How social factors and group dynamics affect feeding and social interaction patterns in pigs

ODD[1] model description

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1. Purpose

The purpose of the model is to gain more insight in the causation of feeding and social interaction behaviour of group-housed growing pigs in conventional housing. The model simulates feeding patterns (e.g. feed intake, feeding rate and meal frequency) and social interaction patterns (e.g. avoidance, interactions and displacement from the feeder). Feeding behaviour in an individually housed pig can be explained by physiological factors such as energy balance and hormonal circadian rhythms. We hypothesise that social factors interact with physiological factors to stimulate or inhibit feeding behaviour of pigs, in which competition for food resources and social facilitation affect behavioural strategies (approach and avoid) and group dynamics. The model is an extension of the previously developed computational model in which individual pigs developed feeding patterns based on growth and internally (physiological) driven feeding motivation (Boumans et al., 2015; Boumans et al., 2017b). The effect of competition (in various group sizes), social facilitation and variation in behavioural strategies (approach and avoidance) on behavioural patterns can be tested in this model.

2. Entities, state variables, and scales

Entities and variables: The model environment represents a conventional (barren) pen with one feeding place (feeder) and water place (drinker). Agents in the model represent growing pigs. The model includes many variables to calculate motivations, behaviours, social interactions and growth of pigs. The main state variables of pigs are described in Table 1.

Temporal resolution: One time step represents one minute and simulations can run for 120 days consisting of 1440 minutes including light and dark periods.

Spatial resolution: The model world represents a pen with limited spatial effects. The pen is not wrapped (pigs cannot move outside the 'walls' of the pen) and only one pig can feed at one time at the patch that represents the feeder.

[1] The model description follows the ODD (Overview, Design concepts, Details) protocol for describing individual- and agent-based models (Grimm et al. 2006, 2010).

Table 1. Entities included in the model with their main state variables and units of measurement

Variable	Description	Unit
Pigs		
Sex	Sex (male, barrow or female)	-
Dominance	Hierarchical rank in the group	Number
Body weight	Body weight of the pig	Kg
Protein weight	Part of the body weight consisting of protein	Kg
Lipid weight	Part of the body weight consisting of lipid	Kg
Age	Age of the pig	Days
Mean body protein deposition	Deposition of protein that affects growth potential	g/day
Daily energy requirement	Sum of daily energy requirement for maintenance and activity	kJ
Daily energy absorption	Sum of daily energy absorption from digested feed	kJ
Stomach content	Amount of feed in the stomach	g
Gut content	Amount of feed in the intestines	kg
Exploration drive	Internal state affecting exploration behaviour	Unitless (0-1)
Lying drive	Internal state affecting lying behaviour	Unitless (0-1)
Drinking drive	Internal state affecting drinking behaviour	Unitless (0-1)
Melatonin value day	Melatonin level during the day	Unitless (0-1)
Melatonin value night	Melatonin level during the night	Unitless (0-1)
Cortisol amplitude	Variation in cortisol levels during the day	Unitless (0-1)
Meal duration	Number of successive time steps that a pig is feeding	Minutes
Meal size	Amount of feed intake per meal	g
Meal frequency	Sum of meals per pig	Number
Explorations	Sum of performed exploration behaviours per pig	Number
Lyings	Sum of performed lying behaviours per pig	Number
Drinkings	Sum of performed drinking behaviours per pig	Number
Movements	Sum of performed movement behaviours per pig	Number
Waitings	Sum of performed waiting behaviours per pig	Number
Remain lyings	Sum of performed remain lying behaviours per pig	Number
Remain standings	Sum of performed remain standing behaviours per pig	Number
Avoidings	Sum of performed avoiding behaviours per pig	Number
Interactions	Sum of interactions per pig	Number
Displacements	Sum of displacements per pig	Number
Environment		
Group size	Number of pigs in the pen	Number
Days	Number of days since start simulation	Days
Time	Time of the day (within 24 hour)	Hour/minutes
Temperature	Ambient temperature in the pen	Celsius
Feeder	Location to feed	grid cell
Drinker	Location to drink	grid cell
DE content diet	Digestible energy level of the diet	kJ/g
Palatability diet	Palatability of the diet	Unitless (0-1)
Amino acid content diet	Content of amino acids in the diet (separately listed in the model for- Lysine, Methionine, Methionine+ Cystine, Threonine, Tryptophan and Isoleucine)	g/kg
Dietary protein content	Amount of total protein in the diet	g/kg
Nutrient availabilities	Apparent amino acid and protein availabilities in the diet	Unitless (0-1)

3. Process overview and scheduling

Who does what and in what order?

The model consists of three sub-models “Update motivations”, “Behaviour” and “Update nutrient balance & grow”. Each time step, in a random order, each pig goes through these sub-models.

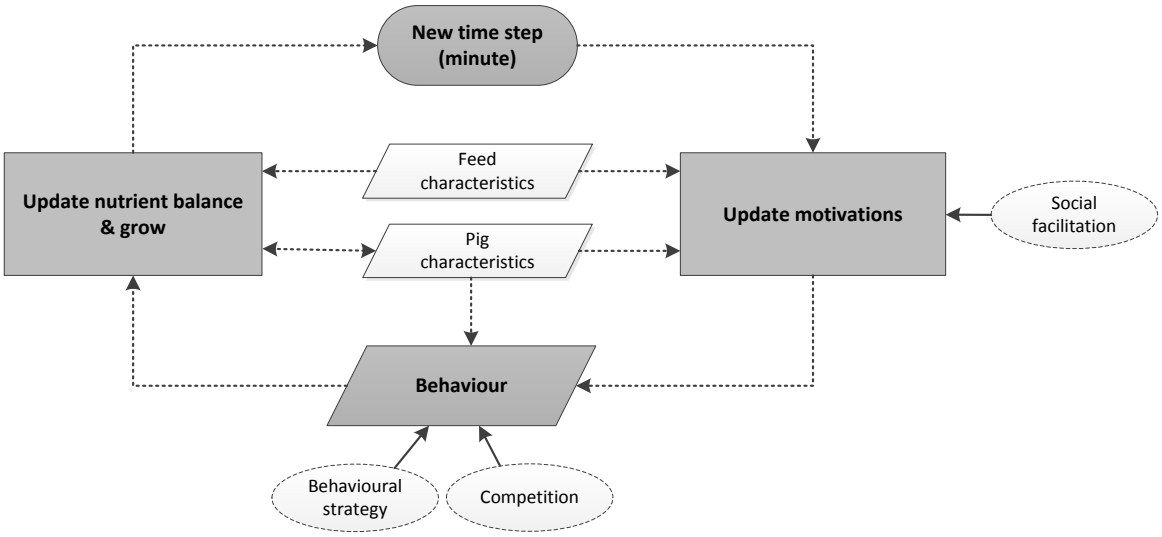

Figure 1. The model consists of three sub-models “Update motivations”, “Behaviour” and “Update nutrient balance & grow”. Pig and feed characteristics affect processes in these sub-models. Social facilitation affects feeding motivation, competition and behavioural strategies affect behaviour (adapted from Boumans et al., 2015).

Sub-model 1: update motivations

- Update endocrine effects (circadian rhythms of hormones)
- Process feed (empty stomach, calculate stomach load and digest)
- Calculate energy balance (calculate energy use, instant energy balance, growth capacity and daily energy balance)
- Calculate feeding motivation (calculate satiation and feeding drive), if another pig feeding this increases feeding motivation (social facilitation effect)
- Calculate other motivations (calculate drives and thresholds for drinking, exploring and lying behaviours

Sub-model 2: Behaviour

- Act on motivation:
  Pigs (in a random order) choose their behaviour (feeding, exploring, drinking, standing or lying) based on their highest motivation. If none of the motivations is above zero, the pig remains standing if its last behaviour was active or remains lying if its last behaviour was inactive.
- If a pig chooses to feed and the feeder is free, it can feed. If the feeder is taken by a pen mate a pig decides to avoid a conflict and perform another behaviour or approach this pig and try to displace it (competition and group dynamics effect). Dependent on the outcome of a conflict, the pig can feed or show an alternative behaviour.

Sub-model 3: Update nutrient balance and grow

- Grow:
  Calculate nutrient intake, utilisation of nutrients for maintenance and growth, utilisation of energy for growth and calculate body weight.

When are state variables updated?
Each state variable is immediately updated as soon as that value is calculated by a process (asynchronous updating).

4. Design concepts

Basic principles
We use the concept of motivation for behavioural decision-making: motivation for a behaviour is the balance between an energy drive and threshold level, and feedback mechanisms can affect the motivation (Hogan, 1997). Furthermore, behaviour is the result of several motivational systems, in which behaviour is result of the highest motivation (which is described as the state-space approach by (McFarland & Sibly, 1975).

For feeding motivation the energy drive and threshold level can be described respectively as feeding drive and satiation. Feeding drive and satiation are affected by metabolic-homeostatic factors (e.g. energy absorption and requirement).

Social mechanisms affect feeding behaviour on different levels:

- Social facilitation increases the attractiveness of the feed, which will increase feeding motivation.
- Social competition can affect the number of conflicts among pigs (a conflict is when two pigs or more want to feed simultaneously).
- Behavioural strategies affect the outcome of a conflict and thus social interaction and feeding behaviour. Pigs can decide to approach and avoid other pigs when in conflict.
  - Approach: an social interaction in which a pig at the feeder can be displaced (if approaching pig wins the interaction) or the approaching pig loses and performs an alternative behaviour
  - Avoid: the pig avoids an interaction and performs an alternative behaviour.

We hypothesise that:
- Feeding patterns of an individually housed pig emerge from an constant internal (mainly physiologically driven) interaction among motivations, behaviours and growth (this was the hypothesis of the previous developed model).
- Social facilitation can increase the probability that group-housed pigs want to feed simultaneously and increase competition.
- Competition explains increased social interactions, a decrease in meal frequency by avoidance and unsuccessful approaching behaviour, and a decrease in meal duration by successful approaching and displacement behaviour.
- The effect of competition on behaviour depends on the behavioural strategy of an individual towards a conflict, which can be affected by feeding motivation

Emergence
The model has emergent patterns of feeding behaviour, social interaction behaviour and growth of pigs:

Feeding behaviour:
- Feed intake (g)
- Meal frequency (No)
- Meal size (g)
- Meal duration (min)
- Feeding rate (g/min)

- Interval time between meals (min)
- Feeding time (min)

Social interaction behaviour:
- Conflicts (No)
- Avoidance (No)
- Approaches (interactions) (No)
- Displacements (wins) (No)
- Unsuccessful displacements (losses) (No)

Growth:
- Body weight gain (g)
- Energy use (kJ)
- Body weight (kg)

AI patterns can be measured per time unit (e.g. min, hour or day) or the distribution over a 24 hour period.

Furthermore, the model also produces patterns in other pig behaviours, such as exploring and resting. These behavioural patterns result from simplified mechanisms and are calibrated to fit within the time budget of pigs observed in intensive housing systems (Bolhuis et al., 2005).

Adaptation
Pigs choose their behaviour based on their highest motivation. However, when a pig wants to feed, but the feeder is already taken, a pig can make several decisions:
- approach and compete (and win or lose), or
- avoid and perform an alternative behaviour (based on other motivations)

Objective
The objective of a pig is to perform motivated behaviours. Feeding motivation represents the need to meet the required energy intake per day for optimal growth. If conflicts occur between pigs for access to the feeder, the pig that experiences a conflict decides on its behaviour based on its benefit belief (the value of the food and chance of winning an social interaction) and its coping style. The benefit belief is based on the level of its own feeding motivation and social rank, and the social rank of the other pig. Coping style is based on a threshold level to compete.

Learning
As we fixed the social ranking in the current model, and the pigs have no memory of previous interactions, there is no learning.

Prediction
When pigs want to feed, but there is no unoccupied feeder, pigs have to decide whether they want to compete. This decision is based on the chance on success, which is based on the relative ranking of the two opponents and feeding motivation

Sensing
Pigs sense that another pig is feeding (this increase the attractiveness of the feed for all other pigs) and a pig knows whether there is another pig at the feeder when it wants to feed and knows the social rank of the opponent pig when in a conflict.

Interaction

Indirect interaction can occur due to social facilitation (a feeding pig stimulates other pigs to feed) and avoidance behaviour (a pig decides to perform another behaviour, without disturbing a feeding pig). Direct interaction can occur due to competition at the feeder, when two (or more) pigs want to feed simultaneously and one of these pigs approaches another. If this pig wins, the opponent moves away and the winner starts feeding, if it loses, the other pig goes on feeding and the loser moves away.

Stochasticity

Stochasticity is used for randomising initial states during setup of the model (gut load, energy level, growth capacity), this is included to cause individual variation. Furthermore, stochasticity is used during conflicts in pigs, where probability and stochasticity is included in the decision to avoid or approach another pig.

Collectives

No collectives are included.

Observation

See information under “emergence”. This data is collected and validated against empirical data. Additional data of motivational states is sampled, and checked to be within expected patterns.

5. Initialisation

The initial state of the model world consists of one feeder, one drinker, time and the selected number (and sex) of pigs in the pen. The number of pigs is constant during the simulation. Temperature is set to 22 degrees Celsius. Variables of the world and pigs with special assigned values at set up are described in Table 2. Other state-variables are set to 0.

Table 2. Values of variables in the model at initialisation of a model run.

Variable	Value	Explanation
Pigs		
Sex	Male, barrow or female	Variable between runs, based on slider
Dominance value (No.)	1-30	To randomly assign a dominance rank to each pig. Values start from 1 and count up (2, 3, etc.)
Initial body weight (kg)	27	Average body weight of pigs of 10 weeks of age.
Initial body protein weight (kg)	4	Based on estimated body protein weight of growing pigs of 27 kg body weight (De Lange, 1995).
Minimum lipid:protein	1	Minimum body lipid and body protein ratio (De Lange, 1995).
Age (days)	70	Average starting age of growing pigs
Mean body protein deposition	Mean: 133 (males), 137 (gilts), 151 (barrows), SD: 0.1	Random assigned values based on a normal distribution with sex-related protein depositions as mean (NRC, 2012). Values were randomised to represent individual growth differences between pigs.
Daily energy balance	1	Assuming a neutral energy balance
Digest duration (min)	180	Digestion duration, based on duration of gastric emptying (Strathe et al., 2008)
Stomach content (g)	Mean: 0.4, SD: 0.1	Randomised value based on a normal distribution, assuming a last meal of 60 g 100 minutes before.
Stomach load	Mean: 0.38, SD: 0.038	Randomised value based on a normal distribution, assuming some feed in the stomach.
Gut content (kg)	Mean: 0.2, SD: 0.1	Randomised value based on a normal distribution, assuming some feed in the intestines.
Feed intake capacity (g)	1383	Based on equation: 111 * weight ^ 0.803 + 111 * weight ^ 0.803 * (LCT - temperature) * 0.025 (NRC, 2012)

Table 2. Continued.

Variable	Value	Explanation
Pigs		
Exploration drive	Mean: 0.75, SD: 0.1	Randomised value based on a normal distribution and chosen to correspond to the average levels of the internal states during the simulation.
Lying drive	Mean: 0.75, SD: 0.1	Randomised value based on a normal distribution and chosen to correspond to the average levels of the internal states during the simulation.
Drinking drive	Mean: 0.75, SD: 0.1	Randomised value based on a normal distribution and chosen to correspond to the average levels of the internal states during the simulation.
Cortisol amplitude	0.99	Based on parameterisation, represents fluctuating cortisol concentrations in the body.
Melatonin value night	0.8	Based on parameterisation, represents a high level of melatonin concentrations in the body over the night.
Melatonin value day	0.4	Based on parameterisation, represents a low level of melatonin concentrations in the body over the day.
Positive feedback	0.05	Based on parameterisation, to reinforce feeding behaviour and cause feeding bouts.
Cost energy expenditure day before	4500	Based on results of simulation runs.
Environment		
Group size	Variable	Can represent various group sizes.
Days	1	Initial simulation day.
Time (h:min)	00:00	Initial time in the model (at midnight).
Temperature (Celsius)	22	Represents a usual temperature in a pen.
Feeder	1	Represents a housing system with one feeder.
Drinker	1	Represents a housing system with one drinker.
DE content diet (kJ/g)	14.2	Represents a commercial growing pigs diet (NRC, 2012).
Palatability	0.7	Based on parameterisation, represents the attractiveness of the feed.
Start light period (h)	06:00	Represents an usual lighting regime
Start dark period (h)	18:00	Represents an usual lighting regime
Dietary amino acid (AA) content Lysine (g/kg)	11	Essential AA, based on values from NRC (2012).
AA content Methionine (g/kg)	3	Essential AA, based on values from NRC (2012).
AA content Methionine + Cystine (g/kg)	6	Essential AA, based on values from NRC (2012).
AA content Threonine (g/kg)	6	Essential AA, based on values from NRC (2012).
AA content Tryptophan (g/kg)	2	Essential AA, based on values from NRC (2012).
AA content Isoleucine (g/kg)	5	Essential AA, based on values from NRC (2012).
Dietary protein content (g/kg)	132	Essential AA, based on values from NRC (2012).
Apparent AA and protein availabilities	0.82	Essential AA, based on values from NRC (2012).

The initial state of a model run is assigned randomly at setup, determined by a specified seed for a pseudo-random number generator.

6. Input data

The model does not use any external input.

7. Submodels

Sub-model 1: Update motivations

A detailed description of the submodel motivation with equations, values and explanations can be found in Boumans et al. (2017b)

Sub-model 2: Behaviour

Behaviour of pigs kept in barren intensive housing systems, in their active period during day-time, consists of about 70-80% lying behaviour and 20-30% active behaviours, such as feeding, exploring and moving (e.g. Bolhuis et al., 2005). Pig behaviours in the model are feeding, exploring, drinking, standing, lying, moving, avoiding, approaching and displacing. These behaviours represent the most common behaviours of pigs.

Pigs choose their behaviour (feeding, exploring, drinking, lying) based on their highest motivation. If none of the motivations is above zero, the pig stays in the same position as the previous behaviour: remains standing if its last behaviour was active or remains lying if its last behaviour was inactive. If a pig chooses to feed and the feeder is free, it can feed. If the feeder is taken by a pen mate a pig decides to avoid a conflict and perform another behaviour or approach this pig and try to displace it (competition and group dynamics effect).

<u>Behaviours if not motivated</u>

Lying position:
A pig:
- Remains on the same location
- Increases its number of daily and hourly stay-lyings with 1

Standing position:
A pig:
- Remains on the same location
- Increases its number of daily & hourly stay-standings with 1
- Increases energy expenditure with activity costs

<u>Behaviours if motivated to feed and feeder is free</u>

A pig remembers each time step whether feeding was its last behaviour. If it performs feeding behaviour in consecutive time step, this feeding behaviour will be seen as the same feeding bout (and thus increase meal size & duration). Performing another behaviour will end the feeding bout.

Feeding:
A pig:
- Faces and moves to the feeding trough
- Determines feeding rate
- Increases energy expenditure with activity costs
- Increases its number of daily & hourly feedings with 1
- Increases its lying drive (the amount of digested feed * 0.00042)

At the end of this sub-model, feed intake, feeding time and stomach content of a pig is calculated (based on the number of pigs that visited the feeder that time step):
- Feed intake = feeding rate / number of pigs feeding that time step
- Feeding time = 1 minute / number of pigs feeding that time step
- Daily feeding time = previous feeding time that day increases with feeding time
- Hourly feeding time = previous feeding time that hour increases with feeding time
- Meal duration = duration of that meal increases with feeding time
- Daily feed intake = previous feed intake that day increases with feed intake
- Hourly feed intake = previous feed intake that hour increases with feed intake

- Meal size = previous feed intake that meal increases with feed intake
- Stomach content increases with feed intake.

Behaviours if motivated to feed and feeder occupied

Avoiding:
A pig:
- Avoids a conflict at the feeder by performing another motivated behaviour or else faces to the feeder on a random location away from the feeder and waits in a lying (if the instant energy balance is below zero) or standing position (if the instant energy balance is above zero).
- Increases its number of daily & hourly avoidings with 1
- Ask its opponent to increase its daily & hourly number of being avoided

Approaching:
A pig:
- Approaches a pig at the feeder.
- Increases its number of daily & hourly approaches with 1.
- If it wins from its opponent:
    - Increases its daily & hourly number of successful displacing other pigs.
    - Performs feeding behaviour.
    - Asks its opponent to increase its daily & hourly number of being displaced.
    - If there is another pig at the feeder, competes again.
- If it loses from its opponent:
    - Increases its daily & hourly number of failing displacing other pigs.
    - Performs another motivated behaviour or else faces to the feeder on a random location away from the feeder and waits in a lying (if the instant energy balance is below zero) or standing position (if the instant energy balance is above zero).
    - Asks its opponent to random move away from the feeder and increase its daily & hourly number of resisted displacing.

Other motivated behaviours

Drinking:
A pig:
- Faces and moves to the drinker.
- Increases energy expenditure with activity costs.
- Increases its number of daily & hourly drinkings with 1.
- Reduces its drinking drive.

Lying:
A pig:
- Moves to a free spot at the closest (upper or lower) wall.
- Increases its number of daily & hourly lyings with 1.
- Reduces its lying drive.

Exploring:
A pig:
- Random moves in the pen.
- Increases energy expenditure with activity costs.
- Increases its number of daily & hourly explorings with 1.

- Reduces its exploring drive.

Sub-model 3: Update nutrient balance & grow

A detailed description of the submodel Update nutrient balance & grow with equations, values and explanations can be found in Boumans et al. (2015).

8. Simulation experiments

The effect of social factors and behavioural strategies on feeding and social interaction patterns was tested in four scenarios:

1. A scenario in which all pigs would avoid competition.
2. A scenario in which all pigs would approach & displace other pigs.
3. A scenario in which pigs can decide to avoid or approach.
4. A scenario in which pigs can decide to avoid or approach, and social facilitation affects feeding motivation.

In these scenarios, the effect of various behavioural strategies (avoiding versus approaching) and the effect of social facilitation was tested.

Furthermore, the sensitivity of model results to parameter values was tested (changing one parameter per simulation with an alteration of 20%). Model results can be found in (Boumans et al., 2017a).

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