A Meta-ontology Framework for Parameter Concepts of Disease Spread Simulation Models

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Abstract: This work reports on an ontological organization (framework) that separates domain knowledge from knowledge of specific views and formalizes conceptual relationships by linking to the meta-ontology structure. We use parameters of animal disease spread simulation models as an example, although all concepts presented could apply to human disease spread simulation as well. A meta-ontology is created to document parameter concepts in different comparable simulation models. It formalizes relationships between parameter concepts. This offers several advantages such as allowing explicit domain knowledge representation and provenance, allowing for the assessment of parameters with respect to domain knowledge, and assisting in usage and evaluation of the models. The meta-ontology allows views about parameter concepts to be captured. This is important because it establishes a neutral view point which allows the assessment of parameter semantics in respect to documented domain knowledge. While this work uses the domain of animal disease spread, the principles of ontological representation of model parameters is applicable to a wide range of domains.

1 INTRODUCTION

Today, we live in an era of global markets. Products and livestock are shipped from one part of the globe to another. While globalization might have benefits to the world economy, the world is facing greater risks of transmission of infectious (including zoonotic) diseases than ever before. It is imperative and important that a country is well prepared to deal with these risks. Simulation models for the spread of diseases are popular tools to study the spread of diseases and to evaluate the effectiveness of control strategies. Over the last decades, several simulation models for animal disease spread have been developed and achieved several objectives such as to mimic the outbreak of animal diseases, to study the aspects of animal disease transmission, to develop support decision systems, to support preparedness planning, and to assess economic impacts, etc. These agent-based simulation models are characterized by large numbers of parameters. Because of the large numbers of parameters, it is challenging to make these models work together and to share the knowledge of a model (as expressed in its parameters) to others or to compare them. This often contributes to high costs and is time consuming. One of the reasons for this problem is that the semantics of these parameters are often overlooked by the models. The semantics of these parameters are determined by the reality that the modeller wish to emulate. This has a great implication because emulation of the same reality can be different based on the views of the modellers, *e.g.* views with different semantics, views with different granularity, and views in different contexts, etc. It is often done implicitly. Because of this implicit representation of the parameters, there are several disadvantages of the current models. This paper explores the use of a meta-ontology framework to represent explicitly the semantics of agent based simulation model parameters to address some shortcomings of the current models such as knowledge representation, knowledge sharing, and assessment of domain knowledge (as expressed in the parameters) allowing a means to share information across simulation models and to assist usage and comparison of these models.

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2 RESEARCH CONTEXT

Parameter-based simulation models are characterized by large numbers of parameters and processes that model the behaviours of phenomena. In this context, we examine parameters of the animal disease spread models for Foot and Mouth Disease (FMD) such as the North American Animal Disease Spread (NAADSM) and InterSpread Plus models. The disease spread simulation models' parameters are used to describe animal units, farm locations, movement of animal units, spread mechanisms and courses of infection. Without disease control mechanisms, a disease spread in an animal population is a result of combination of the farm network, the movement of herds, herd infectiousness (the course of an infection), and disease spread mechanisms. Regardless of how well a model is built, it always is an approximate version of reality. There always exist uncertainties associated with simulation models. There are two types of uncertainty associated with simulation models:

- Model structural uncertainty: "the imperfect representation of processes within a model" (MA et al., 2013)(Kennedy and Hagan, 2001)(Arendt et al., 2012).
- Model parameter uncertainty: "the imperfect knowledge of the values of parameters" (biological parameters, model parameters, and model artifacts) associated with modelling processes (Kennedy and Hagan, 2001)(MA et al., 2013)(Arendt et al., 2012).

For users, the ease of use and interpretation of parameters are key requirements for simulation model builders. In order to evaluate simulation models, we first must agree on parameters and their semantics before an evaluation can take place. They should reflect the intended meaning with respect to the simulation models and the related domain knowledge. It is challenging because there exist many implicit facts that relate to simulation models. It is a result of the modellers' views on how they wish simulation models to be perceived. The progression of the simulation models through time (life cycle) also contributes to the changing of parameters (and especially the changing of their semantics) that makes them harder to use, to maintain and to evaluate.

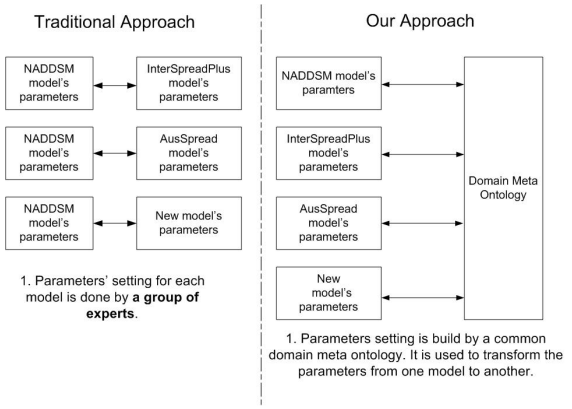


Figure 1: Traditional disease spread parameters setting and ontology approach for comparing models.

3 OUR APPROACH

3.1 Design Scope and Restrictions

The scope of our ontology is to capture core concepts of simulation models' parameters and related domain knowledge. Our study uses:

- Concepts related to the parameters of the NAADSM, InterSpread Plus models and the related FMD domain knowledge for an FMD course of infection, i.e., we use animal disease spread domain as our example. Restrictions within this domain include:
  - For the duration of a state in the FMD infection, the distribution is assumed to be a normal distribution and a Poisson distribution is used as an example
  - A single production type (type of animal) is used for both models
  - Parameters for farm/herd information in NAADSM and InterSpread Plus models are used
  - The farm network is not included in this study
  - Spread mechanism is not included in this study

3.2 Overview of Our System

An overview of our system is depicted in Figure 2. There are two (2) basis components in our approach:

- Knowledge Representation
  - A domain meta-ontology is used to capture core concepts of parameters related to the FMD course of infection as reflected in the FMD domain literature and simulation models. It provides vocabularies to describe parameter concepts of simulation models and related FMD

domain knowledge for an FMD course of infection.

  - Conceptual descriptions of model parameters. They are descriptions of simulation model parameter settings and the related FMD domain knowledge.

- Semantic Engine
  - A semantic engine is used to examine and to assess the parameter concepts and perform parameter transformation from one model to another.

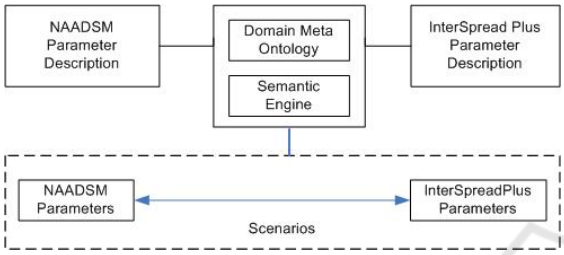


Figure 2: Our system overview.

3.3 Knowledge Representation

3.3.1 Ontology Architecture

A two-layered architecture for our ontology is proposed. It is shown in Figure 3. There are two layers associated with our ontology. In the first layer, the domain meta-ontology has concepts shared by the simulation models and the related FMD domain knowledge. It provides shared vocabularies to describe parameter concepts and the related FMD domain knowledge. The second layer describes the conceptual descriptions of models' parameter settings for the FMD simulation models and related FMD domain knowledge. The shared vocabularies permit parameter descriptions of new models since new model concepts are generally taken from the domain knowledge. Thus, it provides a scalable way to describe the conceptual descriptions of simulation models' parameters.

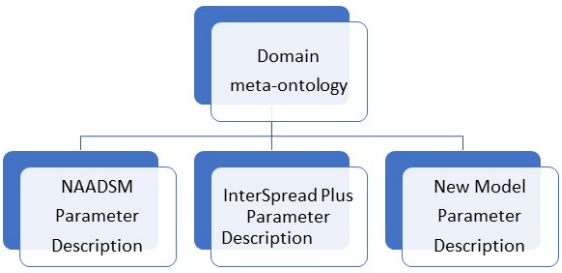


Figure 3: Ontology architecture.

3.4 Knowledge Acquisition

We adopted the method from Uschold and Gruninger (Fox and Gruninger., 1995) by capturing the domain in natural language. Other automatic and semi-automatic knowledge extraction techniques may be used, however, most of these methods are fairly primitive and do not work well on a large and complex domain. We acquired domain knowledge by examining a number of literature works as follows:

- Foot and mouth disease papers (G., 2001)(Mardones et al., 2010)(C. et al., 2016)(Sanson, 1993)(S. et al., 2003)(P. et al., 2006)(R. et al., 2009)(K. et al., 2007)(JM. et al., 2012)(M. et al., 2009)(van Roermund H. et al., 2010)
- NAADSM papers (Harvey et al., 2007) and related papers (Harvey and Reeves, 2012)
- InterSpread Plus papers (MA et al., 2013) and related papers (team, 2018)

We used the above literature to acquire knowledge and case study scenarios to aid in building our ontology.

3.5 Ontology Specification

Our ontology specification provides the core vocabularies or concepts to describe the parameter conceptual model of animal disease spread simulation models such as NAADSM and InterSpread Plus models, and related FMD domain knowledge for an FMD course of infection. There are two components of this specification. The first component is the domain meta-ontology component. It provides the core concepts to describe the parameter conceptual models. The second component is the conceptual descriptions of FMD simulation models' parameters. These are the descriptions of the parameter models for NAADSM, Interspread Plus, and knowledge domain. Among these models, they share the same fundamental parameter concepts related to an FMD course of infection. However, with respect to each concept, the parameters of each model might be set differently. This reflects the complexity and the differences in semantics in choosing the parameter settings for the models. In this section, we construct a series of questions that the domain meta-ontology must be able to answers. These serve as a basis of our specification. It is important to note that our competency questions are to check whether the domain meta-ontology answers to these questions at the terminological level.

3.5.1 Domain Meta-ontology

Our domain meta-ontology is only about the conceptual description of an FMD course of infection (*i.e.* we do not consider the containment or control of the spread). The following questions and answers are to address core concepts that are captured in our ontology (only a small selection are presented here).

Who are the Users of Ontology?

- The users of the ontology are FMD experts and FMD simulation modellers.

What Does the Ontology need to Describe?

- The ontology is to describe parameters and their semantics related to an FMD course of infection for NAADSM and InterSpread Plus simulation models and related FMD domain knowledge.

What is a State?

- A state is a basic unit of a state transition models. It indicates a disease state of an animal unit. A state has following properties:
  - State name
  - State order
  - State duration

What is a State Duration?

- A state duration is the amount of time (usually, days) that an animal unit is in a state.
- It can be specified by the users, *e.g.* modelled as a probability density function.

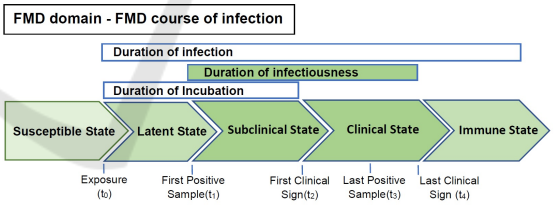
A Course of FMD Infection might have following States:

- Infected State
  - Latent State
  - Subclinical Infectious State
  - Clinical Infectious State
  - Clinical Non-infectious State
  - Immune State or Naturally Immune State
  - Incubation State
  - Infectious State
- Noninfected State
  - Susceptible State

In the domain meta-ontology, we built the core concepts that are needed to describe the semantics of parameter settings of simulation models and the related FMD domain knowledge. Our emphasis is on the states' concepts and other concepts related to an FMD course of infection. We create and use the ontology structure of the states to find and to reason about the incubation state, infected states, non-infected states, infectious states, and non-infectious states related to the simulation models' parameter settings. It can be further developed to work with the states of many other diseases.

3.5.2 Conceptual Descriptions of Simulation Models' Parameter Settings

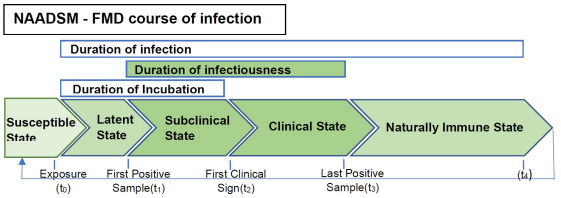
In this section, we discuss the usage of the domain meta-ontology for the description of FMD simulation models' parameters settings and highlight differences between the simulation model concepts. First, we examined some examples of FMD courses of infection. We show the states of an FMD course infection and their definitions which aims to clarify the semantics of the states of simulation models. Second, from the examples, we construct a list of competency questions that the ontology needs to answer. Normally, an animal or an animal unit that associated with an FMD course of infection goes through a number of states as the disease progresses. In essence, we want to describe these concepts as reflected by a model's parameter settings. To show how domain meta-ontology can be used to describe the FMD course of infection, we examine the following cases: the description of an FMD course of infection for FMD domain, NAADSM model, and InterSpread Plus model. The concepts of parameter settings are depicted in Figure 4, 5, and 6.



State Name	State order	State duration	State description
Susceptible state	0		A state when herds are susceptible to infection
Latent State	1	t_0 to t_1	A state when herds are infected but are not infectious
Subclinical state	2	t_1 to t_2	A state when herds are infectious
Clinical state	3	t_2 to t_4	A state when herds are infectious and non-infectious
Immune state	4	from t_4	A state when herds are infected and do not have clinical sign but not infectious

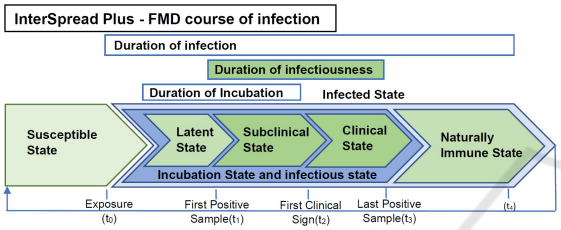
Figure 4: An example of FMD domain course of infection. It is taken and modified from (C. et al., 2016).

In Figure 4, 5, and 6, we provide the state concepts, and their descriptions related to the models' parameter settings. We note that there are differences in the description of the states and state names as shown in the figures. For example, in NAADSM model, clinical state means clinical infectious state whereas in FMD domain, clinical state might have different meaning. The figures show that there are dif-



State Name	State order	State duration	State description
Susceptible state	0		A state when herds are susceptible to infection
Latent State	1	t_0 to t_1	A state when herds are infected but are not infectious
Subclinical state	2	t_1 to t_2	A state when herds are infectious
Clinical state	3	t_2 to t_3	A state when herds are infectious and have clinical sign
Naturally immune state	4	t_3 to t_4	A state when herds are infected and do not have clinical sign but not infectious

Figure 5: An example of NAADSM model's FMD course of infection. It is modified from (Harvey et al., 2007).



State Name	State duration	Description
Susceptible state		A state when herds are susceptible to infection
Incubation state	t_0 to t_2	A state when herds are infected and infectious
Infectious state	t_1 to t_3	A state when herds are infectious
Naturally Immune state	t_3 to t_4	A state when herds are infected and do not have clinical sign and non-infectious

Figure 6: An example of InterSpread Plus FMD course of infection.

ferent states if we compare the FMD course of infection between the NAADSM model, the InterSpread Plus model and the FMD domain knowledge. In the NAADSM model, states are modelled in different granularity as compared to the InterSpread Plus model. Given the conceptual models of the parameter presented by the figures, we want to use our domain meta-ontology to describe the parameters setting. We want to answer the following questions:

- What are states that associated with an FMD simulation model parameter settings?
- What are concepts related to an FMD model parameter setting?
- What is a duration of a state?
- What types of infectious states are associated with an FMD simulation model?
- Which models have an incubation state?
- Which models have a clinical non-infectious state?

In section 3.6, we formally provide a discussion on FMD state relations and descriptions of an FMD course of infection.

3.6 Formal Knowledge Representation

In this section, we present the core part of the formal knowledge representation of our ontology. A complete ontology can be accessed via the link provided in (Nguyen, 2020). There are two parts of the ontology: the terminological components, and the assertion components. We present only core terminological components. The assertion component can be accessed via the previous link. We use Manchester OWL syntax and Protégé (Musen, 2015) for our formal knowledge representation.

3.6.1 Terminological Components

They are used to describe an FMD course of infection in the FMD domain, and NAADSM and InterSpread Plus models. In this section, we discuss core components of our ontology. The generic components are vocabularies that can be used to construct an FMD course of infection. State concepts are key components of our ontology. The domain meta-ontology state relations are depicted in Figure 7. In this figure, it shows the relationship between the primitive classes and defined classes.

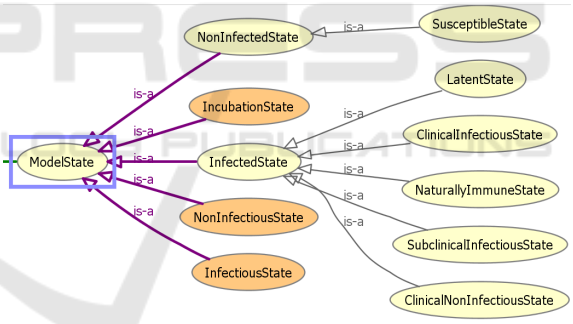


Figure 7: Domain meta-ontology state relation.

In Figure 7, *primitive classes* are depicted in light yellow ovals. The defined classes or *named classes* are depicted in orange ovals. We can use the named classes for reasoning purpose. We can use primitive classes to define more named classes to fit the ontology requirements.

A Description of an FMD Course of Infection.

The description of an FMD course of infection is generally defined in the ProductionType subclass. It occurs here since a course of infection is specific to the animal in which it occurs, *i.e.* the production type since these models are restricted to agricultural animal species. It uses concepts in the Generic class component to describe the concepts related to an

FMD course of infection. We will examine the FMDContextSingleProductionType, NAADSMSingleProductionType, and InterSpreadPlusSingleProductionType classes.

1. FMD Course of Infection: This is the FMD domain course of infection. It is reflected in the definition of the FMDContextSingleProductionType class. In this class, a cover axiom is used to ensure only necessary concepts are used to describe FMDContext. The description of FMDContextSingleProductionType has an object property *hasModelState*. It is used to establish a relation between the production type and a state. In this class, each production type has several states with exactly 1 LatentState, SubclinicalInfectiousState,ClinicalInfectiousState, ClinicalNonInfectiousState, and NaturallyImmuneState.

```
Class: PO:FMDContextSingleProductionType
SubClassOf:
   PO:ProductionType,
   PO:hasModelState only
   (PO:ClinicalInfectiousState
   or PO:ClinicalNonInfectiousState
   or PO:LatentState
   or PO:NaturallyImmuneState
   or PO:SubclinicalInfectiousState),
PO:hasModelState exactly
  1 PO:ClinicalInfectiousState,
PO:hasModelState exactly
  1 PO:ClinicalNonInfectiousState,
PO:hasModelState exactly
  1 PO:LatentState,
PO:hasModelState exactly
  1 PO:NaturallyImmuneState,
PO:hasModelState exactly
  1 PO:SubclinicalInfectiousState
```

2. An FMD course of infection in NAADSM model: It is defined in the NAADSMSingleProductionType class.

```
Class: PO:NAADSMSingleProductionType
SubClassOf:
PO:ProductionType,
PO:isProductionTypeOf some PO:UnitOfNAADSM,
PO:hasModelState only
(PO:ClinicalInfectiousState
 or PO:LatentState
 or PO:NaturallyImmuneState
 or PO:SubclinicalInfectiousState
 or PO:SusceptibleState),
PO:hasModelState exactly
  1 PO:ClinicalInfectiousState,
PO:hasModelState exactly
  1 PO:LatentState,
PO:hasModelState exactly
  1 PO:NaturallyImmuneState,
PO:hasModelState exactly
  1 PO:SubclinicalInfectiousState,
PO:hasModelState exactly
  1 PO:SusceptibleState
```

3. An FMD course of infection in InterSpread Plus model: It is defined in the InterSpreadPlusSingleProductionType class.

```
Class: PO:InterSpreadPlusSingleProduction-
Type
 SubClassOf:
  PO:ProductionType,
  PO:hasModelState only
 (PO:IncubationState
   or PO:InfectiousState
   or PO:NaturallyImmuneState
   or PO:SusceptibleState),
 PO:hasModelState exactly
   1 PO:IncubationState,
 PO:hasModelState exactly
   1 PO:InfectiousState,
 PO:hasModelState exactly
   1 PO:NaturallyImmuneState,
 PO:hasModelState exactly
   1 PO:SusceptibleState
```

Similar to the FMD course of infection for the FMD domain knowledge, descriptions of FMD courses of infection for NAADSM and InterSpread Plus are formally presented. They use the same vocabularies to describe the states related to the FMD course of infection. These models are different in the way that the FMD course of infection is defined as discussed previously. The concepts of these models are reflected via parameter settings aligned with the FMD domain knowledge. Thus, we can leverage the ontology structure to share and infer new knowledge associated with the models.

3.7 Domain Meta-ontology Queries

There are nine competency question (CQ) queries which are used to ask about classes associated with animal unit states, production type, animal unit and duration that are related to the states. They are presented in the section 3.7.1. In this table, we present the CQs and the corresponding queries for domain meta-ontology. The translations for the CQs are very straight forward. Most of the time, they are self-explanatory. In query 7, we filter other subclass based on the super class DiscreteProbabilityDistribution since we use Poisson distribution as an example for all duration of the states. We use the filter clause to remove owl:Nothing from the set of answers because owl:Nothing is a subclass of any class expression.

3.7.1 Domain Meta-ontology CQ's and Queries

1. What all states do an FMD course of infection have?

```
SELECT ?x  WHERE {
    ?x rdfs:subClassOf po:ModelState .
FILTER(?x !=owl:Nothing)}
```

2. What are subclasses of Incubation State?

```
SELECT ?x  WHERE {
   ?x rdfs:subClassOf po:IncubationState .
FILTER(?x !=owl:Nothing)}
```

3. What are subclasses of InfectiousState?

```
SELECT ?x  WHERE {
    ?x rdfs:subClassOf po:InfectiousState .
FILTER(?x !=owl:Nothing)}
```

4. What are subclasses of NonInfectiousState?

```
SELECT ?x  WHERE {
 ?x rdfs:subClassOf po:NonInfectiousState .
FILTER(?x !=owl:Nothing)}
```

5. What are substates of InfectedState?

```
SELECT ?x  WHERE {
    ?x rdfs:subClassOf po:InfectedState .
FILTER(?x !=owl:Nothing)}
```

6. What production types are captured in the ontology?

```
SELECT DISTINCT ?x  WHERE {
    ?x rdfs:subClassOf po:ProductionType .
FILTER(?x !=owl:Nothing)}
```

7. What durations are associated with a state?

```
SELECT DISTINCT ?t WHERE{
  ?x rdf:type po:ModelState .
  ?x po:hasMathematicalFunction ?y .
  ?y rdf:type ?t .
  ?t rdfs:subClassOf ?super .
  ?otherSub rdfs:subClassOf ?super .
  ?t rdfs:subClassOf ?otherSub .
FILTER (?otherSub != ?t)
FILTER (?super =
po:DiscreteProbabilityDistribution)}
```

8. What animal species concepts are captured?

```
SELECT DISTINCT ?x  WHERE {
    ?x rdfs:subClassOf po:AnimalSpecies .
FILTER(?x !=owl:Nothing)}
```

9. What animal units are captured?

```
SELECT DISTINCT ?x  WHERE {
    ?x rdfs:subClassOf po:Unit .
FILTER(?x !=owl:Nothing)}
```

3.8 Application of Meta-ontology Queries

The queries related to the application of the meta-ontology are to further test the meta-ontology, and its objectives. We would like to be able to answer the questions shown in section 3.8.1. We show queries related to the NAADSM model. Similar queries work with the InterSpread Plus model and the FMD domain knowledge conceptual model. We include the complete queries in the link previously provided.

3.8.1 NAADSM Application of Meta-ontology: Competency Questions and Queries

1. What are individual states of NAADSM model?

```
PO:NAADSMModel(?m) ^ PO:hasUnit(?m, ?u)
^ PO:hasProductionType(?u, ?pt)
^ PO:hasModelState(?pt, ?s)->
  sqwrl:select(?s)
```

2. What is incubation state of NAADSM model?

```
PO:NAADSMModel(?m)
^ ParameterOntology:hasUnit(?m, ?u)
^ PO:hasProductionType(?u, ?pt)
^ PO:hasModelState(?pt, ?s)
^ PO:IncubationState(?s)->sqwrl:select(?s)
```

3. What is incubation durations means and variance of a NAADSM model?

```
PO:NAADSMModel(?m1)
^ PO:hasUnit(?m1, ?u1)
^ PO:hasProductionType(?u1, ?pt1)
^ PO:hasModelState(?pt1, ?s1)
^ PO:IncubationState(?s1)
^ PO:hasMathematicalFunction(?s1, ?pd1)
^ PO:hasMeanValue(?pd1, ?mean1)
^ PO:hasVarianceValue(?pd1, ?variance1)
-> sqwrl:sum(?mean1)^sqwrl:sum(?variance1)
```

4. What are state concept differences between NAADSM and Interspread Plus models?

```
PO:NAADSMModel(?m1)
^ PO:hasUnit(?m1, ?u1)
^ PO:hasProductionType(?u1, ?pt1)
^ PO:hasModelState(?pt1, ?ms1)
^ abox:caa(?class1, ?ms1)
.  sqwrl:makeSet(?set1, ?class1)
.  sqwrl:size(?size1, ?set1)
^ PO:InterSpreadPlusModel(?m2)
^ PO:hasUnit(?m2, ?u2)
^ PO:hasProductionType(?u2, ?pt2)
^ PO:hasModelState(?pt2, ?ms2)
^ abox:caa(?class2, ?ms2)
^ sqwrl:makeSet(?set2, ?class2)
^ sqwrl:size(?size2, ?set2)
^ sqwrl:difference(?set3, ?set1, ?set2)
^ sqwrl:size(?size3, ?set3)
^ sqwrl:element(?e3, ?set3)
-> sqwrl:select(?class1, ?size1,
?class2, ?size2, ?size3, ?e3)
```

3.9 Semantic Engine

The semantic engine is responsible for performing the following two tasks:

- Parameter assessment
- Transformation of parameters from one model to another

The parameter assessment and transformation can be performed by leveraging the meta-ontology structure. Queries can be used to extract and evaluate concepts with evidence in domain knowledge and other models. These tasks can be machine driven. However, in the complex scenario, we can use an external framework to assist with these tasks. For example, we can use statistical framework to analyse the statistical distribution related to the duration of a state. We have constructed a small framework to illustrate these tasks but will concentrate here in showing how we use queries and rules to perform required tasks. Furthermore, to demonstrate these tasks, we restrict ourselves to state concepts of an FMD course of infection to show the parameter assessment and transformation tasks.

3.9.1 Parameters Assessment

To perform the parameter assessment, we need to perform the assessment of the state concepts of the simulation models with respect to the concepts of the FMD domain knowledge model. We use the following steps:

- Get state concepts that are aligned between parameters of the simulation models and the FMD domain knowledge.
- Get the instances of the state concepts. Compare the state instances or individuals of FMD domain knowledge to those of the simulation model.
- Do the same for other aligned concepts.

The parameter assessment allows us to know the difference in parameter settings between the parameters of the simulation models and the FMD domain knowledge. We examined two cases:

- Case 1: NAADSM parameter assessment
  - Assessment of latent state
  - Assessment of sub-clinical infectious state
  - Assessment of clinical infectious state
  - Assessment of naturally immune state
- Case 2: InterSpread Plus parameter assessment
  - Assessment of incubation state
  - Assessment of infectious state
  - Assessment of naturally immune state.

Given the knowledge base, we want to answer the queries that are related to the assessment of parameters concepts related to simulation models.

- Simulation model parameter assessment queries
  - Given the asserted state concepts individuals of a simulation model and FMD domain knowledge, can we find the aligned concepts of the two models?
  - Can we infer and assess the duration of the state concepts with respect to FMD domain knowledge given the asserted individuals of the two models?

3.9.2 Transformation of Parameters from One Model to Another

To show how the transformation works for an FMD course of infection, we need to discuss some concepts in FMD domain knowledge that are used to describe an FMD course of infection. An FMD course of infection description is based on primitive classes, defined classes and attributes. The primitive classes are used to construct the defined class. The defined classes, incubation, and infectious states, are defined as:

- Incubation state is a state from infection to onset infectiousness. It is a union of latent state and subclinical infectious state.
- Infectious state is a state of infectiousness. It is a union of sub-clinical infectious state and clinical infectious state.

Without a disease control mechanism, an FMD course of infection is related to the disease state concepts. Because the NAADSM and InterSpread Plus models are designed differently, the incubation, infectious, and infected states are set differently. In the NAADSM simulation model, there are explicit states such as latent state, subclinical infectious state, clinical infectious state and naturally immune state as compared to the InterSpread Plus model's states such as susceptible and infected states (incubation state, infectious state, immune state are explicit, and latent state, subclinical infectious state, clinical infectious state, and immune states may be implicit states). To show how the domain meta-ontology can be used in the parameter transformation of simulation models, we examine how a parameter setting can be expressed or transformed in terms of another model.

We examine the following case:

- Given a parameter set for the NAADSM model, can we generate a semantically equivalent parameter set for the InterSpread Plus model or vice versa?

In order to perform the transformation, we need to define the transformation criteria and transformation procedure.

Definition of Transformation Criteria.

Typically, a transformation criterion for parameters is a number of concepts that are reflected in the simulation models' parameters. These concepts must exist

in both source and destination simulation models for a transformation to take place. If there are missing concepts in the simulation models, the transformation is not possible or might be possible with high uncertainty due to the conceptual heterogeneity existing in the simulation models.

Transformation Procedure.

There are two transformation procedures: Concepts-based transformation procedure and missing concept procedure.

1. Concepts-based transformation procedure:
   - Get the concepts of source models.
   - From the concepts, we can generate required correspondent criteria concept parameters for the destination simulation model's parameters with respect to source concepts.
2. Concepts-based transformation procedure with missing concepts:
   - Perform the concepts-based transformation for aligned concepts of models as described above.
   - With missing concepts, we can estimate or infer missing concepts based on the concepts from the source model's parameters if it is possible to infer or estimate the destination settings. With random estimation, these parameter settings may have high uncertainty because of our lack of knowledge, and it must then be left for the users to decide if they wish to proceed with this level of uncertainty. We can use FMD course of infection domain knowledge that aligned with the source model to assist in the transformation.

We examine the following cases for parameter transformation:

Case 1: Parameter Transformation from NAADSM Model to InterSpread Plus Model. Let us set the criteria for the transformation as:

- Farm unit related concepts
- State concepts: Incubation state, infectious state, immune state.

The NAADSM model can infer the incubation state, infectious state, and naturally immune state from its basic states.

- Incubation state can be obtained from latent state and subclinical infectious state.
- Infectious state can be obtained from subclinical infectious state and clinical infectious state.
- Naturally immune state can be obtained from its state.

The incubation, infectiousness state, and naturally immune state exist in InterSpread Plus. Thus, we can transform from NAADSM to InterSpread Plus in this case.

Case 2: Parameter Transformation from InterSpread Plus to NAADSM. Using the same criterion as in the previous case, however, the state concepts are latent, subclinical infectious, clinical infectious, and naturally immune states. In the InterSpread Plus model we can set the incubation state and the infectiousness state of the FMD course of infection by specifying these states in the following forms:

- With infectiousness state, incubation state, immune state.
- With user defined latent state, infectious state, incubation state, immune state and implicit clinical infectious state and subclinical infectious state.

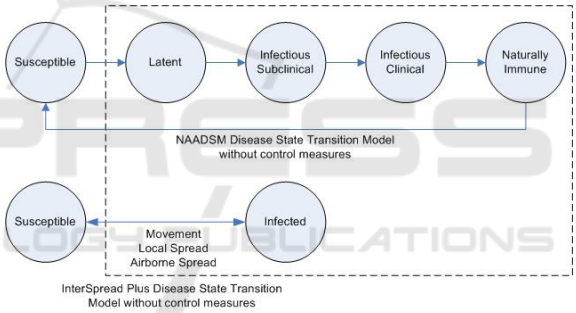


Figure 8: Disease state transition models for NAADSM and InterSpread Plus without control measures.

The challenge in transformation from InterSpread Plus to NAADSM is the missing concepts (latent, sub-clinical, and clinical states) that are required in the NAADSM model. This is depicted in Figure 8. We examine the following cases:

- Case 2a: With latent state, and incubation state, infectious state and naturally immune state it is possible to transform into NAADSM parameter setting because we can obtain the needed concepts to construct NAADM's parameters:
  - Subclinical infectious state can be estimated from incubation and latent states
  - Clinical infectious state state can be estimated with subclinical state and infectious state.
  - Naturally immune state can be obtained from the immune state
- Case 2b: With only infectiousness state and incubation state, a transformation is not possible

because we cannot obtain the latent, subclinical infectious, and clinical infectious states from incubation and infectious states. Although we can randomly generate the latent and sub-clinical durations to match the incubation duration and the sub-clinical and clinical durations to match the infectious duration in InterSpread Plus, this will generate high uncertainty due to lack of knowledge.

In summary, the definition of criteria for parameter transformation is dependent on a number of concepts that are reflected in the parameters' settings.

- Concepts must exist in both models. It is a condition for a transformation to take place.
- With missing concepts, we can perform the parameter transformation as described in a transformation procedure with uncertainty.

4 CONCLUSIONS

In this paper, we propose the use of a meta-ontology framework to capture the semantics of parameters and related domain knowledge associated with an FMD course of infection in animal disease spread simulation models. It permits parameter knowledge sharing, parameter assessment and parameter transformation between models. Our motivation for this approach is to minimize the ambiguity that exists in parameter settings and allow a standard way to describe parameter settings and the related domain knowledge. It promotes the interoperability between simulation models, and the ability to assess domain knowledge. By explicitly describing parameter knowledge and establishing the linkage between parameters and documented domain knowledge, this allows us to have an understanding of the differences between different models' parameters and views of the domain knowledge. It strives to provide a basis for a new way to understand and assess parameter and related views of domain knowledge. The central piece of this work is the focus on the meta-ontology framework construction in capturing the semantics of the parameters, the related FMD course of infection domain concepts and assisting in the assessment and the transformation of parameters between models. This work reports on a novel ontological organization that separates domain knowledge from the knowledge about the parameters in different comparable simulation models and formalizes a relationship between parameters by linking to the domain knowledge part of the ontological structure. It allows explicit knowledge representation, a means to compare animal disease spread simulation models and a means to evaluate views (as expressed in parameters) related to simulation models and domain knowledge. This work also acknowledges the limitations in ontology creation. It is a time consuming process that requires great effort and collaboration of a number of experts in different domains. In general, without experts' assistance, parameter settings alone are not sufficient to account for the differences between the models' parameters due to differences in parameter representation of the models and their assumptions. The introduction of an ontology provides a standard means to document and describe the views of simulation models and views of the domain knowledge. These views are built from ontological concepts that are reflected by the parameters, their semantics and related domain knowledge. The ability to capture conceptual relations, properties and the ability to verify the consistency of the ontology allows facts related to parameter settings to be assessed not only with other simulation models but also to the related domain knowledge.

In future work, we hope to extend our ontological concepts to other domains and to extend the number and types of tasks that our semantic engine can perform including validation of requirements, comparison of concepts between related ontologies, and the transformation of concepts and values between ontologies. We anticipate that these extensions will find use in many domains where there is a need to compare and reconcile competing ontologies.

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