Conceptualising the manure distribution system by means of MAIA

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Abstract

To study the potential for manure-based energy production, we decided to explore possible system behaviours by means of an agent-based model. In order to develop this agent-based model we propose the MAIA framework as this methodology allows the system to be adequately captured for agent-based social simulation. The MAIA framework constitutes a meta-model for Modelling Agent systems based on Institutional Analysis *and is based on the* Institutional Analysis Development *(IAD) framework, which applies an institutional perspective on social system concepts. In order to make use of the MAIA framework a good understanding of the system is required. As a result, we propose to use an integrated system perspective with respect to the system analysis. Conceptualisation of the manure distribution system by means of MAIA results in an enhanced documentation that allows for a feasible translation of the system into computer code.*

Keywords: ***Agent-based modelling*, *Institutional analysis*, *Manure distribution system*, *MAIA***

1 Introduction

Biogas producers are considered vital for the development of a biogas infrastructure and as it is assumed that the utilisation of manure constitutes a considerable potential, local farmers (the potential biogas producers) are confronted with a decision to be involved in energy production. In addition, due to the innovative character of this concept, it is unclear what the prospects for local green gas production are. Farmers are not naturally involved in energy production: they are mainly concerned with livestock farming. It may therefore not come as a surprise that these actors hesitate to participate in local renewable energy production and this is considered a serous problem.

To comprehend whether the manure can be made available for energy production, it is necessary to learn how manure is currently used and valued by the local farmers. As manure contains valuable minerals, it is currently used as fertiliser. Due to intensive livestock farming the manure production exceeds the local demand for manure-based fertilisers, which is considered a problem as this (local) abundance of manure urges for a manure distribution system of which the costs are high. Furthermore, circumstances within the (intensive) livestock farming sector are changing especially due to the amendment of policies that monitor farming activities. Changes within these institutional rules and especially the perceptions that these changes occur unpredictably, affect the decision making of local farmers and will influence the condition that underlie the manure distribution system.

The evolving manure distribution system is complex as changes in the institutions result in different behaviours by the farmers. The introduction of manure-based energy production will only further complicate this evolving social system. To explore the factors that influence the adoption of manure-based energy production, we decided to develop an agent-based model (ABM) to allow the system to emerge from bottom-up.

To develop an ABM, relevant system components should be defined and captured. We propose the MAIA framework as we consider this an appropriate methodology for conceptualising the manure distribution system for agent-based social (computer) simulation, especially when one considers the existence of many institutions being part of the system. The MAIA framework constitutes a meta-model for *Modelling*

Agent systems based on Institutional Analysis and is based on the *Institutional Analysis Development* (IAD) framework, which applies an institutional perspective on social system concepts (Ostrom, 2005).

In section 2 we introduce the MAIA framework. In section 3, we explain what approach one should apply in order to be able to use MAIA for the development of an ABM. This section is followed by a section (4) in which we explain how we used MAIA to conceptualise a manure distribution system to study the potential for manure-based energy production. Finally, we present our conclusions in section 5.

2 The MAIA framework

The MAIA framework is designed by Amineh Ghorbani and supports the use of institutions as a major structure for conceptualising social systems (Ghorbani et al., 2012). The MAIA framework extends and formalises the components of the IAD[1] to present a meta-model for conceptualising social systems for agent-based simulation (Ghorbani et al., 2012).

An institution is defined by Ostrom as "the set of rules actually used by a set of individuals to organise repetitive activities that produce outcome affecting those individuals and potentially affecting others" (Ostrom, 2005). An ABM uses a bottom-up perspective. Individual agents act and react to each other, following their internal rules (Nikolic et al., 2009). The (local) interactions within a system lead to patterns that can be evaluated by the analyst. The MAIA methodology views actors as institutional-driven entities.

Agents form the key concepts of the modelled system and they are placed within a context comprised of physical and social[2] components. Agents should be viewed as intelligent entities with capabilities defined in an operational environment.

The concepts in the MAIA meta-model are used to conceptualise and decompose a system for agent-based modelling. As described in (Ghorbani et al., 2012), the concepts within the MAIA framework are organised in five structures. An overview of these structures is presented in figure 1.

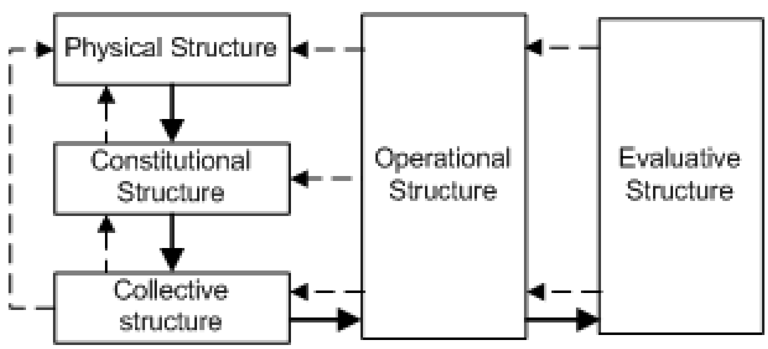

Figure 1: The MAIA meta-model is organised into five structures.

Within the structures relevant information is captured that can be used to translate the system into computer code.

3 Approach for using MAIA

An ABM allows the system to emerge from bottom-up by local interactions of individuals who are captured as agents. By means of an ABM we are able to explore different system behaviours as an ABM can be used to increase the capability to grasp micro-level behaviour and to relate this behaviour to macro-level outcome (North and Macal, 2007).

Since we wish to develop an ABM in which we model local farmers and their decision making behaviour within a dynamic institutional context, we propose the MAIA framework as this methodology allows for the

[1]An institutional framework that provides a collection of concepts present in a social system with an institutional perspective (Ostrom, 2005).

[2]For example the social networks in which agents are embedded.

capturing of the agents as key concepts within the modelled system as the methodology uses institutions as a major structure for conceptualising social systems: *'To understand and explain individual behaviour, which is often extremely complex, institutions can provide a major structure for conceptualising these social systems'* (Ghorbani et al., 2012).

We emphasise that conceptualisation by means of the MAIA framework for agent-based modelling requires a good understanding of the micro-level behaviour. To obtain relevant information and data regarding the system under study, we held interviews with relevant actors and this information is combined with additional data from a literature review. We recommend to apply an integrated system perspective with respect to the analysis as this will result in an improved understanding of the different system aspects and the components it is composed of. An overview of this approach is presented in figure 2. In this figure we show how we related the information obtained to the different concepts of the MAIA framework.

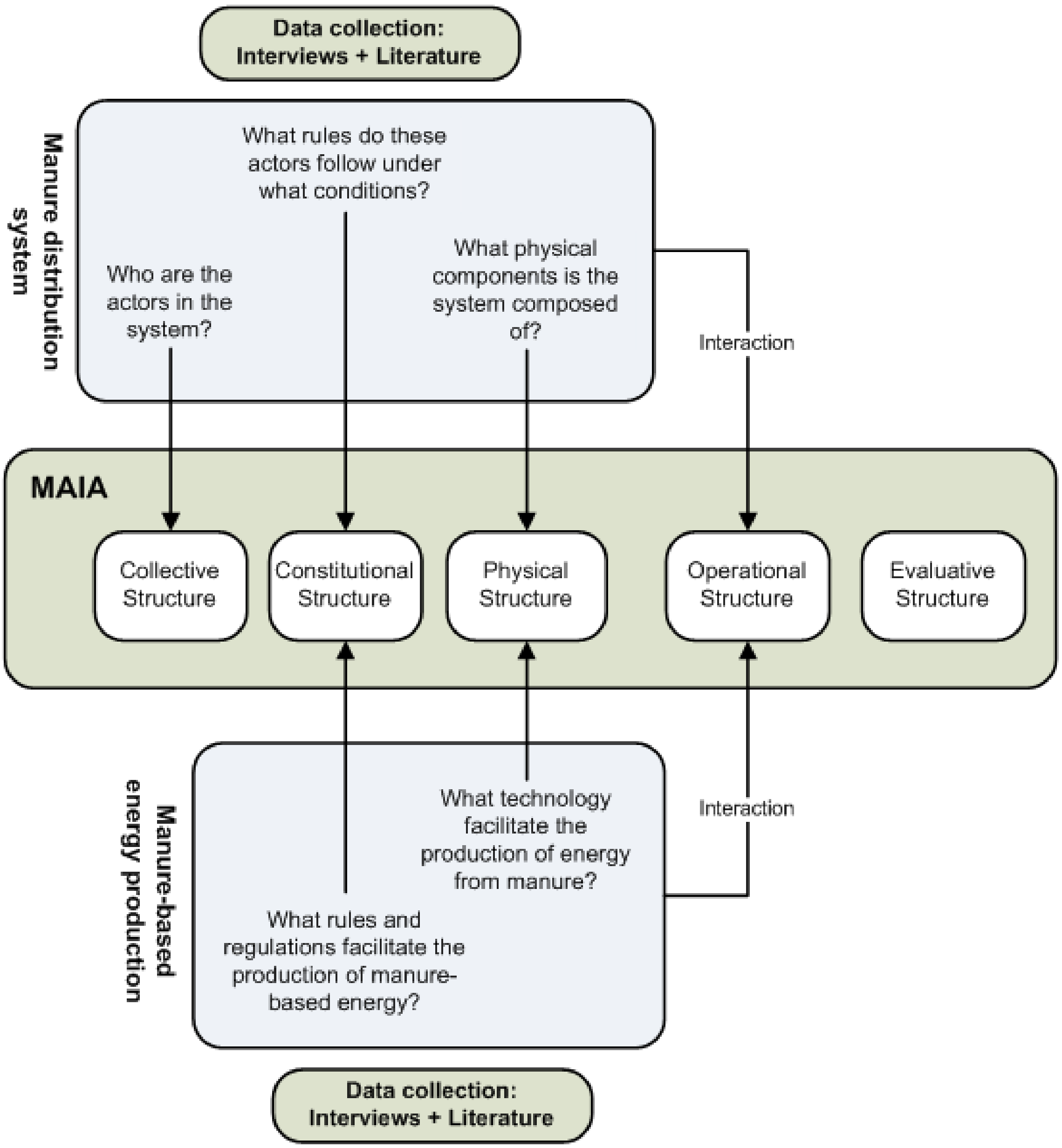

Figure 2: Approach to conceptualise system by means of MAIA for agent-based social simulation.

With respect to figure 2 we provide the following description:

- We stated (many) questions - in this figure we only present the most *fundamental* questions - with respect to the different system aspects as answering these questions would help to fill in the different MAIA concepts.
- Within the *collective structure* actors and their attributes are captured.
- The *constitutional structure* captures the institutional statements and defines what roles different actors are allowed to take.
- The *physical structure* captures the physical components (e.g. animals, manure, technology) of the system.
- The *operational structure* defines the conditions that allow for the interactions of different system components like for instance the agents that are capable of specific actions under specified conditions.
- We used the *evaluative structure* for the validation and verification of the modelled system.
- Conceptualisation by means of the MAIA framework resulted in an enhanced documentation that is used to translate the system into computer code.

4 System conceptualisation by MAIA

As we explained, the MAIA framework allows for the decomposition and conceptualisation of the system for agent-based social simulation. In the following subsections we explain how we conceptualised the manure distribution system by means of the 5 different MAIA structures as presented in figure 1.

4.1 Collective structure

The collective structure is concerned with the actors and their attributes. As explained, the system is considered as a social system and the different actors are referred to as agents. Agents could present both individual actors and composite actors (a group or a party).

4.1.1 Agents

In the model three different agents are defined: the *Animal Farmer Agent*, the *Intermediary Agent* and the *Artificial Fertiliser Supplier Agent*. Since the later two are defined as **external**, only the Animal Farmer Agent is allowed to take roles and follows institutions. Two different types of Animal Farmer Agents are defined: *cattle farmer agents* and *pig farmer agents*.

- **Intermediary Agent**: The Intermediary Agent is an intermediary operating in the system. He collects manure or digestate from the region and distributes these products according to the mineral need within the region. He has knowledge about which Animal Farmer Agents have manure or digestate available and which agents are in need of minerals. He receives money for his activities from Animal Farmer Agents who need to distribute the manure or digestate.
- **Artificial Fertiliser Supplier Agent**: The Artificial Fertiliser Supplier Agent is a company that sells artificial fertiliser to any Animal Farmer Agent who is in need of minerals from artificial fertilisers.
- **Animal Farmer Agent**: This agent owns cattle or pigs. He follows institutions and is allowed to perform actions. All agents will make decisions with respect to the distribution of manure (or digestate), the investment in ME production and the abandonment as well as the expansion of the farm.

4.2 Constitutional structure

The constitutional structure is comprised of three main concepts:

- Roles
- Institutional statements
- Dependency

We define that agents can take different roles. Roles are enacted to reach social objectives (Ghorbani et al., 2012). These activities take place according to some rules. Agents are allowed to take a role if they meet the entry conditions specified for that particular role. When enacting a role, additional capabilities come available. We define that a particular agent can take many different roles and that one particular role can be enacted by many different agents, simultaneously and sequentially (Ghorbani et al., 2012).

Within the system, **rules** are defined that govern agent behaviour. Besides rules, **norms** and **shared strategies** are defined which are all institutional statements. An institutional statement is comprised of the *ADICO*:

- **A**ttributes; the designated roles.
- **D**eontic; the statement can be of the type *prohibition*, *obligation* or *permission*.
- a**I**m; the action taken by an agent defined as a capability of the roles that the statement is part of.
- **C**ondition; indicates when or where the aim should take place.
- **O**r else; indicates what sanction might apply when the statement is not fulfilled.

Rules are comprised of all items of the ADICO. A statement without an explicit sanction is called a norm. Subsequently, a statement without a deontic can be a shared strategy among roles (Ghorbani et al., 2012). In addition, we emphasise that agents do not follow the rules associated with their roles in an automatic sense. Within their decision making process, agents are influenced by their properties, personal values or by the states of other agents as well as the state of the system. As a result, they can decide not to follow a particular rule.

4.2.1 Roles

We decided that only the Animal Farmer Agent is allowed to take roles. Depending on the situation, this agent might take one of the following roles that are defined:

- **Landowner**: The Landowner owns crop- and grassland. Since crop- and grassland should be manured, the Landowner is capable of calculating each year how much nitrogen and phosphate he needs for manuring.
- **Producer**: The Producer is capable of green gas production from manure and obtains revenue from the supply of green gas.

Since pig farmer agents do not own any land, they are not allowed to take the role of Landowner. Both agent types are can take the role of a Producer.

4.2.2 Institutions

Each year the Animal Farmer Agent is confronted with many decisions and within his decision making he is affected by several institutions. In table 1, we present the institutions that form the basis for the rules that influence the behaviour of the agents:

Table 1: MAIA constitutional structure: institutions

Institution	Manure policy (including *derogation*)	Farmer-farmer transport	Subsidy	Abandon of farm	Expansion of farm
Deontic type	Prohibition	Permission	Permission	Obligation	Permission
Type	Formal institution	Formal institution	Formal institution	Informal institution	Informal institution
Subject	Landowner	Animal (Cattle) Farmer Agent	Producer	Animal (Cattle and Pig) Farmer Agent	Animal (Cattle and Pig) Farmer Agent
Content	Agents that take the role of *Landowner* are allowed to manure their land. Depending on the number of hectares, type of soil, and cultivation the amount of nitrogen and phosphate are set. The usage of more then 170 kilogrammes of nitrogen per hectare is prohibited. Furthermore, in case *derogation* applies this amount is increased to 250 kilogrammes of nitrogen. The amount of phosphate is set to 90 kilogrammes for grassland and 65 kilogrammes for cropland.	Agents that have cattle and are able to use more then 80% of the phosphate for manuring of own land, are permitted to transport their excess to neighbouring (cattle) farmer agents within the same location. This against reduced *transport costs* and no *analysis costs*.	Agents that take the role of *Producer* are permitted to obtain a *basic amount* granted by subsidy for the production of green gas.	Farmers are obliged to meet the requirements stated in the *ammonia action programme* to reduce the ammonia emissions from animal housing systems at farms by 2013. In addition, in 2013 the government will amplify the *animal welfare norms*. Since the adjustments to the animal housing systems require investments, a financial burden is placed upon especially pig farmers. Considered the financial situation within this sector, it is expected that a substantial part of these agents will abandon their farm in 2013. Furthermore, a tendency is observed in which farms expand and relatively small-scale farms abandon. To capture this trend, farms that are considered to be more vulnerable for the possible impact might abandon. It is captured that a few percent of both cattle and pig farmer agents will abandon each year.	Agents are permitted to expand their farms. It is implemented that they can expand their farms only two times during a simulation, depending on their local circumstances.

4.3 Physical structure

Within the physical structure, physical components are defined. These components can be used or operated by agents. Furthermore, physical components may have behaviours as well.

We decided to capture the following physical components:

- **Animals**: Animal Farmer Agents own cattle or pigs. These animals produce manure.
- **Land**: Only cattle farmer agents own crop- and grassland.
- **Manure**: All animals produce manure. Depending on the type of the animal an estimation is made of the annual production and mineral composition.
- **Digestate**: Besides the production of green gas, digestate is produced. We assumed digestate to be similar to manure. Since manure from cattle differs in composition compared to manure from pigs, digestate from cattle also differs from pig digestate.
- **Artificial fertiliser**: The fertiliser law puts limits to the excessive usage of minerals from manure. Since the agents that own land might still be in need for minerals, they are permitted to use artificial fertilisers. The artificial fertiliser is priced according to the quantities of nitrogen (kg) and phosphate (kg) it contains.
- **Green gas**: Green gas is produced from manure by means of technology. The volume (m^3) of green gas that is produced depends on the volume of manure that is utilised.
- **Technology**: The technology used for the production of green gas and digestate can be considered as a *conversion unit* which requires manure as an input and produces green gas and digestate at the output. For operating a technology, agents pay annual technology costs.
- **Money**: Every agent has to pay money (€) for the distribution of manure (or digestate), for the possible labour costs with respect to manuring and for the annual technology costs. Likewise, they receive money when they accept manure from a neighbour or Intermediary Agent. Furthermore, they obtain revenue from the supply of green gas.

4.4 Operational structure

As described in (Ghorbani et al., 2012), '*the operational structure describes the conditions in which agents use their capabilities to act and react, and the changes in the status of the system*'.

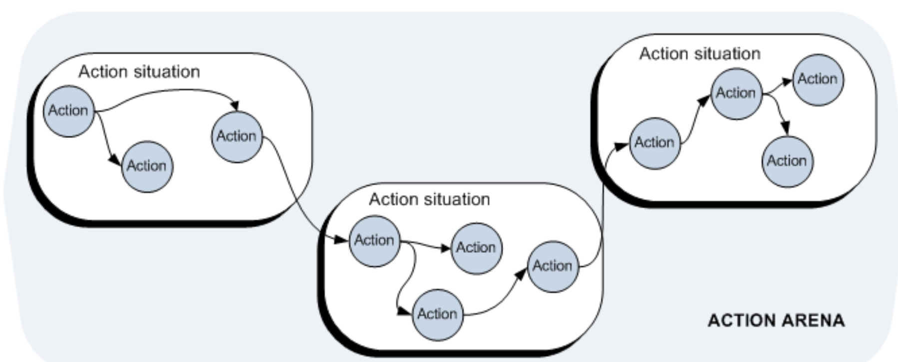

Figure 3: Action arena

Agents perform actions. Within the MAIA framework, actions are defined as '*an operationalised description of the capabilities of roles or the behaviours of agents and physical components specifying the pre and post conditions for a capability/behaviour to trigger, the role, agent or physical component that will be performing that action and the institutions that are involved (if any)*' (Ghorbani et al., 2012).

As shown in figure 3 these *actions* are defined in *action situations* which are part of an *action arena*. The *action sequence* defines the order in which the actions take place. In addition, for each action it is defined which roles should be taken by which agents.

4.4.1 Action situation

We defined three main action situations:

- **Farming**: Within the *farming* action situation all farm-related activities are performed. These activities comprise manuring and the decision making with respect to the expansion and abandonment of the farm.
- **Manure distribution**: In the *manure distribution* action situation, all activities related to the distribution of manure and digestate as well as the buying of artificial fertilisers are performed.
- **Bio-production**: The *bio-production* action situation comprises the activities that are related to the production of manure, green gas and digestate. Within this action situation, the decision to produce green gas is made. Subsequently, annual technology costs will be paid and revenue from green gas will be obtained.

In figure 4, the action sequence is shown. This action sequence shows the overall operational procedure of the system as it defines the order in which the actions take place.

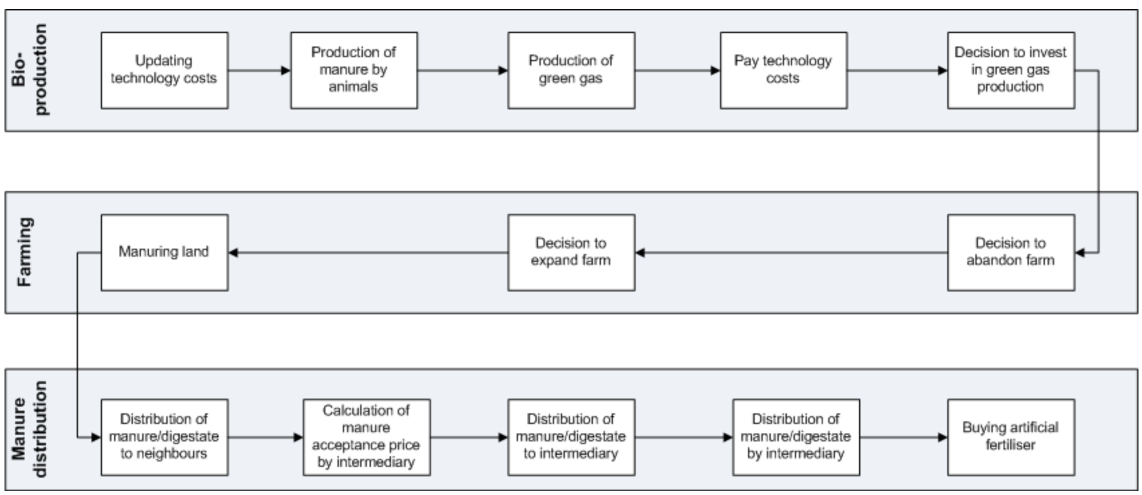

Figure 4: Action sequence

4.4.2 Role enactment

Table 2 shows what roles can be taken by which agents in a particular action situation.

Table 2: Role enactment

Agent	**Action situation**	**Role**
Animal Farmer Agent	Farming	Landowner
Animal Farmer Agent	Manure distribution	Landowner
Animal Farmer Agent	Bio-production	Producer

4.5 Evaluative structure

The evaluative structure is concerned with two questions:

- *Did we build the right model?*
- *Does the model answer our questions?*

To answer the first question, variables should be identified that allow the model to be validated. Direct and indirect relationships between these validation variables are captured in a *validation matrix*.

To answer the second question, variables should be identified that can provide answers to problem domain questions. These problem domain variables should provide insight regarding the model dynamics, e.g. the number and type of green gas producers within the system. Similar to the validation variables, direct and indirect relationships between these variables are captured in a *scope matrix*.

5 Discussion and conclusion

The manure distribution system comprises many actors situated within a dynamic institutional environment. These individuals are considered autonomous and unique with respect to their decision making behaviour. In addition, they are influenced by many different factors and since they have different ways of interacting with each other, it will become clear that - due to these local interactions - the system can emerge in many possible ways, giving rise to a wide variety of possible system behaviours or patterns from bottom-up.

In order to develop an ABM for exploring the possible system behaviours we propose to use the MAIA framework since this methodology uses institutions as a major structure for conceptualising social systems in which agents are the key concepts.

5.1 Discussion

We experienced that a good understanding of the different system components is required in order to capture them for modelling. As a consequence, we recommend to apply an integrated system perspective with respect to the analysis as this will result in an improved understanding of the system.

In general, we perceived that the conceptualisation process by means of the MAIA framework constitutes a good way for identifying relevant system components. The fact that the MAIA framework is comprised of a divers range of relational *structures* encouraged us to explore different system components and forced us to truly evaluate their relevance for capturing.

Since the MAIA framework supports the use of institutions as a major structure for conceptualising social systems, we were able to model institutions in agent decision making and see for example the influence of the manure policy giving rise to the distribution of manure.

We learnt that conceptualisation by means of MAIA resulted in an enhanced documentation. We consider this documentation very beneficial since:

- the documented concepts allowed for an efficient communication between on the one hand the domain expert and on the other the modeller.
- we experienced the documentation very feasible for translating the concepts into a computer model as the documentation is comprised of relational tables and diagrams that can be easily coded.
- we obtained a compact overview of the system. Due to this overview, we were able to revise certain concepts whenever needed in an easy way.

5.2 Conclusion

Within this paper we introduced the MAIA framework and showed how this methodology can be used to conceptualise a manure distribution system. We respect to the use of this methodology we outline the following conclusions:

- In order to use the different MAIA concepts, a good understanding of the system is required. As a result, we propose the use of an integrated system perspective with respect to the system analysis in order to be able to relate different system aspects to the different concepts of the MAIA framework.
- The concepts of the MAIA framework help to structure the system within the conceptualisation phase. As a result, we obtain an abstract overview of the system which allowed for a feasible translation into computer code.
- Conceptualisation by means of the MAIA framework results in an enhanced to documentation which allows for an efficient communication between on the one hand the domain expert and on the other the modeller.

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