slap-tattoo on the shoulders. Since 1 July 2000, the use of a slap-tattoo on the shoulder has been prohibited and only metal ear tags can be used. The metal ear tag carries the unique herd number (seven digits) on one side, and a serial number and an IRS logo on the other side. The serial number consists of six digits: three digits are the last three numbers of the unique herd number, and the three other digits are true serial numbers. In order to prevent loss, the ear tag has to be placed as follows:

- in the thicker parts of the right ear
- in the upper part of the ear
- as close as possible to the head
- attached to the ear with a pair of tongs that fits the ear tag.

A slap-tattoo can only be used after exemption by the product boards of livestock and meat, and only for delivery of pigs to slaughterhouses within the country. For utility pigs (sows etc.) a utility ear tag is used. This has a standardised yellow colour, and holds the unique herd number, a serial number (maximum five positions), the IRS logo and the letters NL. A tattoo is permitted only for breeding pigs, and can only be used in consultation with the breeding company, after exemption by the product boards of livestock and meat.

Each movement of pigs (to and from the farm) must be registered within two days with the central IRS database. Registration can be by telephone using a pin-code (computerised voice-response system – available 24 h a day and seven days a week), electronic mail or by ordinary mail with prescribed IRS forms. In addition, every movement must be accompanied by a specified transport document. The following information is registered for each movement of pigs:

- unique herd number of the farmer
- type of pig movement (within the country, import or export)
- unique herd number of destination of the pigs
- number and type of pigs (breeding pig, finishing piglet or fattener)
- date of movement
- identification number of transport document or import/export certificate number.

The European Union animal movement system (ANIMO)

The creation of the Single Market of the EU required the dismantling of veterinary and zoo-technical barriers to intra-Community trade in animals and animal products. Free movement of animals was a fundamental aim for the common organisation of a Single Market within the EU. However, the movement of live animals and germplasm (i.e. embryos and
organisation. Special attention was paid to importation contacts. The Veterinary Checks Directive 90/425/EEC, which prescribes regulations to control the movement of animals and germplasm, aims to ensure that checks are conducted only at the place of dispatch of a consignment of animals (3). The Directive stipulates that the consignment of animals must be accompanied by a standard health certificate or an identification document stating the conformity of the consignment with EU regulations. Removal of internal border controls deprived Member States of information on the consignments of animals and germplasm entering the territory. The animal movement (ANIMO) computerised system was developed to provide Member States with this information (42). Directive 90/425/EEC specifically requires the Member State of origin to send, on the day of issue of the certificate or document which accompanies the animals or animal products, an electronic message via the ANIMO system to the competent authority of the destination country and to the central competent authority. The message consists of the following information (using specific codes as prescribed in Directive 91/637/EEC) (2):

- date of transmission
- origin (country and unit code, health certificate number and date, and the name of the veterinarian who signed the certificate)
- destination (country and unit code, name of the person to receive the animals and address of place of destination, postal address [town] and post code)
- merchandise (type and code, and number/quantity of animals or animal products)
- means of transport (type of transport [lorry, train, plane, ship, etc.], identification of means of transport [registration of lorry, wagon number, flight number, name of vessel, container number, etc.])
- observations (origin of animals and products).

In addition, importers may be required to notify the competent authority in advance of the proposed import of live animals.

The Netherlands had been officially free of CSF since the outbreaks in 1992. Therefore, the source of CSFV was probably outside the country. The Netherlands exported 499,921 live piglets and 2.7 million live slaughter pigs, and imported 33,548 piglets, 205,031 slaughter pigs and 5,032 breeding pigs in 1997 (28). Since importation of infected pigs carries a high probability of transmission, screening of the ANIMO system for importation of pigs from countries with a history of CSF outbreaks was the first step for the disease emergency organisation. Special attention was paid to importation contacts with Germany, because a pig-fattening herd in the municipality of Delbrück (Paderborn-county) in the Federal State of Nordrhein-Westfalen, was confirmed to be infected with CSFV on 6 January 1997 (37). However, import of CSFV-infected pigs from Germany was excluded on the basis of screening of the ANIMO system.

On 6 February 1997, 240 piglets were shipped illegally from the outbreak-herd NL 97/43 (diagnosed with CSF on 15 March 1997), which was outside the protection and surveillance zones of the first outbreaks in the central area of the epidemic (Fig. 3), to the export collection centre in the city of Den Bosch (5). The piglets had moved to this herd on 4 February 1997 from outbreak-herd NL 97/07 (diagnosed with CSF on 9 February 1997) and from outbreak-herd NL 97/31 (diagnosed on 2 March 1997), when the total movement restriction for the primary outbreak area had not yet been established. The transport on 6 February was illegal because regulations stipulate that pigs must remain at a new location for at least thirty days after movement. These piglets were mixed with piglets from other sources at the export collection centre and exported to a herd in Magione (province of Perugia) and to a herd in Teggiano (province of Salerno) in Italy on 6 February 1997. Furthermore, from this group of mixed piglets at the collection centre in Den Bosch, piglets were transported to a herd in Valle del Tabladillo (province of Segovia) and to a herd in Montgay (province of Lérida) in Spain on 6 February 1997. Outbreak-herd NL 97/43 in the Netherlands was declared officially suspect on 8 February. The central veterinary authorities in Italy and Spain were contacted on 9 and 10 February by the Chief Veterinary Officer (CVO) of the Netherlands with information regarding the shipment of CSF-suspect piglets to Italy and Spain. The content of the information included the following:

- copies of the ANIMO messages detailing consignments of pigs for breeding and production purposes sent to Spain or Italy from the Netherlands in the period from 1 January 1997 to 9 February 1997
- a list of identification and registration numbers of farms of origin that were located in the protection/surveillance zones at that time.

This information, in conjunction with received animal health certificates, offered the possibility to determine for each destination herd whether or not the consignment included pigs originating from farms located in protection/surveillance zones.

In Italy, the herds of destination were quickly identified and were clinically monitored for approximately ten days. These herds were depopulated on 21 and 24 February, after clinical symptoms appeared. Protection and surveillance zones were created in the surrounding areas. Herds in these zones were checked according to EU regulations, no further outbreaks were detected and the protection zones in Teggiano and Magione were lifted on 24 and 25 March 1997 respectively.
The shipments of piglets to Spain arrived on 7 and 9 February 1997. However, the identification of the herds of destination was a lengthy process. The authorities in Spain complained about the fact that the shipments could not be traced through ANIMO, although precise and detailed information on the shipments was received from the CVO of the Netherlands. The herd in Valle del Tabladillo was pre-emptively slaughtered on 25 February, and the herd in Montgay was pre-emptively slaughtered on 24 February. However, before pre-emptive slaughter of the herd in Montgay, 150 piglets were illegally transported to a herd in the municipality of Bell-lloc (in the province of Lerida), which led to an extensive epidemic of CSF in Spain (38).

**Personal interview of the farmer**

Animal identification procedures, the detail and extent of the records and memory of the farmer, co-operation by the farmer, and the investigative skills of the people performing the tracing, all contribute to the success or failure of the tracing operation. Questionnaire investigations and other epidemiological enquiries should be performed on the affected farm as soon as possible after the herd is designated as suspect. Enquiries run more smoothly and farmers are more willing to co-operate in the early stages of the disease control procedure (15).

Farmers sometimes hesitate to provide information, are reluctant to inform on neighbours, fear law suits from persons who may have purchased infected livestock from them, or merely mistrust government agencies (15, 32). Therefore, securing the trust and co-operation of the pig farmer is vital. Questionnaire investigations and other epidemiological inquiries should preferably be performed by a team of at least two experienced and trained investigators, with good social skills and highly trained in counselling skills (8, 47). Specially-designed questionnaires have been developed to ensure the appropriate collection of all relevant data and to standardise the procedure of questioning. In the interview, attention is focused on possible modes of transmission, as categorised according to the Animal Disease Notification System (ADNS) of the EU (52), as follows:

- purchase of infected animals
- transport vehicles
- professional and non-professional visitors
- feeding swill
- carcass collection service of the rendering plant
- use of artificial insemination
- pig slurry
- infected farms in the close vicinity (neighbourhood infection).

**Logbook**

During the 1997-1998 epidemic of CSF in the Netherlands, farmers were required to maintain a logbook. The Animal Health and Welfare Act of the Netherlands (19) stipulates that a logbook must be kept at a pig farm, with two separate registries, as follows:

- a registry of all visitors who have contact with the premises and pig units
– a registry of the vehicles that transport pigs to and from the farm (20).

In Chapter 3 of the Animal Health and Welfare Act concerning the regulation on hygiene with respect to contagious diseases, Article 24 (subsection c) requires the registration of the name and address of visitors to the premises and pig units, the date of the visit, the reason of the visit, the presence of transport vehicles and the identification plates of the transport vehicles on a daily basis, to be undertaken by or in the name of the owner of the animals. In Chapter 2 of the Animal Health and Welfare Act (regulation on hygiene with respect to the transport of animals), Article 20 requires the registration of the following:

– the identification plate and the licence number of every transport vehicle entering the premises
– the date and the time of every visit of transport vehicles
– the date and location of the last cleaning and disinfection of the transport vehicle.

Both Articles came into force on 1 July 1998.

**Abattoir traceback system**

The costs of traceback without a system of animal identification are such that an obvious efficiency would result if all marketed animals were routinely identified for potential future traceback (32). To be efficient, traceback markers for use in abattoirs should be inexpensive, easy to apply, easily located and interpreted at the abattoir, and should not invoke buyer resistance, or interfere with the slaughter process (51). The ability to trace slaughter animals to the herd of origin varies in different countries. In several countries of Europe, where most animals are consigned directly to slaughter, the owner marks each animal so that traceback is simple and rapid. In the Netherlands, two possibilities existed for slaughter pigs until 1 July 2000, namely: a metal ear tag or a slap-tattoo on the shoulders. Since 1 July 2000, only metal ear tags can be used.

At the abattoir, pathological lesions indicative for CSF can be detected during the slaughter process and the subsequent examination by meat inspectors. The protocol ‘recognition of animal diseases at the slaughterhouse’ of the National Inspection Service for Livestock and Meat states that the following symptoms are suspect for CSF:

– splenic infarction
– swelling, haemorrhage or oedema of lymph nodes
– petechiae in the kidneys, larynx or bladder
– atrophy of the thymus
– button ulcers in the ileum and colon.

However, several other syndromes and diseases (e.g. porcine dermatitis and nephropathy syndrome (PDNS) and post-weaning multisystemic wasting syndrome (PMWS) cause pathological lesions that resemble those of CSF (10). At least nine (56%) out of a total of sixteen CSF-infected herds during the recent epidemic of CSF in the United Kingdom (UK) are known to have had a previous history of PDNS, PMWS or both (34). Gresham et al. recently reported an increase in the occurrence of PDNS and PMWS in Great Britain, particularly in the east of England (10). As both syndromes can cause clinical signs similar to CSF, a large number of premises (269) were placed under movement restrictions because of suspected clinical disease during the recent CSF epidemic in the UK. In the majority of these herds, the clinical signs were not subsequently confirmed as CSF.

During the 1997-1998 epidemic of CSF in the Netherlands, no infected herds were detected during the slaughter process or the subsequent examination by meat inspectors. An exponential increase has occurred in the proportion of PDNS-diagnoses of pigs submitted to the necropsy laboratory between 1997 and 2000 (6). In addition, at slaughterhouses in the Netherlands, signs of PDNS were noted in slaughter pigs rather frequently in 1999 and 2000. Traceback of these pigs to the herd of origin involved extensive investigations and as a result of the possible risk of CSF, some slaughterhouses were closed for a day on several occasions.

**Transport records**

The first significant evidence as to the means of introduction of CSFV into the Netherlands was gained from investigation of the transport records of the shippers that transported sows, fatteners and piglets from, and transported replacement stock to, the primary outbreak (5). The General Inspection Service (AID) of the Ministry of Agriculture of the Netherlands, an agency that monitors and enforces transport bans and other legal regulations and which co-operates with the police and the Public Prosecutor, confiscated the transport records of the shippers. The records revealed that both shippers visited the Paderborn area of Germany (shipping pigs to Germany and returning empty to the Netherlands) once a week during the months of December 1996 and January 1997. A primary CSF outbreak was confirmed in this area on 6 January 1997. The CSFV is presumed to have been present in this area from mid- November 1996, before being detected (5). One shipper collected sows from the primary outbreak herd and the other shipper transported piglets from the primary outbreak herd to other fattening herds. Some of the sows collected at the primary outbreak herd by the first shipper were transported to a collection centre of the other shipper. However, an unambiguous connection could not be established. The lorries of the shippers that transported pigs to Germany were not used for transport of pigs from the primary outbreak (as determined using the identification plates of the lorries recorded on the export certificates). However, occasionally a trailer is used in combination with a head truck that has a different identification plate, and only the identification plate of the head truck is registered on the transport record or export certificate.
Therefore, a trailer used in connection with transport to the Paderborn area in Germany could also have been used for transport in connection with the primary outbreak herd. A second possibility is transfer of infectious material (secreta and excreta) from the lorries driving to Germany to other lorries of the same shippers used for transportation of pigs to and from the primary outbreak herd. Cross-contamination could have occurred through physical transportation of secreta and excreta (adhesion to boots) by the lorry drivers if the lorries were not adequately cleaned and disinfected.

As further circumstantial evidence, the viruses isolated in the Paderborn area and in the Netherlands were identical in comparative deoxyribonucleic acid (DNA) sequence analysis (53). The use of molecular epidemiology as a tool for tracing is discussed later in this paper.

Therefore, although an unambiguous connection could not be demonstrated, CSFV was presumed to have been introduced into the Netherlands by a transport lorry that had been in contact with infected pigs or infectious material in the Paderborn area of Germany. During this period, temperatures were extremely low in north-western Europe, especially in Germany and the Netherlands (−10°C to −20°C), conditions which favour the preservation of CSFV and may have hampered proper cleaning and disinfection of the lorries.

Investigation of transport records played a major role in uncovering the most likely routes of transmission among herds infected in the early stages of the epidemic. During the epidemic, an estimated thirty-nine herds in the Netherlands were already infected before the primary outbreak was detected and full movement restrictions and sanitary measures were implemented (40). The day before full movement restrictions were enforced, massive transportation of pigs was observed, probably because rumours of a possible CSF outbreak were circulating. Retrospective analysis has indicated that transportation lorries accounted for 52% of the most likely transmission routes associated with infection of the earlier mentioned group of thirty-nine pig herds (5).

**Pre-emptive slaughter**

When no other leads can be identified as to the origin of infection, two categories remain, namely: neighbourhood infections and unknown reason (43). The phenomenon of neighbourhood infections was noted during outbreaks of CSF in the Netherlands in the 1930s (29), and continued to be of importance in describing the course of infection within regions (36, 43, 46, 50). The mode of spread of CSFV between herds over short distances is still unknown. Several vectors and routes can be hypothesised: people, flies, rodents and airborne transmission. The mechanism of neighbourhood infections urgently needs to be clarified. In most countries, tracing of the CSF is hampered because pigs are not identified and no registration of movements occurs. Even where these facilities exist, as in the Netherlands, approximately 50% of the outbreaks could not be traced to the origin (5, 43). Reports from Germany, France and Belgium indicate that the problems faced in tracking the source of infection are common in areas with intensive pig production (13, 14, 25, 48).

During recent outbreaks in Germany and Belgium, secondary cases, without a clear origin of infection, were concentrated in close vicinity of a primary outbreak, and the frequency of secondary outbreaks was inversely related to the distance from the primary outbreak (13, 14, 50). In response to this situation, pre-emptive slaughter of contact herds and herds within a 1-km radius of outbreaks was used in these cases (36, 46) and in Belgium the use of pre-emptive slaughter was a prerequisite to control the epidemic in 1993 and 1994. The efficacy of pre-emptive slaughter as a tool to reduce an epidemic of CSF was supported by quantitative studies of the 1997–1998 epidemic in the Netherlands (4, 23). The purposes of pre-emptive slaughter are as follows (5):

a) reduction of the infectivity of infected herds by reducing the length of the infectious period and reducing the number of infectious pigs

b) reduction of the number of susceptible animals, which results in a reduction in the contact rate and the number of different herds that can be contacted.

Recent quantitative analyses of the 1997–1998 epidemic in the Netherlands (41) and of the 1994 epidemic of CSF in the East Flanders Province of Belgium (21) indicate that the probability of a neighbourhood infection decreases with an increase in distance to an infected herd.

Whether pre-emptive slaughter of pig herds was justified during this epidemic, not only to halt the epidemic, but also from an ethical and economical point of view, was fiercely debated in the Netherlands (5). Clearly, strong emphasis should be placed on identification of the source of introduction of CSFV into a herd, regardless of the route, but given the fact that a considerable number of outbreaks cannot be traced to the origin, pre-emptive slaughter is a pragmatic and effective tool to reduce the proportions of an epidemic of CSF, particularly in areas densely populated with pigs. Pre-emptive slaughter should therefore be recommended as an obligatory eradication tool in EU regulations for such areas (5).

The determination of an optimal radius for depopulation around an infected herd will depend on the specific circumstances of the infected herd; the longer the estimated period of infectiousness of the herd for the environment, the larger the radius should be. During the 1997–1998 epidemic of CSF, a radius of 1 km appeared to be sufficient, especially when depopulation was performed in this area within two to four days of the diagnosis of the infected source herd. However, if the mass destruction of animals is to be minimised in the future, several scientific questions must be answered. Firstly,
the mechanism of neighbourhood infections must be clarified, and secondly, the criteria for pre-emptive slaughter of pig herds must be optimised.

Sampling procedures in pre-emptive slaughter herds shortly before depopulation are similar to those in infected herds (26). However, the size of blood and virological samples taken shortly before pre-emptive slaughter of a herd is not sufficient to detect infected animals at the beginning of the infection process (5). Under these circumstances, all animals would need to be sampled to detect these animals. Therefore, a low proportion of infected herds among the pre-emptively slaughtered herds should not be put forward as proof of the inefficiency of pre-emptive slaughter (44), because the sampling protocol will have missed recently infected herds. However, since the infectivity of these herds is small, the danger of transmission to the surroundings is also fairly small and the benefit of pre-emptive slaughter for disease eradication is optimal in these circumstances (5).

Geographical information systems

Geographical information systems (GIS) are computerised information systems that allow for the capture, storage, manipulation, analysis, display and reporting of geographically referenced data (31). Essentially, the technique is a combination of computerised mapping technology and database management systems (DBMS), in which spatial data sets from diverse sources are managed and analysed.

The strength of a GIS is the ability to combine data which is spatially referenced with attributes linked to this spatial reference. As an example, herd ownership, herd size, herd type or animal disease status can be linked to the geographical location of the herd. In addition, livestock density, disease prevalence per square kilometre or disease incidence per square kilometre per time period can be linked to a previously defined area.

Due to the occurrence of herd-to-herd transmission of CSFV by various infection routes, among which neighbourhood infection is one of the most important (5), several eradication measures are spatially related. The use of GIS, producing geographical maps with the spatial distribution of the spread of disease, can be very helpful in supporting spatially related eradication measures such as the establishment of areas with specific restrictions such as protection and surveillance zones with radii of 3 km and 10 km around infected herds, respectively.

During traceback, GIS were used to support the following:

– personal interviews of farmers, by supplying the investigator with information on location and content of herds in the neighbourhood of the infected herd
– selection and decision-making regarding herds eligible for pre-emptive slaughter in the neighbourhood of infected herds.

In the period from 1995 to 1997, the NAHS developed a GIS to support disease control and disease eradication programmes in the Netherlands. This GIS consists of the commercially-available mapping software MapInfo©, a database with (x;y) co-ordinates of all farm locations in the Netherlands from the Offices of the Land Registry of the Netherlands, digital topographical colour maps of the country (scales of 1:25,000 and 1:125,000) and NAHS databases containing herd- and disease-related data.

At the onset of the epidemic of CSF, a separate GIS/CSF database was created at the NAHS. This database consisted of all data available within the NAHS that was necessary to support the eradication of CSF. Herd data such as ownership, farm address, herd type (multiplier, finishing or mixed herd, artificial insemination centre, hobby farm or children’s zoo) and veterinarian of the herd was available from the national herd registration database. Herd size and number of animals per category (sows, replacement stock, finishing pigs) were available from the national monitoring programme for swine vesicular disease.

Outbreak data available from the local crisis centre (LCC), and needed to apply the GIS functions were also added to the GIS/CSF database. These data included dates of depopulation, outbreak number of infected herds, contact or neighbouring herds in case of pre-emptive slaughter and actual counts of animals present at the farm (boars, sows, suckling piglets, weaned piglets, rearing gilts and finishing pigs separately).

Several databases were created during the epidemic, containing information on different types of zones (based on restriction policies). The GIS department of the NAHS received the formal and authorised description of new or altered protection and surveillance zones or other areas from the national disease control authorities. These descriptions were outlined in a layer of the GIS, using the 1:25,000 topographical map of the Netherlands as a backdrop. Depending on the restriction policies in the area, a specific amount of data was added, such as the name of the area, related infected herd(s), type of restrictions and date of establishment, modification and withdrawal of the status of that area.

Two major shortcomings became increasingly apparent while operating the GIS during the 1997-1998 epidemic. Firstly, the (x;y) co-ordinates for approximately 20% of the herds were not sufficiently accurate to pinpoint the exact location of the herds, although most were wrong by only a few hundred metres. In most cases, this inaccuracy resulted in an error of less than 1% in the selection of herds in specific areas. Several measures were implemented to further reduce the number of errors and to improve the quality of the co-ordinates of the herds. However, the culling department could not rely entirely on the information from the GIS, especially for pre-emptive slaughter of herds within 1 km of an infected herd. Field observations were often necessary to ensure that no herds were overlooked.
The epidemic will have to be maintained lower than one by the virus isolates introduced. This was particularly relevant in those outbreaks of differing virulence associated with very closely related viruses.

Role of molecular epidemiology in tracing

Technological advances have facilitated genetic typing of viruses based on the determination and comparison of nucleotide sequences for fragments of viral genomes. This approach can be used to establish the relatedness of different virus isolates, which is useful for classification and can help trace patterns of virus spread, exposing weaknesses in control strategies (24). Genetic typing of CSF virus DNA will provide information on the genotype class, which can be compared to matching sequences held in international CSFV sequence databases. This is very useful in developing ideas about introduction of the virus in the primary outbreak. However, this information has to be backed up by other epidemiological tracing information, because information on the genotype class is usually not sufficient to identify the source of introduction (30). Genetic typing has proved very useful as a means of tracing the spread of CSFV and is generally considered superior to antigenic typing has proved very useful as a means of tracing the spread of CSFV and is generally considered superior to antigenic methods (17). The method has been used to demonstrate the following:

- virus dissemination from the point source of introduction
- transmission between domestic pigs and wild boar
- transmission across national borders
- outbreaks of differing virulence associated with very closely related viruses
- local persistence of particular variants, usually in infected wild boar
- differentiation between field and vaccine viruses.

During the 1997-1998 CSF epidemic, comparative sequence analysis of virus isolates was used to confirm suspicions about the source of the primary outbreak. As previously described, the first clues on the possible introduction of CSFV into the Netherlands were provided by the investigation of animal transport records; CSFV could have been introduced from the Paderborn area in Germany, where a primary outbreak was confirmed on 6 January 1997. The viruses isolated in the Paderborn area and from the primary outbreak in the Netherlands were identical in comparative sequence analysis (53). Furthermore, during the epidemic, monitoring of the strain was important, to ascertain whether the same strain of CSFV was responsible for all the outbreaks or whether any new isolates were introduced. This was particularly relevant in those cases in which no traceable epidemiological relationship existed with other outbreaks (53). Results indicated that the same strain of CSFV was implicated in all of the outbreaks.

This strain of CSFV, believed to be introduced from Germany to the Netherlands in 1997, was subsequently spread to Italy, Belgium and Spain (5, 11). Phylogenetically, this strain is of subgroup 2.1. Until the involvement in this epidemic, the subgroup 2.1 viruses had been reported only sporadically in Europe (24). These viruses have never been isolated from wild boar in Europe. The first European isolate was recorded in Germany in 1989, and thereafter in the Netherlands (1992) and Switzerland (1993). A 2.1 subgroup virus was also discovered as a contaminant of wild boar meat imported from the People’s Republic of China to Austria in 1993.

A critical appraisal of the effectivity of tracing

One of the most important goals of tracing activities during an epidemic of CSF is reduction in the transmission of CSFV between herds (through tracing of herds or vectors having had contact with an infected herd), because it is crucial to end the epidemic as rapidly as possible. Other important aims of tracing are the detection of the primary source of infection and the elimination of re-introduction of infection from this source (e.g. swill, wild boar, transport lorries, etc.). The transmission of CSFV between herds can be expressed as the herd reproduction number, \( R_h \), which is defined as the average number of outbreaks caused by one infectious herd. Given this definition of \( R_h \), it follows that if \( R_h < 1 \), the epidemic will decline and eventually disappear. In contrast, if \( R_h > 1 \), the virus will continue to spread. Therefore, the primary goal of measures implemented by the veterinary authorities during an epidemic is to eliminate infectious herds before each herd has infected on average more than one other herd (40). To enable this, the infectious herds must first be detected. One of the tools used to achieve that goal is forward tracing. If tracing is to be effective, and most infectious herds are to be traced forward by the tracing unit, then \( R_h \) must be maintained lower than one by use of a strategy that includes tracing, movement restrictions and stamping out of infected herds. However, practice shows that this is not always possible, particularly in areas that are densely populated with pigs (25, 36, 40, 46).

During the 1997-1998 epidemic in the Netherlands, 10.3% of the total number of infected herds were detected via direct contact-tracing by the tracing unit (5), and an additional 10% of the outbreaks were identified via pre-emptive slaughter, for which the tracing unit was also responsible. An evaluation of 270 outbreaks out of a total of 327 outbreaks in Germany between 1993 and 1997 indicated that 20% of the total number of infected herds were detected via direct contact-tracing and an additional 1.1% of the outbreaks were identified.
via pre-emptive slaughter (9). Preliminary findings of the epidemic of CSF in the UK in 2000 (34) indicated that five (31%) out of sixteen infected herds were detected through tracing activities. These sparse data suggest that some variation exists in the proportion of infected herds detected through tracing activities in these countries. Instinctively, the fundamental processes of disease emergency management do not appear to be as effective as would be desired. The question that arises is why is tracing alone not capable of detecting infectious herds in such a way that $R_0 < 1$? A thorough analysis of this problem would have to focus on, among others, the following questions:

– is information on infection routes complete?
– does the tracing of infectious contacts occur too late (already infected before detected)?
– is the protocol according to which tracing activities should be executed up to date and in optimal shape?
– are tracing activities performed exactly according to the prescribed protocol?
– does the organisation have sufficient capacity (tracing specialists) to perform the tasks?

The lack of information on infection routes is a major issue. No route of transmission is identified in approximately 50% of outbreaks of CSF (9, 25, 43, 46, 48, 50). Similarly, during the 1997-1998 epidemic of CSF in the Netherlands, no route of transmission was found in 50% of the outbreaks; 39% were classified as neighbourhood infections and 11% as unknown (5). A recent retrospective study investigating neighbourhood infections during this epidemic did not reveal any new infection routes or vectors for transmission of CSFV (7).

To optimise control measures for CSF with respect to the use of resources, tracing may be better based on the probability of transmission of CSFV, given a contact between an infectious and susceptible herd (transmission rates). During the 1997-1998 CSF epidemic in the Netherlands, these transmission rates were estimated for the following contact types: animals, transport lorries, visitors to farms, transport contacts related to the pig welfare disposal scheme, contaminated semen for artificial insemination, collection service of the rendering plant, and an infected herd within a radius of 500 m, 500 m-1,000 m and 1,000 m-2,000 m (41). From the combination of these transmission rates, the rate at which these contacts occur and the number of different herds that have contact with each other, a ranking of contacts that have priority for tracing can be established by the tracing unit. This allows tracing to be performed more effectively, to try to reduce transmission of CSFV between herds.

In conclusion, an analysis of the issues relating to the non-optimal performance of the tracing systems used in the eradication campaigns for CSF epidemics in different countries should be undertaken. This may lead to the development of improved tracing systems in the future.
reconnu atteint, inventorie tous les lieux et les déplacements d’animaux susceptibles d’avoir facilité la propagation de la maladie. Cette recherche qui se fait dans les deux directions, en amont vers la source de la contagion, et en aval vers les lieux et les animaux qui ont pu être contaminés, est la clef de voûte de la gestion zoosanitaire en cas d’urgence. Les auteurs présentent les grandes lignes des systèmes de suivi et de traçage utilisés lors de l’épizootie récente de peste porcine classique survenue aux Pays-Bas en 1997 et 1998.

**Mots-clés**

---

**Resumen**
Cualquier brote de una enfermedad animal de la Lista A de la Oficina Internacional de Epizootias, como es el caso de la peste porcina clásica, acarrea graves consecuencias para el bienestar animal, la producción ganadera, las exportaciones de animales y productos de origen animal y el medio ambiente. La experiencia demuestra que, a mayor rapidez de detección y reacción ante un posible brote infeccioso, mayor eficacia de las medidas de emergencia adoptadas y menor coste social, económico y ambiental de la enfermedad.

En la mayoría de los países, la estrategia de gestión zoosanitaria predominante se ha cifrado en la concepción y aplicación de medidas que minimicen el riesgo de penetración de enfermedades en el país o la región. No obstante, ni los más eficaces sistemas de gestión preventiva pueden garantizar la ausencia absoluta de brotes de enfermedades animales. La piedra angular de la gestión de emergencias sanitarias es el rastreo, un procedimiento que empieza con la presencia conocida de la infección en un ejemplar, un rebaño o una manada y continúa con el seguimiento de todos los posibles lugares u organismos que se hayan podido ver expuestos, ya sea hacia atrás (en dirección de la fuente de infección) o hacia adelante (hacia los lugares y animales expuestos a la infección). Los autores ofrecen una introducción y una visión general de los sistemas de seguimiento y rastreo utilizados durante una reciente epidemia de peste porcina clásica que se declaró en los Países Bajos entre 1997 y 1998.

**Palabras clave**
References


