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Assessment of the interactions between the European Foot-and-Mouth Disease Spread model (EuFMDiS) and the SIGMA project

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Abstract

The European Food Safety Authority (EFSA) launched the project SIGMA to improve data collection, data quality and EFSAs ability to perform epidemiological analyses. SIGMA also aims to provide the member states with an epidemiological tool to use with the data they submitted to SIGMA. This work assesses the feasibility of integrating the European Foot-and-Mouth Disease Spread model (EuFMDiS) as the epidemiological tool and the EFSA Scientific Data Warehouse where the SIGMA data will be stored. In the assessment it is investigated how and which data in SIGMA could be used in EuFMDiS, possible IT solutions and possible user cases. The results show that an integration could be possible from a technical perspective but would require more investigation on legal aspects. The majority of the data needed for EuFMDiS do not exist in SIGMA and it is important to consider the purpose of an integration and if the same benefits could be achieved without an integration.

Key words: SIGMA, EuFMDiS, data, integration, disease, modelling

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1. Introduction

1.1. Background and Terms of Reference as provided by the requestor

This contract was awarded by EFSA to the SIGMA Consortium:

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Partner 5:
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VAT registration number: EE100018015

Contract title: Technical support to improve and automatize data collection and reporting on animal disease outbreaks and surveillance (SIGMA)

Contract number: OC/EFSA/ALPHA/2018/01

1.2. SIGMA

The European Food Safety Authority (EFSA) launched the project SIGMA to improve data collection from the European Union Member States (MSs), aiming to reduce manual input and double reporting from the MSs, increasing data quality and facilitating the storage and usage of standardized and up-to-date data from the MSs. The outcome of the project will improve EFSAs ability to perform epidemiological analysis and reports on animal disease outbreaks within Europe (EFSA, et al., 2019).

During the first phase of SIGMA, EFSA aims (among other goals) to design a data model to gather essential data on European Commission mandated diseases: African swine fever (ASF), avian influenza, lumpy skin disease and *Echinococcus multilocularis*. Phase 1 also aims to provide access to tools for epidemiological analysis that each MS can use with the data already submitted to EFSA (EFSA, et al., 2019). One such tool is a web tool developed by the Friedrich Loeffler Institut (FLI), using data submitted by MSs and collected in the EFSA scientific data warehouse (S-DWH) through the SIGMA project. This is a data analysis tool regarding animal disease (primarily ASF) and will allow the MSs to produce a series of reports as output. The choosing of the other tool was investigated during the SIGMA project in work package (WP) 7, object 4 (read more in *Section 1.3*).

During SIGMA Phase 1, population data and laboratory data is collected from 13 countries on domestic pigs infected with ASF and stored in the S-DWH. During 2022, data on avian influenza will be collected and stored in the S-DWH, to be followed by the other diseases mentioned above.

1.3. SIGMA WP7 object 4

SIGMA WP7, object 4, had two main goals. The first was to make an inventory of the data analysis and reporting tools in use by the MSs. The second goal was to analyse the technical feasibility for the integration of some of the identified data analysis and reporting tools into the EFSA web services platform.

The selection of suitable tools was based on a survey among the SIGMA Consortium and MSs as well as an inquiry among relevant software communities and repositories. Inclusion and exclusion criteria were then defined and applied to the tools in a selection process. Detailed information was gathered about the tools that met the inclusion criteria and their technical feasibility for integration in the EFSA dashboard was evaluated (Cocca & Lindberg, 2019).

In the next step of the project, EFSA would choose a second tool to be investigated concerning feasibility of integration with the EFSA dashboard and to be shared with the MSs. One tool that was not included in the investigation of WP7 object 4 was the European Foot-and-Mouth Disease Spread model (EuFMDiS), which was mentioned in the scientific report of SIGMA (EFSA, et al., 2019) as one of the consolidated tools that is already in use with the aim of making it available to the member states of EFSA. The reason it was not included in the report of SIGMA WP7 object 4 (Cocca & Lindberg, 2019) was mainly that it was not mentioned in the survey where the participants listed the tools in use nor in public repositories (GitHub and Zenondo).

However, EuFMDiS was chosen by EFSA as the second tool to investigate because the combination of the higher quality data made available from the SIGMA project and the EuFMDiS model could improve the preparedness and planning of disease outbreaks which in turn could reduce the socio-economic consequences. This investigation is in the scope of this report.

1.4. EuFMDiS

The development of EuFMDiS was promoted by The European Commission for the Control of Foot-and-Mouth Disease (EuFMD) and is an adaptation of the Australian Animal Disease Spread Model (AADIS) (European Commission for the Control of Foot-and-Mouth Disease, 2021).

EuFMDiS is a continental-scale model used to simulate outbreaks of foot-and-mouth disease (FMD) within and between countries. Development for other diseases is also underway, including ASF. It is designed to support decision making and planning of emergency outbreaks in Europe. By giving information on the risk of disease introduction, establishment and spread, control approaches, and post-outbreak management, it provides valuable decision support. One important benefit of EuFMDiS is the possibility of simulating spread between various countries, as there are high levels of trade, travels, and risks of disease spread via movement of livestock between European countries. The model software can be used non-commercially under a licensing agreement with EuFMD (Bradhurst, et al., 2021).

EuFMDiS uses data on livestock populations categorized by different herd types. The countries are divided into one or more geographical regions to represent regional heterogeneities in the livestock production. The model simulates FMD spread within and between herds, as well as within and between countries, through different transmission mechanisms. Different control measures are then eligible to simulate control of the disease spread (Bradhurst, et al., 2021). All control measures stated in the EU directives on FMD disease control are included in EuFMDiS (de Vos, Gonzales, Hagenaars, & Dekker). It is also possible to enter data on costs and available resources for controlling FMD. EuFMDiS then provides reports of the simulation results, giving users information on outcomes (as number of infected holdings or duration of the outbreak), costing, how holdings and herds are affected by the outbreak in different ways, and more (European commission for the control of foot-and-mouth disease, 2018a).

1.5. Aim

This work is a task within order form 05 of the SIGMA project and investigates the feasibility of providing MSs with access to the EuFMDiS model, to use it with the input data that the MSs already provided to EFSA within the SIGMA framework.

This report aims to provide EFSA with

- A description of EuFMDiS
- The input data required for EuFMDiS
- A preliminary data mapping from the SIGMA data to EuFMDiS and eventual adaptation of the SIGMA data
- An assessment of possible IT architecture to use EuFMDiS with data from SIGMA (S-DWH)
- A suggestion of practical EuFMDiS software access for the MSs

Emphasis is placed upon the input data of EuFMDiS and the preliminary data mapping, as the IT architecture and practical access are more important if the decision is made to integrate SIGMA and EuFMDiS.

2. Methods

This assessment was compiled through a review of available documents (scientific reports, data model documents or templates, manuals, and other complementary documents) about EuFMDiS and SIGMA.

Moreover, experts were consulted during a meeting and through email correspondence. These experts were:

- Gabriele Zancanaro – Project leader of SIGMA, EFSA
- Graeme Garner – Developer of EuFMDiS
- Richard Bradhurst – Software developer of EuFMDiS
- Koen Mintiens – Responsible for implementation, coordination, and development of EuFMDiS
- Fabrizio Rosso – Project coordinator at EuFMD

The following documents have been used to describe SIGMA and EuFMDiS in *Section 0* (Results). Some of the documents were sent from the experts as they are not available publicly, which are marked with "*".

- Scientific report on the SIGMA Animal Disease Data Model: A comprehensive approach for the collection of standardised data on animal diseases (EFSA, et al., 2019)
- Excel sheets describing the SIGMA data model *

- Development of a transboundary model of livestock disease in Europe (Bradhurst, et al., 2021)
- EuFMDiS Country data requirements (European commission for the control of foot-and-mouth disease, 2018b)
- Review of EuFMDiS (de Vos, Gonzales, Hagenaars, & Dekker)
- EuFMDiS User Manual * (European commission for the control of foot-and-mouth disease, 2018a)
- Spreadsheet templates and instructions for data input in EuFMDiS *

3. Results

3.1. SIGMA data stored in EFSA Scientific data warehouse

As mentioned in *Section 1.2* the first phase of SIGMA covers population data and laboratory data on ASF from 13 countries. Thus, the SIGMA animal disease data model (σ-ADM) currently includes the variables for population and laboratory data, some mandatory and some optional (the latter marked with "*"), shown in *Table 1* and *Table 2*.

Table 1 - SIGMA: Population data

Attribute/Column	Description
recordId	Unique identifier of the single record, i.e. at subUnit level. The data provider is suggested to use a concatenation of the Establishment ID + Sub Unit ID + Extraction date (YMD) + a sequential number (optional). NOTE: the recordID must be unique within and between the datasets over time (i.e. each record ID must appear only one time in the EFSA DataWareHouse)
recordCensusY	Year when the information on the subUnit has been EXTRACTED from the system
recordCensusM	Month when the information on the subUnit has been EXTRACTED from the system
recordCensusD	Day when the information on the subUnit has been EXTRACTED from the system
estabId	Official identifier as recorded in the national register (or dummy identifier, if strictly necessary) of the Establishment. NOTE: this information is protected by the EU GDPR.
estabType	Type of Establishment, characterised by a specific purpose
estabPers*	Number of people interacting with the animals or with the environment in which the animals live (establishment level)
estabCoordPrecision	Precision of the provided coordinates. Mandatory if geo-coordinates are provided
estabYCoord*	Latitude (WGS84 decimal degrees) - possibly 4 digits or more - North = pos values / South = neg values (e.g. 38.8897° will stand for 38° 53′ 23″ N)
estabXCoord*	Longitude (WGS84 decimal degrees) - possibly 4 digits - East = pos values / West = neg values (e.g.-77.0089° will stand for 77° 00′ 32″ W)
estabMunicipality*	Municipality of the Establishment
estabArea	NUTS code level 3 of the Establishment
subUnitId	Official identifier as recorded in the national register (or dummy identifier, if strictly necessary) of the SubUnit. NOTE: this information is protected by the EU GDPR.
subUnitSpecies	The common name, the genus and the species of the animals kept and/or bred in the Subunit of concern.
subUnitPurpType*	Type of final product of the SubUnit OR aim for which the animals are kept and/or bred
subUnitRepLevel	The reproductive level of the animals in the subunit of concern. Relevant only for the Sub Units having Purpose = Breeders
subUnitCapacity*	The capacity of the sub-unit, i.e. the permitted maximum number of animals that the sub-unit can host
subUnitActualNumber*	Actual number of animals present in the sub-unit at a given time, i.e. at the most recent census activity. NOTE: in case the establishment is a slaughterhouse, the value requested is the yearly average throughput.
subUnitProdType*	Outdoor / Indoor management of the animals
subUnitCoordPrecision	Precision of the provided coordinates
subUnitYCoord*	Latitude (WGS84 decimal degrees) - possibly 4 digits or more - North = pos values / South = neg values (e.g. 38.8897° will stand for 38° 53′ 23″ N)
subUnitXCoord*	Longitude (WGS84 decimal degrees) - possibly 4 digits - East = pos values / West = neg values (e.g.-77.0089° will stand for 77° 00′ 32″ W)
subUnitMunicipality*	Municipality of the located Subunit
subUnitArea	NUTS code level 3 of the located entity

Table 2 - SIGMA: Laboratory data

Attribute/Column	Description
progId	National unique identification code of the programme / project for which the sampling activity was performed
progType*	Definition of the overall legal / administrative framework within which the sampling activity was performed
progLegalRef	Reference to the legislation underpinning the sampling activity (Repeatable)
progInfo.com*	Description of the goal to be achieved with the sampling activity. There are three options: 1) Freedom from disease 2) Outbreak containment 3) Detection.
sampStrategy*	Description of the underpinning (statistical) methodology for the selection of the samples
sampPoint*	Point, in the food chain, where the sample was taken. (See Doc. ESTAT/F5/ES/155 "Data dictionary of activities of the establishments").
progInfo.targetGroup	Clinical characteristics of the group to which the animal belongs
sampUnitType	Sampling unit. It is the entity from which the samples are taken to draw conclusions on its status. Default value = ANIMAL (G199A)
sampEventId	Dummy identifier of the sampled animal. Relationship 1 to many with sampId.
sampUnitIds.animalId*	Official Identification number of the animal (if strictly necessary, a dummy identifier can be provided instead of the official ID)
sampUnitIds.subUnitId*	Official identifier as recorded in the national register (or dummy identifier, if strictly necessary) of the SubUnit. NOTE: this information is protected by the EU GDPR.
evalInfo.nationalCaseId*	Identification number in the european notification system (ADNS / ADIS)
sampUnitIds.sampHuntingGround*	National Identifier of the hunting ground where the wild animal has been shot / found dead. Shapefiles of the national hunting grounds shall be provided separately to EFSA. The Hunting Ground CANNOT be considered a way to describe where the animal was intercepted: longitude and latitude should always be preferred when available.
sampMatCode.base	Category of matrix tested. Default / fixed = NON-FOOD (A0BYQ)
sampMatType	Macro-category of the sampled matrix. DEFAULT VALUE = ANIMAL SAMPLE (S000A)
sampMatCode.part*	Description of the matrix (tissue / substance) analysed. E.g., blood / liver / …
sampId	Identification code of the SAMPLE taken
sampSize*	Number of SAMPLING UNITS included in the sample. (IF >1 the sample is pooled), independently from the material collected. Examples are: neck skin from poultry (the final sample may be a composition of skin coming from more thatthan one animal); feed (the final sample can be the composition of more than 1 quantity taken in different points of a herd or silos)
sampSizeUnit	Unit of measurement of the sample size. DEFAULT VALUE = ANIMAL (G199A)
sampY	Year of sampling. In case the sampling has been performed over a period of time the start date (as year) of sampling should be reported. If not available use the year of acceptance of sample at the laboratory
sampM	Month of sampling. In case the sampling has been performed over a period of time the start date (as month) of sampling should be reported. If not available use the month of acceptance of sample at the laboratory
sampD	Day of sampling. In case the sampling has been performed over a period of time the start date (as day) of sampling should be reported. If not available use the day of acceptance of sample at the laboratory
sampMatCode.prod	Category of the sampled animal (Farmed / Wild)
sampMatCode.source	Animal species
sampMatCode.animage	Age class of the individual(s) at the time of the sampling. MANDATORY IF "sampMatCode.prod" == WILD
sampMatCode.gender*	Sex of the animal
sampMatText*	State of decomposition of the carcass when the sample was taken (proxy for the time elapsed between the death and the finding)
sampCountry	Country where the sample was taken for laboratory testing (ISO 3166-1-alpha-2).
sampArea	NUTS code level 3 of the located entity.

sampMunicipality*	Municipality of the located entity (LAU, Local Administrative Unit)
sampInfo.coordPrecision	Precision of the provided coordinates. Mandatory IF the geo-coordinates are provided
sampInfo.latitude*	Latitude (WGS84 decimal degrees) - possibly 4 digits or more - North = pos values / South = neg values (e.g. 38.8897° will stand for 38° 53′ 23″ N)
sampInfo.longitude*	Longitude (WGS84 decimal degrees) - possibly 4 digits - East = pos values / West = neg values (e.g.-77.0089° will stand for 77° 00′ 32″ W)
anMethRefId	Identifier for the method used in the laboratory. Note: if not existing, it can be a dummy identifier. Please don't use the same ID for different methods.
anMethType	Type of analytical method used (Screening / Confirmation)
anMethCode	Encoding of the method or instrument used from the ANLYMD catalogue.
anMethInfo.methSensitivity*	The diagnostic sensitivity of the laboratory test used, i.e. the probability that the method returns a positive result given that the sample is truly positive (e.g. infected, infested, contaminated, etc.). The value is expressed in probabilistic terms, going from 0 to 1.
anMethInfo.methSpecificity*	The diagnostic specificity of the laboratory test used, i.e. the probability that the method returns a negative result given that the sample is truly negative (e.g. not infected, not infested, not contaminated, etc.). The value is expressed in probabilistic terms, going from 0 to 1.
resId	Unique identifier of the single test result.
paramType	Defines if the parameter reported is an individual residue/ analyte, a summed residue definition or part of a summed residue definition. DEFAULT VALUE = "INDIVIDUAL" (P001A)
paramCode	Description of the analytical parameter targeted by the test. The values vary according to the disease of interest, e.g. HPAI/LPAI; ASF virus & the Genotype (1 to 16); E. multilocularis; ...
paramCode.antH	H antigen
paramCode.antN	N antigen
resType	Indicates the type of result (qualitative/quantitative) and whether it could be quantified/determined or not.
resQualValue	Qualitative result of the test (positive /negative)
resVal	The result of the analytical measure. The unit of measure is defined in "resUnit"
resUnit	Unit of measurement for the values reported in "resVal". Also valid for "resLOD" and "resLOQ".
resLOD	Limit of detection expressed in the unit specified by the element "resUnit"
resLOQ	Limit of quantification expressed in the unit specified by the element "resUnit"
analysisY	Year on which the analysis has been concluded
analysisM	Month on which the analysis has been concluded
analysisD	Day on which the analysis has been concluded
anPortSeq*	Sequential number assigned to analysis performed on DIFFERENT PORTIONS of the SAME sample
anPortSize*	Final weight of the sample PORTION tested
anPortSizeUnit	Unit of measurement (e.g. grams) of the size/amount of the PORTION
labId*	Identification code of the laboratory. (National laboratory code if available). This code should be nationally unique and consistent through all data domain transmissions. If the labCountry is reported it becomes mandatory
labCountry*	Country where the laboratory is located (ISO3166-1-alpha-2).

3.2. EuFMDiS input data

The EuFMDiS model requires various datasets and parameters to be able to produce realistic outputs. Data and parameters are stored or inserted in a relational database, text files, or through the graphical user interface (European commission for the control of foot-and-mouth disease, 2018a). The model consists of three main components: the livestock population, the spread of FMD, and the disease control phase (European commission for the control of foot-and-mouth disease, 2018b). Some spread pathways and control measures can be enabled or disabled (European commission for the control of foot-and-mouth disease, 2018a).

This section describes the data and parameters used in EuFMDiS, fetched primarily from the EuFMDiS manual, spreadsheet templates, and the document on country data requirements. Input data are described in the sections below. Some required data might be missing as the section is only based on complementary documents to the model. The pilot version of EuFMDiS provides default values for all input parameters (de Vos, Gonzales, Hagenaars, & Dekker).

- Livestock population dataset
- Within-herd spread
- Spread pathway configuration
  - The disease spread simulation between herds (both within and between countries) is done by an agent-based model (ABM). The two options for disease spread modelling in EuFMDiS are a separate representation of several spread pathways (headings below) or a simplified simulation of disease transmission, which is not explained in this report. The first approach is strongly recommended but requires detailed data on animal and product movement patterns, which all countries may not have .
  - Direct contact spread
  - Indirect contact spread
  - Local spread
  - Airborne spread
  - The modelling of airborne spread in EuFMDiS requires access to data from weather stations (and their locations). EuFMDiS calculates the number of days suitable for wind-borne spread per month for each weather station to estimate the risk of airborne spread . The airborne spread is only modelled for pig herds as pigs excrete larger quantities of virus relative to other species .
  - Spread via assembly centres
- Control measures configuration
  - First infected holding (IH) detection
  - Movement restrictions and quarantine
  - Suspect holdings reporting
  - Surveillance visits
  - Tracing (direct/indirect)
  - IH operations
  - Vaccination (suppressive or protective ring vaccination)
  - Team Resources
  - Post-outbreak management
- Scenario configuration

- Outbreak cost
- Model report configuration

3.2.1. Livestock population dataset

To model disease outbreaks, it is important to have complete data on livestock populations. Livestock data in EuFMDiS is comprised of:

- Herd dataset, including herd categories (herd types)
- Country boundaries and defined regions (digital maps)

(European commission for the control of foot-and-mouth disease, 2018b).

The herd dataset (of herds within the country or study area) contains an identifier for the herd, the herd type, herd size, and longitude and latitude of the herd. One holding could have multiple herds of different herd types and should be reported per herd but would have the same coordinates. The columns of the dataset are shown in *Table 3* with explanations.

Table 3 – EuFMDiS Dataset: Herds

Herds		
Columns	**Explanation**	**Example value**
herd_id	A number allocated by the computer in the EuFMDiS model	
Country_ code	A two-letter code defined for some countries (which are part of the EuFMDis project) in the instructions for EuFMDis	IT
herd_type	A number (ID) representing one of the defined herd-types (agreed upon between the countries that are part of the EuFMDiS project). If needed new categories could be defined. All categories may not be present in every country.	3
herd_size	Number of animals in the herd	189
herd_long	Longitude of herd location (in decimal degrees)	40.790311
herd_lat	Latitude of herd location (in decimal degrees)	15.872856

The herd types (herd categories) should preferably be around 10-12 categories, to keep the model set up manageable. In the pilot project of EuFMDiS nine herd categories were predefined, these are listed in *Table 4* (European commission for the control of foot-and-mouth disease, 2018b).

Table 4 – EuFMDiS predefined herd categories

herd_type_id	Species	Description
1	Cattle	Large commercial dairy herd
2	Cattle	Large commercial beef herd
3	Cattle	Small commercial cattle herd

4	Cattle	Commercial buffalo
5	Sheep/goats	Commercial small ruminants
6	Swine	Large-scale commercial fattening pig herd
7	Swine	Large scale commercial breeding pig herd
8	Swine	Small-scale commercial pig
9	Mixed	Backyard herd

Within country livestock production regions should be defined by the country representatives (4-6 regions per country). It is suggested to use Eurostat's Nomenclature of Territorial Units for Statistics (NUTS) level 2 boundaries. Digital maps (shapefiles) of country boundaries and the defined regions are required as input data to the model. Locations of animal markets, assembly centers, weather stations and local government boundaries may also be important during the modelling (European commission for the control of foot-and-mouth disease, 2018b).

3.2.2. Within-herd spread

In EuFMDiS within-herd spread is modelled for each infected herd with an equation-based model (EBM) that takes into account the herd type, size, and the pathogen of interest. The EBM is a SEIRDC-model (susceptible, exposed, infectious, recovered, deceased, clinical) which requires parameterization per herd type as the parameters may vary for different species and production systems. The required input parameters are shown in *Table 5* (European commission for the control of foot-and-mouth disease, 2018a).

Table 5 – EuFMDiS Parameters: Within-herd spread

Parameters for within-herd spread		
Parameter	**Description**	**Example value**
Beta	Effective contact rate	6
Latent period	Average duration of the latent period (days)	2
Infectious period	Average duration of the infectious period (days)	4
Clinical period	Average duration of the clinical period (days)	12
Clinical lag	Average number of days after infection that clinical signs appear	5
Proportion clinical	The proportion of the herd that will show detectable clinical signs (expressed as a value between 0 and 1)	1
Minimum vaccine immune period	Parameter in a beta-PERT distribution of the number of days that the herd will be vaccine immune	150
Most likely vaccine immune period	Parameter in a beta-PERT distribution of the number of days that the herd will be vaccine immune	180
Maximum vaccine immune period	Parameter in a beta-PERT distribution of the number of days that the herd will be vaccine immune	210
Minimum natural immune period	Parameter in a beta-PERT distribution of the number of days that the herd will be naturally immune	180
Most likely natural immune period	Parameter in a beta-PERT distribution of the number of days that the herd will be naturally immune	280
Maximum natural immune period	Parameter in a beta-PERT distribution of the number of days that the herd will be naturally immune	365
Seropositive lag	Number of days after infection that a herd becomes serologically positive	5
Seropositive duration	Duration in days that a herd remains serologically positive.	365

3.2.3. Spread pathway configuration

The disease spread simulation between herds (both within and between countries) is done by an agent-based model (ABM). The two options for disease spread modelling in EuFMDiS are a separate representation of several spread pathways (headings below) or a simplified simulation of disease transmission, which is not explained in this report. The first approach is strongly recommended but requires detailed data on animal and product movement patterns, which all countries may not have (European commission for the control of foot-and-mouth disease, 2018b).

3.2.3.1. Direct contact spread

The modelling of direct contact spread is based on animal movement data. There are four tables to be populated (*Table 6, Table 7, Table 8* and *Table 9*) and the values could be retrieved directly from movement data records if available, otherwise the values should be estimated with the assistance of local experts. The direct spread pathway can be enabled or disabled.

Table 6 – EuFMDiS Dataset: Movement onto and off farms – direct movements

Movements onto and off farms Data should be aggregated per herd type, region, and country. Consignment size is the expected number of animals in a single consignment for a herd of this type in this region.	
Column	**Description**
Country	Two letter country code
Region	Code for the agreed livestock production regions in your country
Herd_type	Number representing the agreed herd categories
Animal consignments moving off per herd per year (N)	Number of animal consignments that move off a typical herd of this type in this region per year (average)
Consignment size (minimum)	Number of animals in a consignment (minimum)
Consignment size (maximum)	Number of animals in a consignment (maximum)
Consignment size (most likely)	Number of animals in a consignment (most likely)
Summer (% off)	Percentage of movements off that occur in summer (value between 0-100)
Autumn (% off)	Percentage of movements off that occur in autumn (value between 0-100)
Winter (% off)	Percentage of movements off that occur in winter (value between 0-100)
Spring (% off)	Percentage of movements off that occur in spring (value between 0-100)
Animal consignments moving on per herd per year (N)	Number of animal consignments that move onto a typical herd of this type in this region per year
Summer (% on)	Percentage of movements on that occur in summer (value between 0-100)
Autumn (% on)	Percentage of movements on that occur in autumn (value between 0-100)
Winter (% on)	Percentage of movements on that occur in winter (value between 0-100)
Spring (% on)	Percentage of movements on that occur in spring (value between 0-100)

Table 7 – EuFMDiS Dataset: Destination type – direct movements

Destination type Data should be aggregated per herd type, region and country. Enter data as the proportion (percentage) of all consignments for this herd type over a 12-month period that would be expected to go to the different destinations.	
Column	**Description**
Country	Two letter country code

Region	Code for the agreed livestock production regions in your country
Herd_type	Number representing the agreed herd categories
Another holding (%)	Percentage of movements off that go to another holding in the same country (value between 0-100)
Slaughterhouse (%)	Percentage of movements off that go to a slaughterhouse in the same country (value between 0-100)
Market	Percentage of movements off that go to a market in the same country (value between 0-100)
Assembly point (%)	Percentage of movements off that go to an assembly point in the same country (value between 0-100)
EU member state (%)	Percentage of movements off holding that go to a EU Member State without going through assembly centre (value between 0-100)
Another country	Percentage of movements that go to non-EU country without going to assembly centre (value between 0-100)

Table 8 - EuFMDiS Dataset: Movement distances – direct movements

Movement distances This worksheet is used where countries have not subdivided their country into livestock production regions. Instead of using a region to region contact matrix, we use simple beta pert distributions.	
Column	**Description**
Country code	Two letter country code
Herd_type_ID	Herd type of origin (values 1- 9)
Summer_min	Minimum distance (km) a livestock consignment might be expected to go from this herd type in summer
Summer_most likely	Most likely distance (km) a livestock consignment might be expected to go from this herd type in summer
Summer max	Maximum distance (km) a livestock consignment might be expected to go from this herd type in summer
Autumn_min	As above, repeat for other seasons
Autumn_most likely	As above, repeat for other seasons
Autumn_max	As above, repeat for other seasons
Winter_min	As above, repeat for other seasons
Winter_most likely	As above, repeat for other seasons
Winter_max	As above, repeat for other seasons
Spring_min	As above, repeat for other seasons
Spring_most likely	As above, repeat for other seasons
Spring_max	As above, repeat for other seasons

Table 9 - EuFMDiS Dataset: Herd-to-herd – direct movements

Herd-to-herd (direct movements) This data needs only to be entered once for each source herd type. You don't need to enter separately for each region of your country. The values for all possible destination herd types from one herd type should add up to 1.	
Column	**Description**
Country code	Two letter country code
source herd	Herd type of origin (values 1- 9)
herd 1	Probability that consignment of animals from the source herd type will go to herd type 1 (value between 0-1)
herd 2	Probability that consignment of animals from the source herd type will go to herd type 2 (value between 0-1)
herd 3	Probability that consignment of animals from the source herd type will go to herd type 3 (value between 0-1)
herd 4	Probability that consignment of animals from the source herd type will go to herd type 4 (value between 0-1)
herd 5	Probability that consignment of animals from the source herd type will go to herd type 5 (value between 0-1)

herd 6	Probability that consignment of animals from the source herd type will go to herd type 6 (value between 0-1)
herd 7	Probability that consignment of animals from the source herd type will go to herd type 7 (value between 0-1)
herd 8	Probability that consignment of animals from the source herd type will go to herd type 8 (value between 0-1)
herd 9	Probability that consignment of animals from the source herd type will go to herd type 9 (value between 0-1)

3.2.3.2. Indirect contact spread

Indirect contact spread, such as movements of contaminated products, people, vehicles, etc., could be more difficult to parameterize due to less available data. There are three tables to be populated for indirect contact spread (*Table 10, Table 11* and *Table 12*). To be able to estimate the values, the developers have provided a calculation template to help the user, not shown in this report.

Table 10 - EuFMDiS Dataset: Indirect contacts per year

Indirect contacts per year Data should be entered as the average number of indirect contacts per herd type per year.	
Column	**Description**
Country code	Two letter country code
Region	Code for the agreed livestock production regions
Herd_type	Number representing the agreed herd categories (values 1- 9 if there are 9 herd categories)
Number of indirect contacts per herd per year (N)	Total number of indirect contacts that a typical herd of this type in this region has with other herds per year
Summer (% off)	Percentage of indirect contacts that occur in summer (value between 0-100)
Autumn (% off)	Percentage indirect contacts that occur in autumn (value between 0-100)
Winter (% off)	Percentage of indirect contacts that occur in winter (value between 0-100)
Spring (% off)	Percentage of indirect contacts that occur in spring (value between 0-100)

Table 11 - EuFMDiS Dataset: Indirect contact distances

Indirect contact distances Data should be entered as the distances in km of indirect contacts with other holdings for an average herd for each herd type.	
Column	**Description**
Country code	Two letter country code
Region	Code for the agreed livestock production regions
Herd_type	Number representing the agreed herd categories (values 1- 9 if there are 9 herd categories)
Minimum distance	Shortest distance over which an indirect contact is likely to occur
Most likely distance	Most likely distance over which an indirect contact is likely to occur
Maximum distance	Longest distance over which an indirect contact is likely to occur

Table 12 - EuFMDiS Dataset: Herd-to-herd – indirect contacts

Herd-to-herd (indirect contact) This data is entered once for each source herd type and provide information about the indirect contacts between herds. You don't need to enter separately for each region of your country. The values for all possible indirect contacts with other herd types from one source herd type should add up to 1.	
Column	**Description**

Country code	Two letter country code
source herd	Herd type of origin (values 1- 9 if there are 9 herd categories)
herd 1	Probability that an indirect contact from the source herd type will be with herd type 1 (value between 0-1)
herd 2	Probability that an indirect contact from the source herd type will be with herd type 2 (value between 0-1)
herd 3	Probability that an indirect contact from the source herd type will be with herd type 3 (value between 0-1)
herd 4	Probability that an indirect contact from the source herd type will be with herd type 4 (value between 0-1)
herd 5	Probability that an indirect contact from the source herd type will be with herd type 5 (value between 0-1)
herd 6	Probability that an indirect contact from the source herd type will be with herd type 6 (value between 0-1)
herd 7	Probability that an indirect contact from the source herd type will be with herd type 7 (value between 0-1)
herd 8	Probability that an indirect contact from the source herd type will be with herd type 8 (value between 0-1)
herd 9	Probability that an indirect contact from the source herd type will be with herd type 9 (value between 0-1)

3.2.3.3. Local spread

Local transmission of a disease could include direct spread via straying of stock, short-range aerosol spread across fences, etc. Susceptible herds within a default radius of 3 km of infected herds are at risk of becoming infected through the local spread pathway. The probability of transmission is decided stochastically in EuFMDiS based on the set of parameters shown in *Table 13*. Default values for these parameters are derived from published studies but are configurable (European commission for the control of foot-and-mouth disease, 2018a).

Table 13 – EuFMDiS Parameters: Local spread

Local spread		
Parameter	**Description**	**Example value**
Enabled	Pathway enabled	true
Pb	Baseline probability (per region) that a local contact between herds on different holdings results in infection.	0,036
Pb	Baseline probability (per region) that a local contact between herds on the same holding results in infection.	0,5
p(t)	Normalized infectious prevalence of the source herd as generated by the herd's EBM	
Si	Relative infectivity of a species (in relation to sheep)	Cattle: 2 Sheep: 1 Pigs: 4 Other: 2.3
Pi	Power law constants that provide per-species tuning of the effect of herd size on infectivity. Values range from 0 indicating no effect through to 1 indicating a linear relationship	Cattle: 0.55 Sheep: 0.55 Pigs: 0.55 Other: 0.55
Ss	Relative susceptibility of a species (in relation to sheep)	Cattle: 6 Sheep: 1 Pigs: 0.4 Other: 2.5
Ps	Power law constants that provide per-species tuning of the effect of herd size on susceptibility. Values range from 0 indicating no effect through to 1 indicating a linear relationship	Cattle: 0.55 Sheep: 0.55 Pigs: 0.55 Other: 0.55
wb	Weight applied to the local spread probability reflecting the level of biosecurity measures in place for a susceptible herd	Small pigs: 0.8 Large pigs: 0.25 Others: 1
wx	Weight applied to the local spread probability reflecting seasonal impact on infectivity	1
wn	Weight applied to the local spread probability reflecting that local spread may organically dampen once an outbreak has been declared due to increased awareness of risk, decreased movements of people and vehicles, etc.	0,5
r	Radius of the local spread area enclosing each infected herd	3km
Min new infections	Parameter for the beta-PERT distribution of the likely number of infections resulting from an effective local contact.	1
Mode new infections	Parameter for the beta-PERT distribution of the likely number of infections resulting from an effective local contact	2

Max new infections	Parameter for the beta-PERT distribution of the likely number of infections resulting from an effective local contact	5

3.2.3.4. Airborne spread

The modelling of airborne spread in EuFMDiS requires access to data from weather stations (and their locations). EuFMDiS calculates the number of days suitable for wind-borne spread per month for each weather station to estimate the risk of airborne spread (European commission for the control of foot-and-mouth disease, 2018b). The airborne spread is only modelled for pig herds as pigs excrete larger quantities of virus relative to other species (European commission for the control of foot-and-mouth disease, 2018a).

3.2.3.5. Spread via assembly centres

Assembly centres are considered an important part of the livestock marketing in Europe and are assumed (in the model) to be primarily used as an intermediary before consignments leave the source country. Three possible destinations are defined: MS part of the study area, another MS, or another country. At the destination country, consignments can go to a holding facility or to a slaughterhouse. Data from participating countries were used to estimate the probabilities of the destination country and consignment premises type for shipments coming from assembly centres (European commission for the control of foot-and-mouth disease, 2018a). Some data on movements via assembly centres is entered in *Table 7* (Section *0 The disease spread* simulation between herds (both within and between countries) is done by an agent-based model (ABM). The two options for disease spread modelling in EuFMDiS are a separate representation of several spread pathways (headings below) or a simplified simulation of disease transmission, which is not explained in this report. The first approach is strongly recommended but requires detailed data on animal and product movement patterns, which all countries may not have
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Direct contact spread).

3.2.4. Control measures configuration

There are seven control measures (each explained in a subsection below) used in EuFMDiS which can be switched on or off in the model. For many countries it may be difficult to estimate parameters and data needed for modelling the control measures due to little experience. To estimate parameters, these countries could first focus on important parameters that may vary between countries, while other parameters could be derived from published values from other European countries (European commission for the control of foot-and-mouth disease, 2018b).

3.2.4.1. First infected holding (IH) detection

Silent spread of the disease occurs until the first detection of an IH, at which point the model switches to the control phase. This detection can be disabled (silent spread), fixed (fixed day at a specific or random farm), or passive (using pre-configured probabilities) (European commission for the control of foot-and-mouth disease, 2018a).

The fixed first IH detection uses a configured day during the simulation when the first infected holding is detected. Which herd is detected could be specified by ID or chosen randomly. Parameters used are shown in *Table 14* (European commission for the control of foot-and-mouth disease, 2018a).

Table 14 – EuFMDiS Parameters: Fixed first IH detection

Fixed first IH detection		
Parameter	**Description**	**Example value**

Day	Simulation day on which first IH detection will occur	21
Mode	Criteria for selecting the first IH. Options are by herd ID, by species, or any herd.	any
Herd ID	Herd ID of the first IH. Only relevant when fixed detection mode is by herd ID.	34716
Species	Priorities for choosing the species of the first IH. Options are 0 (do not detect), 1 (highest priority), 2 or 3 (lowest piority). Only relevant when fixed detection mode is by species.	Cattle: 2 Sheep: 3 Pigs: 1 Other: 3

For a passive first IH detection, more parameters are required. This method uses stochastic processes for detection and reporting of IHs based on defined parameters. The parameters are shown in *Table 15* (European commission for the control of foot-and-mouth disease, 2018a).

Table 15 – EuFMDiS Parameters: Passive first IH detection

Passive first IH detection		
Parameter	**Description**	**Example value**
Minimum clinical prevalence	Minimum proportion of a herd that must be exhibiting clinical signs for the herd to be a candidate for passive detection (i.e., clinical signs noticed and reported to a veterinarian). Values are defined per herd type per region.	Small commercial beef: 0.1
Probability of holding detection	Probability that passive detection of an infected herd (defined as clinical signs being noticed and a veterinarian consulted), occurs on a holding. Values are defined per herd type, per region. y = axb/(cb+xb) where: y = probability of detection x = days since herd became infected a, b and c are the coefficients of a fitted curve that reflects probability of detection over time (factoring in clinical prevalence)	
Probability of assembly centre detection	Probability that passive detection of an infected herd (defined as clinical signs being noticed and a veterinarian consulted), occurs at an assembly centre. Values are defined per herd type, per region.	
Probability of slaughterhouse detection	Probability that passive detection of an infected herd (defined as clinical signs being noticed and a veterinarian consulted), occurs at a slaughterhouse. Values are defined per herd type, per region.	
Probability of reporting	Probability that a veterinarian suspects FMD, sends samples to a lab and FMD is confirmed. Values are defined per herd type, per region.	0,592
Slaughterhouse confirmation lag	Time between reporting disease at a slaughterhouse and the declaration of the source holding as an IH.	3 days
Assembly centre confirmation lag	Time between reporting disease at an assembly centre and the declaration of the source holding as an IH.	4 days
Holding confirmation lag	Time between reporting disease at a holding and the declaration of the holding as an IH.	5 days

3.2.4.2. Movement restrictions and quarantine

Immediately after the first IH detection, EuFMDiS implements a livestock standstill of at least three days to curb the direct spread and assembly centre spread pathways. The level of movement reduction is defined for each pathway as illegal movements may still occur during the standstill. Two types of control zones are defined. Protection zones (PZ) which immediately enclose the infected holdings with the highest level of control and surveillance zones (SZ) which enclose the PZs. The coverage areas of the control zones are greater at the start of the outbreak and are reduced as the control program progresses. The parameters entered for movement restrictions in EuFMDiS are shown in *Table 16*. Parameters for throttling rates are also entered for non-infected jurisdictions (NIJ) and free zones (FZ) outside the PZs and SZs (European commission for the control of foot-and-mouth disease, 2018a).

Table 16 – EuFMDiS Parameters: Movement restrictions

Movement restrictions		
Parameter	**Description**	**Example value**
Enabled	Determines whether movement restrictions are enabled or disabled.	true
Standstill duration	Duration in days of the livestock standstill. Values are defined per jurisdiction.	3 days
Jurisdiction transition	Duration in days that controlled areas are jurisdiction-based (PZs are set to the LVU of the IH, and SZs are set to the jurisdiction of the IH). After this duration has elapsed the controlled areas are defined radially. Values are defined per jurisdiction and are relative to the first day of the control program.	0 days (i.e., bypass jurisdictional controlled areas)
Radial transition	Duration in days that controlled areas are defined by the 'first' set of PZ/SZ radii. After this duration has elapsed the controlled areas are defined by the 'second' set of PZ/SZ radii. Values are defined per jurisdiction and are relative to the jurisdiction transition day defined above.	14 days
PZ 1st radius	First PZ radius in km. Values are defined per jurisdiction.	10 km
PZ 2nd radius	Second PZ radius in km. Values are defined per jurisdiction.	3 km
SZ 1st radius	First SZ radius in km. Values are defined per jurisdiction.	25 km
SZ 2nd radius	Second SZ radius in km. Values are defined per jurisdiction.	10 km
NIJ direct throttling rate	The level of throttling applied to the Direct Spread pathway in the non infected jurisdiction during the livestock standstill. Values (0..100) are defined per jurisdiction.	98%
NIJ indirect throttling rate	The level of throttling applied to the Indirect Spread pathway in the non infected jurisdiction during the livestock standstill. Values (0..100) are defined per jurisdiction.	50%
NIJ assembly centre throttling rate	The level of throttling applied to the Assembly Centre Spread pathway in the non-infected jurisdiction during the livestock standstill. Values (0..100) are defined per jurisdiction.	100%
NIJ jump throttling rate	The level of throttling applied to the Jump Spread pathway in the non infected jurisdiction during the livestock standstill. Values (0..100) are defined per jurisdiction.	45%
PZ direct throttling rate	The level of throttling applied to the Direct Spread pathway inside PZs. Values (0..100) are defined per jurisdiction.	98%
PZ indirect throttling rate	The level of throttling applied to the Indirect Spread pathway inside PZs. Values (0..100) are defined per jurisdiction.	85%
PZ assembly centre throttling rate	The level of throttling applied to the Assembly Centre Spread pathway inside PZs. Values (0..100) are defined per jurisdiction.	100%
PZ jump throttling rate	The level of throttling applied to the Jump Spread pathway inside PZs. Values (0..100) are defined per jurisdiction.	87%
SZ direct throttling rate	The level of throttling applied to the Direct Spread pathway inside SZs. Values (0..100) are defined per jurisdiction.	98%
SZ indirect throttling rate	The level of throttling applied to the Indirect Spread pathway inside SZs. Values (0..100) are defined per jurisdiction.	50%
SZ assembly centre throttling rate	The level of throttling applied to the Assembly Centre Spread pathway inside SZs. Values (0..100) are defined per jurisdiction.	100%
SZ jump throttling rate	The level of throttling applied to the Jump Spread pathway inside SZs. Values (0..100) are defined per jurisdiction.	55%
FZ direct throttling rate	The level of throttling applied to the Direct Spread pathway in the FZ. Values (0..100) are defined per jurisdiction.	50%
FZ indirect throttling rate	The level of throttling applied to the Indirect Spread pathway in the FZ. Values (0..100) are defined per jurisdiction.	25%
FZ assembly centre throttling rate	The level of throttling applied to the Assembly Centre Spread pathway in the FZ. Values (0..100) are defined per jurisdiction.	100%
FZ jump throttling rate	The level of throttling applied to the Jump Spread pathway in the FZ. Values (0..100) are defined per jurisdiction.	28%
Lifting delay	The number of days that an RH (resolved holding) remains enclosed by a controlled area after IH Operations have completed.	21 days

3.2.4.3. Suspect holdings reporting

In the modelling of the control phase, reporting of suspect premises commences the day after the detection of the first infected holding. Reports could be both true positive or false positive where true positive reports are calculated stochastically based on clinical prevalence in a herd, probability of reporting, and expected time to report. The number of false positive reports is decided with a ratio of false to true reports and are assigned to random herds that are not infected. *Table 17* and *Table 18* show the dataset and parameters on suspect premises reporting entered in EuFMDiS (European commission for the control of foot-and-mouth disease, 2018a).

Table 17 - EuFMDiS Dataset: Suspect premises reporting

Suspect premises (SP) reporting The likelihood of an owner noticing and reporting possible disease cases during an outbreak when a control program is underway. This could depend on clinical signs, how closely owners observe their animals, and the attitudes to reporting, and is therefore estimated by herd type.	
Column	**Description**
Country code	Two letter country code
Herd type	Number between 0 and 9 representing the agreed herd categories
Owner reporting (%)	Estimated proportion (%) of owners in this herd category that are likely to see and report suspect cases of FMD in their herd

Table 18 - EuFMDiS Parameters: Suspect premises reporting

Suspect premises reporting		
Parameter	Description	Example value
Enabled	Determines whether SH reporting is enabled or disabled.	true
Ratio of false SHs to true SHs	Determines the number of false SHs generated (as a ratio of the number of true SHs). For example, if set to 3, there will be 3 false SHs generated for every true SH.	2.34 (McLaws et. al., 2007)
False SH moving average	The window in days over which a moving average of true SHs is calculated. This defines the number of true SHs for the purposes of generating false SHs.	3
False SH/PZ ratio	The proportion of false SHs allocated inside PZs.	0,6
False SH/SZ ratio	The proportion of false SHs allocated inside SZs.	0,3
False SH/FZ ratio	The proportion of false SHs allocated in the FZ.	0,1

3.2.4.4. Surveillance visits

During the simulated outbreak, surveillance visits are modelled to detect new outbreaks or declare a holding as free from infection. Visits are carried out to holdings that require surveillance (identified through tracing, suspect reporting, and active inspections in protection zones), namely suspected holdings (SH), contact holdings (CH), trace holdings (TH), and holdings in protection zones (PZH). The holdings can be in SZs, PZs, or FZs. The process is typically limited by available personnel resources. Input parameters in EuFMDiS for the surveillance visits are shown in *Table 19* (European commission for the control of foot-and-mouth disease, 2018a).

Table 19 - EuFMDiS Parameters: Surveillance visits

Surveillance visits

Parameter	Description	Example value
Enabled	Determines whether surveillance is enabled or disabled.	true
Visit priority (first level)	First level priority (1..7) assigned to a scheduled surveillance visit based on holding classification and declared area. For example, a CH in the FZ can be assigned a higher surveillance visit priority than a CH in an PZ.	CH/FZ: 1 CH/SZ: 1 TH/FZ: 2 TH/SZ: 2 SH/FZ: 3 SH/SZ: 3 CH/PZ: 4 TH/PZ: 5 SH/PZ: 6 PZH/PZ: 7
Visit priority (second level)	Second level priority (1..7) assigned to a scheduled surveillance visit based on herd type.	
Visit frequency	The number of days after a surveillance visit has completed that a follow-up visit is scheduled if needed.	3
Visit duration	Duration in days that a surveillance visit takes to complete. Defined per herd type.	
Period under surveillance	The duration in days over which surveillance visits are scheduled for a particular holding of interest. Defined per holding classification and declared area. Note that when SHs, traced back CHs and traced back THs are assessed negative they revert to UH/SZH/PZHs depending on the enclosing declared area. Traced forward CHs/THs that are assessed negative retain their CH/TH status for the duration of the surveillance period.	CH/FZ: 7 CH/SZ: 7 TH/FZ: 14 TH/SZ: 14 SH/FZ: 7 SH/SZ: 7 CH/PZ: 7 TH/PZ: 14 SH/PZ: 7 PZH/PZ: 14
Local PZH radius	Radius of the local PZH area enclosing each infected herd. PZHs inside this area are subject to surveillance.	3 km
Minimum clinical prevalence	The minimum clinical prevalence that a herd must be exhibiting in order to be assessed positive as a result of a surveillance visit. A holding can be assessed positive if either (a) the minimum clinical prevalence is met, or (b) a configurable number of days has passed since the holding was first infected. This covers the case where a holding may have transitioned through to a naturally immune state prior to its first surveillance visit.	0,05
Maximum days undetected	The maximum number of days that a holding can have been infected before a surveillance visit automatically yields a positive result.	10 days
Lab results required	Determines whether laboratory test results are required before a holding can be declared an IH.	Yes
Lab results delay	The time needed for laboratory test results to become available after a surveillance visit has concluded.	1 day
Overdue threshold	The maximum duration that an CH/SH/TH can be waiting for a scheduled surveillance visit before the visit priority is automatically increased. PZHs that have been waiting for a visit for longer than their configured surveillance period are flushed from the pending visit queue.	2 days

3.2.4.5. Tracing (direct/indirect)

Tracing is the process of following up movements of animals (and products) that have moved to an infected holding (backward tracing) or from an infected holding (forward tracing). The tracing is done in a specified time window and the traced holdings can be true or false cases (infected or not infected). *Table 20* shows the parameters to enter, many of which are entered per animal species (European commission for the control of foot-and-mouth disease, 2018a).

Table 20 - EuFMDiS Parameters: Tracing

Tracing		
Parameter	**Description**	**Example value**
Direct tracing enabled	Determines whether tracing of direct contacts is enabled or disabled.	true
Indirect tracing enabled	Determines whether tracing of indirect contacts is enabled or disabled.	true

False tracing enabled	Determines whether false traces are generated.	true
Backwards tracing window	The duration in days over which backwards tracing is conducted on an infected holding of interest.	14 days
Forwards tracing window	The duration in days over which forwards tracing is conducted on an infected holding of interest.	14 days
Direct trace minimum duration	Minimum number of days required to complete a direct contact trace (parameter for a beta-PERT distribution)	Cattle: 0 days Sheep: 1 day Pigs: 1 day Other: 1 day
Direct trace most likely duration	Most likely number of days required to complete a direct contact trace (parameter for a beta-PERT distribution)	Cattle: 1 day Sheep: 2 days Pigs: 2 days Other: 2 days
Direct trace maximum duration	Maximum number of days required to complete a direct contact trace (parameter for a beta-PERT distribution)	Cattle: 1 day Sheep: 3 days Pigs: 3 days
Indirect trace minimum duration	Minimum number of days required to complete an indirect contact trace (parameter for a beta-PERT distribution)	Cattle: 1 day Sheep: 1 day Pigs: 1 day Other: 2 days
Indirect trace most likely duration	Most likely number of days required to complete an indirect contact trace (parameter for a beta-PERT distribution)	Cattle: 2 days Sheep: 3 days Pigs: 3 days Other: 3 days
Indirect trace maximum duration	Maximum number of days required to complete an indirect contact trace (parameter for a beta-PERT distribution)	Cattle: 2 days Sheep: 5 days Pigs: 3 days Other: 5 days
Direct trace effectiveness	Dampening rate on the number of successful direct contact traces. This represents shortcomings in the underlying tracing systems and direct movement data.	Cattle: 0.98 Sheep: 0.85 Pigs: 0.95 Other: 0.90
Indirect trace effectiveness	Dampening rate on the number of successful indirect contact traces. This represents shortcomings in the underlying tracing systems and indirect movement data.	Cattle: 0.8 Sheep: 0.7 Pigs: 0.8 Other: 0.7

3.2.4.6. IH operations

The operations at an IH include culling, disposal (stamping out) and decontamination. Stamping out is implemented on infected holdings and potentially on CHs and suspect holdings SHs. Input parameters and configuration options are shown in *Table 21* (European commission for the control of foot-and-mouth disease, 2018a).

Table 21 - EuFMDiS Parameters: Infected holding operations

IH operations		
Parameter	**Description**	**Example value**
Enabled	Determines whether IH Operations is enabled or disabled.	true
Cull IHs	Determines whether IHs are automatically culled. Values are defined per jurisdiction.	yes
Cull CHs	Determines whether CHs are automatically culled. Values are defined per jurisdiction.	no
Ring culling	Determines whether all holdings within a configurable distance of each IH are automatically culled. Values are defined per jurisdiction.	no
Ring culling trigger day	The control day upon which ring culling will commence. A value of 0 indicates that ring culling can be triggered on any control day. Values are defined per jurisdiction.	14
Ring culling trigger IHs	The cumulative number of IHs that triggers ring culling. A value of 0 indicates that ring culling can be triggered by any number of cumulative IHs. Values are defined per jurisdiction.	25

Ring culling radius	Radius employed for ring culling purposes (per above). Values are defined per jurisdiction.	3 km
Cull SHs	Determines whether all SHs within a configurable distance of each IH are automatically culled. Values are defined per jurisdiction.	no
SH culling radius	Radius employed for SH culling purposes (per above). Values are defined per jurisdiction.	10 km
Culling duration	The duration in days to cull a particular herd type.	2 days
Disposal duration	The duration in days to dispose a particular herd type.	4 days
Disinfection duration	The duration in days to disinfect a particular herd type.	2 days

3.2.4.7. Vaccination (suppressive or protective ring vaccination)

Vaccination is one option to support stamping out during an outbreak in EuFMDiS. There are different triggers to start the vaccination, which can be configured. The user can choose if the vaccination is carried out inside known infected areas (PZs), outside PZs, or mass vaccination across broader areas. The vaccination process is limited to the available vaccine doses and team resources. Vaccination can be prioritized by herd type, herd size, time in queue, and/or distance to infected holding. Parameters configurable for vaccination are shown in *Table 22* (European commission for the control of foot-and-mouth disease, 2018a).

Table 22 - EuFMDiS Parameters: Vaccination

Vaccination		
Parameter	**Description**	**Example value**
Enabled	Determines whether Vaccination is enabled or disabled.	true
Policy	Policy for handling vaccinates: options are (a) waste (b) salvage (c) retain	waste
Control day trigger	Determines whether the vaccination program commences on a fixed day of control program. Note that vaccination triggers can be 'anded' together.	true
Control day	The day of the control program at which vaccination commences (per above).	7
IH count trigger	Determines whether the vaccination program commences once a certain number of IHs have been declared. Note that vaccination triggers can be 'anded' together.	false
IH count	The cumulative number of IHs at which vaccination commences (per above).	3
Pending culls trigger	Determines whether the vaccination program commences once there are a certain number of holdings pending culling. Note that vaccination triggers can be 'anded' together.	false
Pending culls	The number of pending culls required to trigger vaccination	0
Area of infection trigger	Determines whether the vaccination program commences once a specific area of infection (defined by the convex hull of IHs) has been reached. Note that vaccination triggers can be 'anded' together.	false
Area of infection	The area of infection required to trigger vaccination	0
Detection density trigger	Determines whether the vaccination program commences once a specific detection density (defined by the cattle density surrounding the index case holding) has been reached. Note that vaccination triggers can be 'anded' together.	false
Detection density	The detection density required to trigger vaccination	0
Immunity lag	The duration from when a herd is vaccinated to when it achieves immunity. A herd's immunity is unchanged from the day of vaccination until half the lag period has expired, after which it increases in a linear manner. For example, if the immunity lag is set to 6 days then the immunity is unchanged from days 1 to 3 and then increases linearly between days 4 to 6.	6 days
Vaccination priority (per herd type)	Priorities of vaccination visits (per herd type). Options are 0 (do not vaccinate), 1 (highest priority), through to 10 (lowest piority). Values are defined per jurisdiction. Note that these fields are used to enable/disable vaccination per-jurisdiction, for example, to configure NSW as stamping out only, set all the priority fields (for the NSW row) to 0. Conversely to configure VIC as stamping out plus vaccination, set the priority fields (for the VIC row) to values > 0 (as required).	

Inner radius	Inner radius (in km), of the vaccination annulus defined around an IH.	0 km
Outer radius	Outer radius (in km), of the vaccination annulus defined around an IH.	3 km
Outside-in	The direction in which vaccination visits are conducted inside the vaccination annulus. Options are yes (outside-in) or no (inside-out).	yes
New IHs only	Determines the vaccination retrospectivity. Options are yes (new IHs only) or no (all IHs).	no
Retrospectivity window	Limits the number of IHs that trigger vaccination according to how many days in the past that the IH was declared. Only applies when vaccination retrospectivity is set to 'all IHs'.	7 days
User defined criteria	Determines whether the decision to vaccinate a particular herd is dependent on the user-defined vaccination zone criteria.	true
Vaccination zone	User-defined vaccination zone criteria (defined per herd). A value > 0 triggers vaccination. A value of 0 means 'do not vaccinate'.	0
Visit duration	The duration in days of a vaccination visit. Defined per herd type.	1 day
Vaccine bank doses	The number of doses that the vaccination bank holds (defined per jurisdiction).	
Shared vaccine bank enabled	Determines whether each jurisdiction has its own distinct vaccine bank or whether there is a single EU wide shared vaccine bank.	false
Vaccine effectiveness	Proportion of animals in a vaccinated herd that achieve immunity. This models the efficacy of the vaccine in use and also natural variability as to whether a particular animal develops immunity.	Cattle: 0.85 Sheep: 0.80 Pigs: 0.87 Other: 0.84
Vaccine dose	The amount of vaccine (in 'dose' units), that an animal of a particular species requires.	Cattle: 1 Sheep: 0.5 Pigs: 1 Other: 0.5

3.2.4.8. Team Resources

The required and available personnel for the activities, i.e., surveillance, culling, disposal, decontamination, and vaccination, is modelled in EuFMDiS. It is assumed that the initial number of resources, from a certain day of the control program, will increase linearly during the control program to a defined maximum number. A dataset of the numbers of personnel resources available per jurisdiction and activity is used in the model, see *Table 23* (European commission for the control of foot-and-mouth disease, 2018a).

Table 23 - EuFMDiS Dataset: Team resources

Team resources The number of available teams is estimated and entered for each of the activities: surveillance, culling, disposal, decontamination, and vaccination.	
Column	**Description**
Activity	The type of activity (Surveillance visits, culling, disposal, disinfection/decontamination, vaccination)
Initial	The initial number of teams available to do this activity at the start of the outbreak
Maximum	The maximum number of teams you expect to be able to have available
Ramp start	Number of days into the control program until the number of teams starts to increase
Ramp end	Number of days into the control program until the maximum number of teams is available

3.2.4.9. Post-outbreak management

When the outbreak is considered contained, activities are undertaken in order to regain a disease-free status. In EuFMDiS, the post-outbreak management is conducted in different clusters around resolved holdings (holdings that have been culled or have acquired immunity). The first cluster is the PZ and around the PZ is the SZ, both with user defined radius. Surveillance during the post-outbreak period is done in all vaccinated holdings (VHs), protection zone holdings (PZHs) and surveillance zone holdings

(SZHs). This surveillance is conducted through serological testing. Configurable parameters for post-outbreak management are shown in *Table 24* (European commission for the control of foot-and-mouth disease, 2018a).

Table 24 - EuFMDiS Parameters: Post-outbreak management

Post-outbreak management		
Parameter	**Description**	**Example value**
Enabled	Determines whether post-outbreak management is enabled or disabled.	false
Trigger day	Number of days from the declaration of the last IH (or VH, whichever is later) to the commencement of post-outbreak surveillance.	30
Radius	Radius (in km) used to construct the post-outbreak surveillance clusters. A cluster is formed from the set of RHs that are within two radius' of at least one other RH in the cluster, and comprise all properties that were at one stage during the outbreak a VH, PZH or SZH, and lie within one radius of any RH in the cluster.	10
Non vaccination screening test ID	The ID of the lab test to use for screening tests of non-vaccinated herds. The ID indexes into a row in the Labtest DB table.	2
Non vaccination confirmatory test ID	The ID of the lab test to use for confirmatory tests of non-vaccinated herds. The ID indexes into a row in the Labtest DB table.	3
Vaccination screening test ID	The ID of the lab test to use for screening tests of vaccinated herds. The ID indexes into a row in the Labtest DB table.	3
Vaccination confirmatory test ID	The ID of the lab test to use for confirmatory tests of vaccinated herds. The ID indexes into a row in the Labtest DB table.	3
Post-outbreak management policy	Policy for handling vaccinates post outbreak. Options are: retain – vaccinates are retained and subject to post-outbreak NSP tests remove – vaccinates are removed and not subject to post-outbreak NSP tests.	remove
Visit duration	Duration in days that a surveillance visit takes to complete. Defined per herd type. Note that the durations for regular surveillance visits are re-used for post-outbreak surveillance visits.	
Visit priority	Surveillance visits are carried out in one cluster at a time. VHs have priority over PZHs and PZHs have priority over SZHs. A second level priority (1..7) is assigned to a scheduled surveillance visit based on herd type.	
Test ID	Identifies a particular test (e.g. 2 corresponds to C ELISA)	
Test name	The name of the test (e.g. C-ELISA)	
Species ID	Each test has sensitivity/specificity parameters defined per species.	
Sensitivity (vaccination)	Sensitivity of the test when vaccination has been used	
Specificity (vaccination)	Specificity of the test when vaccination has been used	
Sensitivity (non vaccination)	Sensitivity of the test when vaccination has not been used	
Specificity (non vaccination)	Specificity of the test when vaccination has not been used	
Cost	Cost (in $EUR) of the test	
Throughput	Not currently used.	
Sero positive lag	Number of days after infection that a herd becomes sero positive.	
Sero positive duration	Duration in days that a herd remains sero positive.	
Post-outbreak lab results delay	The time needed (in days) for laboratory test results to become available after a surveillance visit has concluded.	
Herd VH confidence level	The confidence level at which to test a cluster of VH herds. A value of 0 means test no herds in the cluster. A value of 100 means test all herds in the cluster. A value of 95, for example, means test sufficient herds such that we are 95% confident that the desired target prevalence (e.g., 5%) would be detected.	
Herd VH target prevalence	The target prevalence at which to test a cluster of VH herds (per above).	

Herd PZH confidence level	The confidence level at which to test a cluster of PZH herds. A value of 0 means test no herds in the cluster. A value of 100 means test all herds in the cluster. A value of 95, for example, means test sufficient herds such that we are 95% confident that the desired target prevalence (e.g., 5%) would be detected.	
Herd PZH target prevalence	The target prevalence at which to test a cluster of PZH herds (per above).	
Herd SZH confidence level	The confidence level at which to test a cluster of SZH herds. A value of 0 means test no herds in the cluster. A value of 100 means test all herds in the cluster. A value of 95, for example, means test sufficient herds such that we are 95% confident that the desired target prevalence (e.g., 5%) would be detected.	
Herd SZH target prevalence	The target prevalence at which to test a cluster of SZH herds (per above).	
Animal VH confidence level	The confidence level at which to sample animals in a VH herd. A value of 0 means sample no animals in the herd. A value of 100 means sample all animals in the herd. A value of 95, for example, means sample sufficient animals such that we are 95% confident that the desired target prevalence (e.g., 2%) would be detected.	
Animal VH target prevalence	The target prevalence at which to sample a VH herd (per above).	
Animal PZH confidence level	The confidence level at which to sample animals in an PZH herd. A value of 0 means sample no animals in the herd. A value of 100 means sample all animals in the herd. A value of 95, for example, means sample sufficient animals such that we are 95% confident that the desired target prevalence (e.g., 2%) would be detected.	
Animal PZH target prevalence	The target prevalence at which to sample an PZH herd (per above).	
Animal SZH confidence level	The confidence level at which to sample animals in a SZH herd. A value of 0 means sample no animals in the herd. A value of 100 means sample all animals in the herd. A value of 95, for example, means sample sufficient animals such that we are 95% confident that the desired target prevalence (e.g., 2%) would be detected.	
Animal SZH target prevalence	The target prevalence at which to sample a SZH herd (per above).	
Removal rate	The daily rate at which vaccinates can be removed from the population.	

3.2.5. Scenario configuration

Table 25 shows the parameters for configuring the scenario setup to run EuFMDiS.

Table 25 – EuFMDiS Parameters: Scenario configuration

Scenario configuration		
Parameter	**Description**	**Example value**
Database name	Identifies the project database to be used.	EUFMDIS_PILOT
Map grid boundaries	Defines the lines of longitude and latitude that enclose the country under study.	
Borders	Defines the borders shape file for the country under study.	central_european_borders
Regions	Defines the regions shape file for the country under study.	central_european_regions
Scenario name	Defines the name of the scenario. All model output files are prepended with the scenario name.	baseline
Scenario end mode	Determines the trigger that ends a scenario: Options are: 1) fixed - scenario ends on a fixed day. 2) control-based - scenario ends when no E/I holdings and no pending control actions. 3) detection - scenario ends after the detection of the first IH.	earliest
Scenario max length	Maximum length of a scenario in days	365
Number of runs	Defines how many times a scenario is re-run.	10

Seed mode	Defines how the primary cases are generated. Options are: 1) Manual – the seed herd(s) are explicitly defined in the scenario config file. 2) Random – the seed herd(s) are randomly generated according to criteria specified in the scenario config file. 3) Snapshot – the seed herds are read in from a pre-defined snapshot file. A snapshot file is created when the user invokes the 'save' function via the Run Panel. 4) Batch – the seed herd IDs are read in sequentially (one per run), from a text file.	false
Number of manual seeds	Defines the number of manually defined seed herds. Only applies when the scenario seed mode is manual.	1
Seed herd ID(s)	Defines the ID of the primary case herd. Only applies when the scenario seed mode is manual.	109047
Seed herd initial SEIR ratios	Defines the initial SEIR compartment ratios for the seed herd. If the SEIR ratios are defined as zeros then the number of latent and/or infectious animals (defined below) are used for the seed herd. Only applies when the scenario seed mode is manual.	S=0.0 E=0.0 I=0.0 R=0.0
Number of latent animals in the seed herd	Only applies when the scenario seed mode is manual and the initial SEIR ratios are set to zero.	4
Number of infectious animals in the seed herd	Only applies when the scenario seed mode is manual and the initial SEIR ratios are set to zero.	0
Number of random seeds	Defines the number of randomly defined seed herds. Only applies when the scenario seed mode is random.	1
Random seed herd type	Specifies the herd type of the randomly selected seed herd. Legal values are 0 (don't care), 1..10). Only applies when the scenario seed mode is random.	7
Random seed herd region	Specifies the region of the randomly selected seed herd. Legal values are 0 (don't care), 1..25). Only applies when the scenario seed mode is random.	0
Random seed herd state	Specifies the jurisdiction of the randomly selected seed herd. Legal values are 0 (don't care), 1..7). Only applies when the scenario seed mode is random.	2
Random seed herd minimum size	Specifies the minimum size of the randomly selected seed herd. Only applies when the scenario seed mode is random.	100
Random seed herd maximum size	Specifies the maximum size of the randomly selected seed herd. Only applies when the scenario seed mode is random.	500
Random seed herd initial SEIR ratios	Defines the initial SEIR compartment ratios for the random seed herd. If the SEIR ratios are defined as zeros then the number of latent and/or infectious animals (defined below) are used for the seed herd. Only applies when the scenario seed mode is random.	S=0.0 E=0.0 I=0.0 R=0.0
Number of latent animals in the random seed herd	Only applies when the scenario seed mode is random and the initial SEIR ratios are set to zero.	4
Number of infectious animals in the random seed herd	Only applies when the scenario seed mode is random and the initial SEIR ratios are set to zero.	0
Re-use random seed(s) between runs	When set to true the same randomly selected seed(s) are used for each scenario run. When set to false, new randomly selected seed herds are selected for each scenario run.	false
Batch seed file	The name of the file containing the seed herd IDs. Only applies when the scenario seed mode is batch.	
Batch seed min latent	If the number of animals in the batch seed herd is less than or equal to the 'min latent herd size' (defined below), then the number of latent animals is set to 'min latent'. If the number of animals in the batch seed herd is greater than the 'min latent herd size' (defined below), then the number of latent animals is randomly set to a value between 'min latent' and 'max latent. Only applies when the scenario seed mode is batch.	1
Batch seed min latent herd size	The herd size criteria used when determining the number of latent animals in the batch seed herd (see above). Only applies when the scenario seed mode is batch.	50
Batch seed max latent	The maximum number of latent animals in a seed herd (only applies when the scenario seed mode is batch).	4

3.2.6. Outbreak costs

In order to model the costs of an outbreak, data are entered in three tables (*Table 26*, *Table 27* and *Table 28*). Some complementary parameters, such as the costs of culling vaccinated animals for different purposes or costs due to loss of trade, are also needed (European commission for the control of foot-and-mouth disease, 2018a).

Table 26 - EuFMDiS Dataset: Animal level costs

Animal level costs Costs should be entered in euros. In this table costs are entered for a typical animal per animal type (cattle: dairy of beef, buffalo, small ruminant and pig)	
Column	**Description**
Country	Two-letter country code
Animal	Type of animal
Cull	Average cost of culling an animal of this type
Disposal	Average cost of disposing of an animal of this type
Vaccination	Average cost of vaccinating an animal of this type
Compensation	Average value of an animal of this type for compensation purposes

Table 27 - EuFMDiS Dataset: Herd level costs

Herd level costs Costs should be entered in euros, for an average herd for the different herd types.	
Column	**Description**
Country	Two-letter country code
herd_type	Number representing the agreed herd categories
Surveillance visit cost per herd	Cost of doing a surveillance visit on a typical (average) herd of this type
Decontamination/disinfection cost per herd	Cost of cleaning/decontamination/disinfection of a typical (average) herd of this type

Table 28 - EuFMDiS Dataset: Other costs

Other costs Costs should be entered in euros per day.	
Column	**Description**
Country	Two-letter country code
Cost of running a national disease control centre	Management/infrastructure cost of operating national disease control centre (average cost per day)
Cost of running a local disease control centre	Management/infrastructure cost of operating local disease control centre (average cost per day)

3.2.7. Model report configuration

In the model report configuration, the user can choose which output reports to generate from the simulation. The available reports include but are not limited to model configuration, summary of control measure metrics, costs, how farms and herds are affected by the outbreak by different measures, and a summary of spread pathway metrics (European commission for the control of foot-and-mouth disease, 2018a).

3.3. Conceptual data mapping between SIGMA AND EuFMDiS

This section covers the overlap between existing data in the S-DWH and input data in the EuFMDiS model. The population dataset in SIGMA and the livestock population dataset in EuFMDiS are quite similar and *Section 3.3.1* shows a suggestion of how to map them. The laboratory data in SIGMA do not directly match the data in EuFMDiS and the majority of input parameters and datasets in EuFMDiS do not have a match in SIGMA. However, the laboratory data in SIGMA could potentially be used in the post-outbreak management component of EuFMDiS as some parameters are similar (*Section 3.3.3*) or to calculate some of the other disease-specific parameters used in EuFMDiS (which will not be covered in this assessment). Some other possible data overlaps or usage of SIGMA data in EuFMDiS are stated here.

Note that SIGMA currently only contains data on ASF while EuFMDiS, including some default parameter values, is adapted to FMD. However, EuFMDiS could be used for other diseases and, as previously mentioned, development of an adaption to ASF is underway. The suggested mappings in this section are thus conceptual between similar datasets, columns, or parameters.

3.3.1. Livestock populations data mapping

3.3.1.1. Populations

The first and most obvious data mapping is the population dataset in SIGMA and the herd dataset in EuFMDiS. The dataset in SIGMA includes information about establishments which can consist of various "subUnits". In EuFMDiS, data are entered per herd and herds with the same coordinates are considered to belong to the same holding. Each "subUnitId" in SIGMA could be mapped to a herd ID in EuFMDiS. Even if the IDs are not necessarily the same between SIGMA and EuFMDiS, this could be through a unique identifier for each herd (subunit). The parameter "estabArea" in SIGMA consists of the NUTS code level 3 of the establishment, containing the country code in which the subunit is located. The coordinates of subunit (SIGMA) and herd (EuFMDiS) are both given in decimal degrees and could be mapped. The variable "subUnitActualNumber" in SIGMA corresponds to herd size in EuFMDiS. The values of the SIGMA variables: "estabType", "subUnitSpecies", "subUnitPurpType" and "subUnitActualNumber" could be used to define or determine the herd types in EuFMDiS. See more in *Section 3.3.1.2 Herd types*. *Figure 1* shows the suggested mapping between the variables in SIGMA population data set and EuFMDiS herd dataset, with certain colours for the corresponding variables.

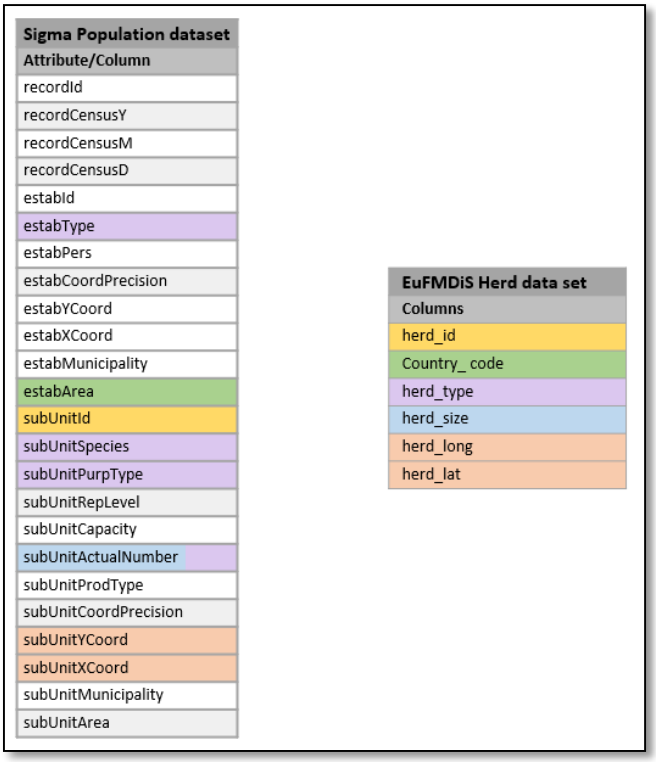

Figure 1 - Conceptual mapping of population datasets

3.3.1.2. Herd types

As mentioned in *Section 3.2.1*, different herd types (about 10 to 12) should be defined in EuFMDiS. In the pilot project of EuFMDiS nine categories were defined. This section shows a suggestion of which values of the SIGMA variables "estabType", "subUnitSpecies", "subUnitPurpType" and "subUnitActualNumber" correspond to each of the nine predefined herd categories from the pilot. If other herd categories are used in EuFMDiS, the mapping could be done differently, e.g., if another disease were to be modelled.

Table 29, *Table 30* and *Table 31* list the possible values for the SIGMA variables ("estabType", "subUnitSpecies" and "subUnitPurpType") that can be mapped to the different herd types.

Table 29 - SIGMA parameter estabType: Possible values

estabType	Description
Quarantine premises	Establishment where the animals are kept in isolation with no direct or indirect contact with animals outside this epidemiological unit, for the purpose of ensuring that there is no spread of one or more specified diseases while the animals in isolation are undergoing observation for a specified length of time and, if appropriate, testing and treatment. [based on Regulation (EU) 2016/429 (AHL), art. 4(38)]
Assembly centre	Establishment, approved by the competent authority, where kept terrestrial animals are assembled from more than one establishment for a period shorter than the required residency period for the species of animals concerned, for NATIONAL and INTERNATIONAL movements
Market	Establishment, registered by the competent authority, where kept terrestrial animals are assembled from more than one establishment for a period shorter than the required residency period for the species of animals concerned, for NATIONAL movements
Exhibition	Permanent establishments where animals of domestic or wild species are kept for exhibition to the public for 7 or more consecutive days a year (e.g. zoos, petting centres), with the exception of circuses and pet shops.
Show	Temporary events where animals of domestic or wild species are brought together for exhibition to the public for less than 7 consecutive days a year

Farm	Establishment where the animals are kept by humans, since birth OR for a rearing / production period OR for the required residency period for the species of animals concerned, for commercial purposes i.e. to breed and/or rear and/or sell animals and/or products of animal origin. Hatcheries are excluded
Genetic centre	Establishment where the animals (bovines, equines, swine, sheep, goats) are kept by humans, for the collection of germinal products.
Hatchery	An establishment which incubates and hatches eggs and supplies day-old chicks (art 2, Council Directive 2009/158/EC of 30 November 2009 on animal health conditions governing intra-Community trade in, and imports from third countries of, poultry and hatching eggs)
Slaughterhouse	Slaughterhouse establishment used for slaughtering and dressing animals, the meat of which is intended for human consumption (Regulation (EC) No 853/2004). Slaughtering of hunting game is included. Stalls, pens, covered areas or fields associated with or part of slaughterhouse operations are included.
Health & Research centres	Any permanent, geographically limited and approved establishment where one or more species of animal are habitually: (i) kept for fundamental or applied scientific research; or (ii) bred for the purposes of such research (iii) kept to undergo veterinary medicine practices. E.g. research laboratories, veterinary hospitals, etc.
Pasture / Co-Pasture	2000/115 refers to land used for (common) grazing which is under the control of a local authority

Table 30 - SIGMA parameter subUnitSpecies: Possible values

subUnitSpecies		
Cattle (as animal)	Sheep (as animal)	Phasianidae (as animal)
Water buffalo (as animal)	Goat (as animal)	Perdix (as animal)
Pig (as animal)	Deer (as animal)	Grey Partridge (as animal)
Wild boar (as animal)	European moose (as animal)	Japanese Quail (as animal)
Boar–pig hybrid (as animal)	Red Deer (as animal)	Common Quail (as animal)
Horse (as animal)	Fallow deer (as animal)	Northern Bobwhite Quail (as animal)
Asses (as animal)	Reindeer (as animal)	Ptarmigan (as animal)
Mules (as animal)	Roe deer (as animal)	Partridge (as animal)
Rabbit (as animal)	Ruminants (generic) (as animal)	Pheasant (as animal)
Hare (as animal)	Gallus gallus (chicken) (as animal)	Pigeon (as animal)
Camel (as animal)	Grouse (as animal)	Pigeon breeding flock (as animals)
Dromedary (as animal)	Guinea-fowl (as animal)	Duck (as animal)
Llama (as animal)	Turkey (as animal)	Goose (as animal)
Alpaca (as animal)	Quail (as animal)	Generic poultry (as animal)
Vicugna (as animal)		

Table 31 - SIGMA parameter subUnitPurpType: Possible values

subUnitPurpType	Description
Germinal products	'germinal products' means: (i) semen, oocytes and embryos intended for artificial reproduction; (ii) hatching eggs [Regulation (EU) 2016/429 (AHL), art. 4(27)]
Breeders	'Breeders' are animals of high genetic value kept for reproduction purposes. E.g. grandparents and parent flocks (poultry); pedigree dams and sires; etc.
Meat/Fattening	Rearing or keeping in captivity animals for the primary purpose of producing meat
Milk	Rearing or keeping in captivity animals for the primary purpose of producing raw milk, i.e. milk produced by the secretion of the mammary gland of farmed animals that has not been heated to more than 40ºC or undergone any treatment that has an equivalent effect.
Egg	Rearing or keeping in captivity animals for the primary purpose of producing eggs, where 'Eggs' means unfertilised eggs in shell — e.g. broken, fresh table or cooked eggs — that are produced by farmed birds and are fit for direct human consumption or for the preparation of egg products AND technical purposes (cosmetics)
SPF	For research establishments and purposes (vaccines, …) Eggs, Pigs, Chickens, Rabbits, …

Foie-gras	Rearing or keeping in captivity animals for the production of foie gras, where foie-gras means the livers of geese, or of ducks of the species Cairina muschata or Cairina muschata x Anas platyrhynchos which have been fed in such a way as to produce hepatic fatty cellular hypertrophy
Game	Animals kept in captivity for restocking supplies of game animals
Own Consumption	The sub-unit has no commercial activity
Wool	Outer coat of sheep, yaks, etc, which consists of curly hairs
Fur	Dressed skin of certain fur-bearing animals, with the hair left on
Hide	Raw skin of a large animal, as a cow or horse, obtained by the removal of the hair. Usually further processed to produce leather.
Skin	Tissue forming the outer covering of a vertebrate with its outer layer possibly covered by hair, scales, feathers, etc… which stays unseparated by the inner layer.
Feathers	Flat light waterproof epidermal structures forming the plumage of birds, each consisting of a hollow shaft having a vane of barbs on either side.
Mixed purposes	Rearing one or more animal species for multiple production purposes (e.g. meat and milk)

In *Table 32*, each pre-defined herd type in EuFMDiS is mapped to certain values of some variables in the SIGMA population dataset. As the herd types in EuFMDiS are also defined by size, a limit value (X) of the size of the herd (subUnitActualNumber) can be chosen to differentiate between large and small herd types.

Table 32 - Suggested mapping between SIGMA variable values and pre-defined herd types in EuFMDiS.

EuFMDiS	**SIGMA**			
Herd type	estabType	subUnitSpecies	subUnitPurpType	subUnitActualNumber
Large commercial dairy herd	Farm	Cattle	Milk	Size > X
Large commercial beef herd	Farm	Cattle	Meat/Fattening	Size > X
Small commercial cattle herd	Farm	Cattle	Breeders Milk Meat/Fattening	Size < X
Commercial buffalo (water buffalo)	Farm	Water buffalo	Milk Meat/Fattening	
Commercial small ruminants	Farm	Sheep Goat	Breeders Meat/Fattening Milk Wool	
Large-scale commercial fattening pig herd	Farm	Pig Wild boar Boar-pig hybrid	Meat/Fattening	Size > X
Large scale commercial breeding pig herd	Farm	Pig Wild boar Boar-pig hybrid	Breeders	Size > X
Small-scale commercial pig	Farm	Pig Wild boar Boar-pig hybrid	Breeders Meat/Fattening Mixed purposes	Size < X
Backyard herd	Farm	Cattle Water buffalo Sheep Goat Pig Wild boar Boar-pig hybrid	Own Consumption	

3.3.1.3. Other geographical information of livestock

The subunits and establishments in SIGMA have information about the NUTS level 3 region in which it is located (variables "estabArea" and "subUnitArea"), which could be of use in EuFMDiS. However, EuFMDiS requires digital maps of the livestock production regions (suggested NUTS level 2 regions) which cannot be obtained from SIGMA.

In EuFMDiS, locations of animal markets and assembly centres could be important, and this information is available in SIGMA alongside coordinates for establishments where the value of the variable "estabType" is "market" or "assembly centre".

3.3.2. Spread pathways data mapping

The direct and indirect contact spread modelling in EuFMDiS mainly requires data on animal movements, which do not exist in SIGMA. However, one parameter in EuFMDiS is the **number of indirect contacts with other herds**, per herd per year (by herd type and region, see *Table 10*). This parameter could partly be calculated from the SIGMA population dataset which contains information about the herd type, region, and the variable "estabPers" (not mandatory), which is the **number of people interacting with the animals or the environment at the establishment**, see *Table 1*. However, the number of indirect contacts in EuFMDiS also includes contacts with products, vehicles, etc. in addition to interactions with people, while the SIGMA parameter "estabPers" mainly concerns personnel at the establishment. More data on indirect contacts, e.g., contacts per season, is also required in EuFMDiS.

EuFMDiS models the probability of airborne spread from infected to susceptible pig herds based on information about the herds, weather data, and other parameters. The SIGMA population dataset contains the variable "subUnitProdType" which carries information about whether the subunit animals are indoors (without any contact with the external environment) or outdoors (with contact with the external environment). This knowledge could be used in the airborne spread modelling in EuFMDiS as herds with indoor production might not be affected by airborne spread. However, the variable in SIGMA is optional and EuFMDiS might not have the functionality to exclude specific herds from the airborne spread.

As stated, SIGMA does not contain animal movement data, therefore the probabilities of end points from assembly centres used in EuFMDiS to model spread via assembly centres could not be derived from SIGMA. However, the SIGMA population dataset contains coordinates for assembly centres and markets that could be used in the EuFMDiS livestock population (see *Section 3.3.1.3*).

3.3.3. Control measures data mapping

The control measures in EuFMDiS are used to evaluate the impact of different measures on a disease outbreak. These parameters do not generally exist in SIGMA. The post outbreak management part of EuFMDiS requires data on laboratory tests and the sensitivity and specificity for different test types per species (see *Table 24*). The default values are provided by the National Animal Health laboratory of Australia, thus EuFMDiS users should fill in this data table as the values might vary between countries and laboratories. Similar information about laboratory tests is required in the SIGMA laboratory dataset (*Table 2*), although some variables are optional. This information might be difficult for countries to obtain, but if countries are able to include this information in SIGMA, the values may also be used in EuFMDiS. Either per country or if possible, data from various countries in SIGMA could be used to calculate default European values for EuFMDiS. *Figure 2* shows some parameters from the laboratory dataset in SIGMA and parameters in the post-outbreak management section in EuFMDiS, and a possible mapping by colour.

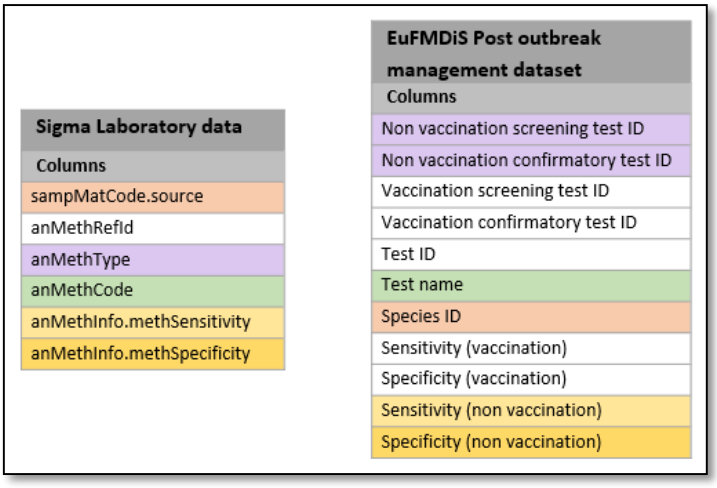

Figure 2 - Conceptual mapping between laboratory data in SIGMA and post outbreak management data in EuFMDiS

Table 33 and *Table 34* show the parameters in Figure 2 with descriptions and some example values.

Table 33 – Some of the SIGMA laboratory parameters

Parameter	Description	Example values
sampMatCode.source	Animal species	
anMethRefId	Identifier for the method used in the laboratory. Note: if not existing, it can be a dummy identifier.	
anMethType	Type of analytical method used	Screening / Confirmation
anMethCode	Encoding of the method or instrument used from the ANLYMD catalogue.	ELISA (Enzyme-linked immunosorbent assay)
anMethInfo.methSensitivity*	The diagnostic sensitivity of the laboratory test used.	
anMethInfo.methSpecificity*	The diagnostic specificity of the laboratory test used.	

* optional

Table 34 – Some of the EuFMDiS Post-Outbreak management parameters

Parameter	Description
Non vaccination screening test ID	The ID of the lab test to use for screening tests of non-vaccinated herds. The ID indexes into a row in the Labtest DB table.
Non vaccination confirmatory test ID	The ID of the lab test to use for confirmatory tests of non-vaccinated herds. The ID indexes into a row in the Labtest DB table.
Vaccination screening test ID	The ID of the lab test to use for screening tests of vaccinated herds. The ID indexes into a row in the Labtest DB table.
Vaccination confirmatory test ID	The ID of the lab test to use for confirmatory tests of vaccinated herds. The ID indexes into a row in the Labtest DB table.
Test ID	Identifies a particular test (e.g. 2 corresponds to C ELISA)
Test name	The name of the test (e.g. C-ELISA)
Species ID	Each test has sensitivity/specificity parameters defined per species.
Sensitivity (vaccination)	Sensitivity of the test when vaccination has been used

Specificity (vaccination)	Specificity of the test when vaccination has been used
Sensitivity (non vaccination)	Sensitivity of the test when vaccination has not been used
Specificity (non vaccination)	Specificity of the test when vaccination has not been used

3.4. IT architecture integrating SIGMA and EuFMDiS

EuFMDiS is a software compatible with Windows and Linux. It requires installation of complementary softwares (Java and PostgreSQL) and the user needs to create a database (with help from the manual) in which to store the data used in the model. The manual for EuFMDiS explains how input data can be added through the database, text files, or the user interface. According to one of the developers of EuFMDiS, the model could also be made available through the web, which is done in Australia with the AADIS-model, the corresponding model to EuFMDiS in Australia, where it runs in the cloud on a virtual machine.

The S-DWH stores the data collected from the MSs through the SIGMA project. Once the MSs have submitted data to the S-DWH they will be able to access their own data using web applications (EFSA, et al., 2019). The data in the S-DWH may be accessed through an API or by querying data directly from the databases, depending on desired IT-architecture for integrating SIGMA and EuFMDiS.

To use the data from SIGMA as a part of the input to EuFMDiS some formatting is required by the MS, by EFSA or by the developers of EuFMDiS. The above sections show suggestions of possible mapping between some data in SIGMA and EuFMDiS but often the mapping does not translate directly, with the exception of some parameters in the SIGMA population data and the herd data in EuFMDiS (see *Section 3.3.1*).

Integrating SIGMA data to EuFMDiS will therefore require either a reorganization of some SIGMA data, adjustment of the input format in EuFMDiS or data processing. If data in SIGMA are used in the calculations of parameters in EuFMDiS, it could be done separately by the user or through an automatic flow. When the data from SIGMA are processed in the desired way, the output should be integrated in EuFMDiS, for example manually or via an API. The technical solution for integrating SIGMA data into EuFMDiS could be done in various ways, and six possible options are sketched conceptually in *Figure 3*. Option 1 implies that the data processing is done within the SIGMA IT solution and that the outcome, adapted for EuFMDiS, could be retrieved via an API, querying a database or via a manual process. Option 2 is similar, but the processing of the SIGMA data is in this option done within the EuFMDiS software. The third option suggests an external solution for data processing but would still need some work done in SIGMA and EuFMDiS. In the forth option, EuFMDiS is integrated within the SIGMA IT architecture and not as a separate software. Option 5 and 6 infer more manual work from the user. Depending on the IT solution it might be preferred that EuFMDiS is run in the cloud instead of locally.

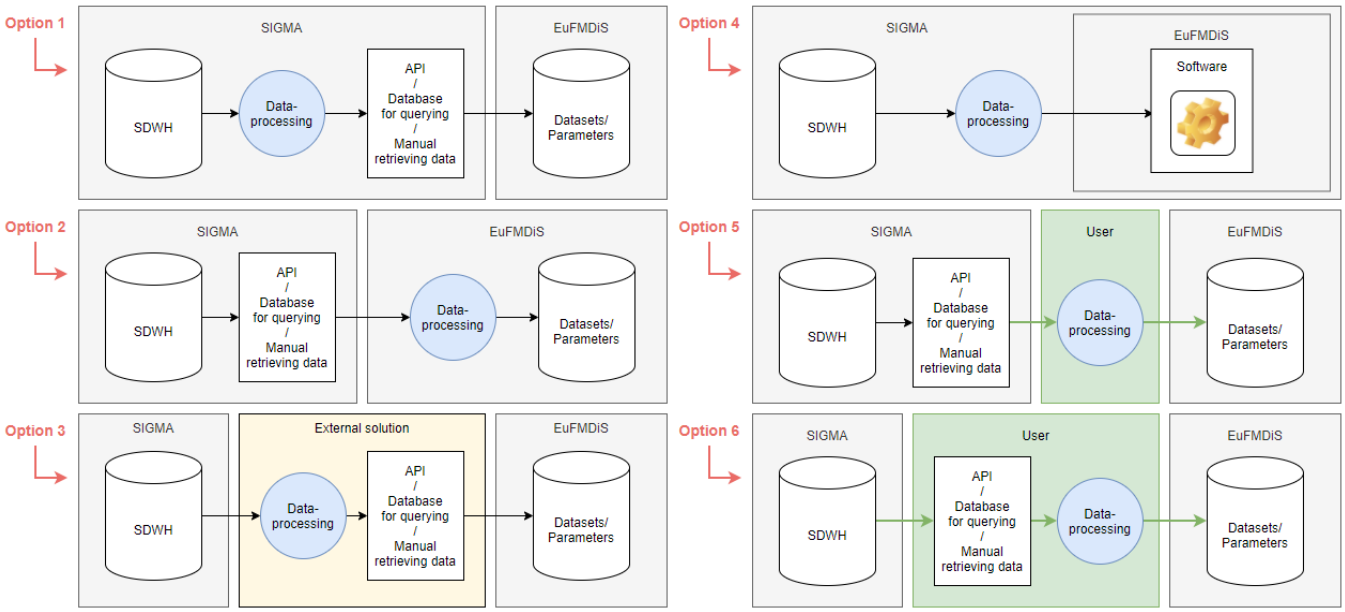

Figure 3 - Conceptual sketches of different suggested options of technical solutions integrating SIGMA data and EuFMDiS

3.5. User cases and data security

EuFMDiS is designed to support planning and decision making for emergency outbreaks in Europe (Bradhurst, et al., 2021). EFSA is an agency funded by the EU with the purpose of providing a source of scientific advice and communicating risks associated with the food chain (European Food Safety Authority, 2021). EFSA is routinely asked for scientific support in epidemiological analysis of animal disease outbreaks by the European Commission (EFSA, et al., 2019). Using the EuFMDiS might be of interest for various user groups or customers in Europe, including EFSA, as it could improve the preparedness and planning for disease outbreaks and lower the negative consequences.

The scope of using EuFMDiS may vary between the users. For example, one country may want to evaluate different country-specific control measures in a disease outbreak within the country or the risk of disease introduction from another country, depending on common control strategies or differing control strategies between countries. EFSA may use EuFMDiS for disease spread modelling and making predictions of a disease spreading in various countries in Europe or evaluating different control measures.

The customers may not be the same as the users. The users of the EuFMDiS must have knowledge of epidemiology and statistics as well as experience in animal disease control, regardless of if it is integrated with SIGMA or not, to use the model adequately and produce realistic outputs. Values of all the possible input parameters must be chosen carefully (de Vos, Gonzales, Hagenaars, & Dekker).

Depending on the IT solution, the user might access EuFMDiS through the cloud as a web application, with data retrieved from SIGMA via web solutions, or by downloading data from SIGMA and using it in EuFMDiS run locally on the user's computer. If the users are a group across multiple countries, they could access data from each other via web solutions, or by sending data and using the model locally. The possibilities are many and will depend on the IT architecture and require consideration of legal aspects and data security.

Table 35 shows some potential user cases if SIGMA and EuFMDiS are integrated. Depending on the user case, different agreements on data security are needed as the data in SIGMA and EuFMDiS contain

sensitive information on holdings, laboratory test results, and more. If a European country wants to use EuFMDiS with only data from their own country, the main security required is that the country data is only visible for that country, which is already true in SIGMA. If EuFMDiS is run in a cloud solution integrated with SIGMA data, the model initialisation and data should only be visible to authorized countries for the specific study, which could be solved with password-protected accounts. If a country wants to use EuFMDiS with data from other countries, agreements between countries will be needed concerning data in SIGMA and in EuFMDiS, regardless of if it is run locally or in the cloud, and password-protected accounts could be a solution to access the data. Some variables or datasets may also need to be anonymized or obfuscated, if possible, in order to share data between countries, which is made possible both in SIGMA (EFSA, et al., 2019) and in the pilot project of EuFMDiS (Bradhurst, et al., 2021)

According to one of the consulted experts, collaboration and agreements between certain countries that use EuFMDiS for a common model could be relatively easy, and a pilot study between various countries has already been conducted. If EFSA were to use EuFMDiS, the legal aspects would be more complicated and require the involvement the European Commission. If results from running EuFMDiS are to be published that may also require agreements from participating countries.

Table 35 - Potential user cases of SIGMA and EuFMDiS

Customer/user	Level
European country	Country level
	Country level, plus data from neighbour countries
European countries	European level / parts of Europe
EFSA	European level / parts of Europe

All IT solutions need data protection to ensure that data is only accessible to legitimate users. This needs to be investigated further if it is decided that SIGMA data is to be integrated with EuFMDiS.

4. Discussion

The SIGMA project aims to reduce manual work from the member states and improve the ability of EFSA to perform analysis on animal disease outbreaks in Europe. EuFMDiS is a model to simulate disease spread and evaluate risks, costs, control measures and different outbreak scenarios. EuFMDiS requires many input parameters and datasets, which could be difficult for the users to get hold of or structure, and some underlying data may not exist which requires advanced estimations. As the MSs submit data to EFSA and the SIGMA project will facilitate storage and usage of standardized data, this could also facilitate the use of EuFMDiS, either if the user is one or many European countries.

The data mapping result section show some suggestions of which data from SIGMA (existing in phase 1 of the project) might be used as input data in EuFMDiS. However, some suggested mappings or calculations of parameters may not be relevant. Moreover, the overlap of data only covers a small part of the input data used in EuFMDiS. Some parameters and parts of EuFMDiS are optional but disabling many spread pathways and control measures means that the full potential of the model is not used, and in that case, there are surely other models or tools better suited. Animal movement data is also an important part of EuFMDiS, which does not exist in SIGMA.

To use data from SIGMA in EuFMDiS (as suggested in the conceptual mapping) would imply that some data processing or calculations need to be done. Either this could be done manually by the user (suggested as options 5 and 6 in *section 3.4*), but this would mean increased workload from the member states. This might not be desired as the SIGMA project aims to reduce manual work from the member states. Another way is to build an automated or semi-automated flow, to process or calculate data from SIGMA to EuFMDiS, as suggested in options 1-4 in *section 3.4*. Even these options could imply manual work from the member states, which should be avoided. Building an automated or semi-automated data flow between SIGMA and EuFMDiS or integrating the software solutions would probably be technically possible, but would also require investigations and solutions of data security and legal aspects.

As mentioned in the results, collaborations between countries using EuFMDiS may not require advanced legal agreements, but if EFSA would use EuFMDiS it could be much more complicated and involve the European commission. The user case where various countries use data from SIGMA and run EuFMDiS in collaboration, the integration could be useful for sharing data between countries, but EuFMDiS would still need more data input. The user case where only one country uses EuFMDiS for internal purposes would mean that the full potential of the model is not used and in that case the integration may not give enough benefit.

One important question to consider is what the purpose or goal of the integration of SIGMA data and EuFMDiS would be. There might be many purposes, such as increasing the ability of EFSA to perform disease outbreak analyses, providing an epidemiological tool to MSs submitting data to SIGMA or encourage more European countries to use EuFMDiS. Another significant purpose would be to increase preparedness for European disease outbreaks. It should then be considered if the integration would fulfil the goals and purposes, or if similar benefit could be achieved by using SIGMA and EuFMDiS separately.

Collaboration between EFSA and EuFMD could be beneficial for both parts, even if the SIGMA data and EuFMDiS are not integrated with a technical solution. Some parameters in EuFMDiS need expert consultation, which might be done by help from EFSA. If SIGMA would collect more data later on, that may also imply greater benefit of the integration. However, providing the MSs with access to an epidemiological tool integrated in the SIGMA IT solution is not limited to EuFMDiS. Other tools have been investigated (Cocca & Lindberg, 2019) and another tool could fit that purpose. Cocca and Lindberg (2019) list various epidemiological tools suited for integration into the S-DWH, many of which are open source.

Henceforth continued discussions between EFSA and EuFMD could be useful to answer some of the raised questions from this assessment and to discuss how to move forward.

5. Conclusions

A technical integration between data collected in the SIGMA project and EuFMDiS could be feasible from a technical perspective but would also require more investigation of legal aspects. The majority of the input data needed for EuFMDiS does not exist in SIGMA and an important question to consider is the purpose of the integration and if the same purposes and benefits could be achieved without a technical integration. It would also be important not to increase the required manual work from the MSs. Further collaboration between EFSA and EuFMDiS could be beneficial for both parts even if a technical integration is not done, as data from SIGMA or EFSA could ease the use of EuFMDiS and EuFMDiS could support EFSA to perform disease outbreak analyses which would also be beneficial for the MSs.

Abbreviations

AADIS - Australian animal disease spread model

ABM - agent-based model

ASF – African swine fever

CH – contact holdings

EBM - equation-based model

EFSA - European food safety authority

EU – European union

EuFMD - European commission for the control of foot-and-mouth disease

EuFMDiS - European Foot-and-Mouth Disease Spread model

FLI - Friedrich Loeffler Institut

FMD - foot-and-mouth disease

FZ – free zones

IH- infected holding

MS - member states

NIJ - non-infected jurisdictions

NUTS - Eurostat's nomenclature of territorial units for statistics

PZ – protection zones

PZH - protection zone holdings

RH – resolved holding

S-DWH – EFSA scientific data warehouse

SEIRDC - susceptible, exposed, infectious, recovered, deceased, clinical

SH – suspected holdings

SZ – surveillance zones

SZH - surveillance zone holdings

TH – trace holdings

VH – vaccinated holding

WP – work package

σ-ADM - SIGMA animal disease data model

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