# Simulation of precision feeding systems for swine

Linh Manh Pham*
*VNU University of Engineering and Technology*
*144 Xuan Thuy, Cau Giay*
Hanoi, Vietnam
linhmp@vnu.edu.vn

Hieu Nguyen-Ba
*Faculty of Animal Science*
*Vietnam National University of Agriculture, Trau Quy, Gia Lam*
Hanoi, Vietnam
nbhieu@vnua.edu.vn

Hoai Son Nguyen
*VNU University of Engineering and Technology*
*144 Xuan Thuy, Cau Giay*
Hanoi, Vietnam
sonnh@vnu.edu.vn

Huy-Ham Le
*VNU University of Engineering and Technology*
*144 Xuan Thuy, Cau Giay*
Hanoi, Vietnam
hamle@vnu.edu.vn

***Abstract*—Precision livestock farming has become an inevitable trend for agricultural industry in the world. In that field, precision feeding is widely acknowledged because of its potential to reduce feed costs, environmental footprint and to improve animal health and welfare. Precision feeding involves modern multidisciplinary technologies such as information technology, mechanics, electronics, automation, etc. Such a system consists of automatic troughs linked to a computer system to exploit data collected from the individual animals (e.g. body weight, feed intake and feeding behaviour), and/or from ambient sensors. Data is processed and analysed based on mathematical models to make predictions, warnings for farmers or to formulate diets that fit requirements of each individual animal at each production period. However, implementing such a system often requires high investment, which may go beyond the capabilities of smallholders and small/medium laboratories. Furthermore, the risk of implementing by design but not conforming to reality is very high. To avoid this problem, we introduce an agent-based modelling approach to simulate precision feeding systems for swine. Two simulation experiments were conducted to provide predictions about the growth of individual pigs and the usefulness of precision feeding systems over classic feeding models.**

***Index Terms*—precision feeding system, simulation, agent-based modelling, swine, efficiency**

## I. INTRODUCTION

Livestock production is currently confronting an urgent challenge of sustainability. On the one hand, the human population has been exploding over a few recent decades and is predicted to reach 9.1 billion by 2050 [1]. To feed such a large number of people, the world would need to produce 70% more food than is available today. In which meat production alone is expected to increase by more than double to reach 470 million tons per year. On the other hand, current livestock production is criticized for causing environmental problems, deteriorating animal health and welfare, impairing food safety and competing with human-edible food.

Pig production is one of the major sectors that competes directly with humans for edible cereals. Moreover, feed cost represents approximately 60% total costs in the pig production chain and hence substantially affects economic outputs. Feed also has a large impact on other pillars of sustainability such as product quality, environment, animal health and welfare [2]. Therefore, the efficiency of utilizing feed plays an essential role in pig production to both sustain the increasing human population and enhance its sustainability. In order to improve feed efficiency, it is essential to feed pigs diets that meet exactly their nutrient requirements. In case of overfeeding, excess nutrients that cannot be retained by the animal, will be excreted to the environment. In contrast, insufficient supply of essential nutrients results in decreased animal performance, health and welfare.

Precision feeding is a new approach that aims to better account for individual variation in nutrient requirements of a population. Precision feeding implies the use of feeding techniques that provide the right quantity of feed, with the right nutrient composition and at the right time to a small group of animals or to each individual within the group [3]. In details, precision feeding requires (1) a real-time determination of nutrient requirements for each individual within the group (often done using models based on factorial approach) and (2) the use of automated technology (i.e. automatic feeding station) to distribute tailored diet for the animal and to monitor animal's real-time performance (e.g. body weight, feed intake, and feeding behaviour). The latter will be used as feedback for the estimation of individual nutrient requirements. Therefore, precision feeding is promising in maximizing the performance potential of individuals and minimizing the environmental impacts. In fact, recent results in growing-finishing pigs have shown that individual precision feeding significantly reduced feed costs, Nitrogen intake and excretion compared to multi-phase group feeding without hampering pig's performance [4]. Moreover, because animal's performance and feeding behaviour are monitored individually and in real-time, precision feeding also benefits animal health and welfare through early detections of abnormality [5].

Animal welfare has been initially taken seriously in Vietnam and has been officially included in the Law on Veterinary

*Corresponding author.

Medicine since 2015 [6]. Therefore, precision feeding has a great potential to apply in the pig production in our country. However, by far the application of precision feeding is very limited in Vietnam mainly because of its price and the need to re-construct housings. Moreover, many precision feeding methods that apply different algorithms for estimating important output production parameters such as cumulative feed intake (CFI) and body weight (BW) are under development but the evaluation of these algorithms is time consuming (e.g. a pig raising will take many days) and costly (e.g. feed, monitoring labor) while comparing these methods or algorithms with each other is difficult due to random factors. To solve these difficulties, it is necessary to build a precision feeding simulation system that will help to evaluate the effectiveness of different precision feeding solutions, which can be costly and time consuming if conducted in a field experiment. Therefore, the aim of this study is to design a simulation system to represent the application of precision feeding in a typical Vietnamese pig farm. The simulations from the system provide an overview of different methods to design and operate precision feeding techniques in Vietnam.

The rest of this paper is organized as follows. Section II presents the fundamental methods used in our proposed model and simulation of the precision feeding systems (PFS). Section III describes the feeding models and their implementation on a simulation platform. Section IV reports some preliminary results of experiments on simulations of classical feeding and precision feeding models, and from that we also give some discussions. Finally, Section V presents related work and Section VI concludes the paper.

## II. METHODOLOGY

### *A. Agent-based modelling*

Modelling based on agents is a technique that occurred in the 1990s. It aims to model the real-world on the basis of what are termed agents for different things. Agents exist together in an in-silico world and have characteristics and behaviors. They can also change and influence each other [7]. A system is modelled as a collection of autonomous decision-making agents for agent-based modeling. Each agent evaluates its particular circumstances and decides on further actions based on a group of rules. An agent may conduct various behaviors, such as production, consumption or sales, in line with the system it represents. Competitive interactions between agents are features of agent-based modeling (ABM) that rely on computer power to investigate dynamics that are outside the scope of mathematical approaches.

Precision feeding represents a paradigm shift in pig feeding, because the optimum dietary nutrient level is not seen as an attribute of static population but as a dynamic process that for each animal evolves independently according to its own intrinsic (e.g., genetics, health, production status, etc.) and extrinsic (e.g., management, environmental and social stressors, etc.) modulating factors [8]. Because of this dynamic, we have selected ABM as the most suitable method for simulating precision feeding systems. This approach implies modelling each single pig in its surroundings and monitoring its behavior during the observation period while it is interacting with the feeding system.

### *B. Feed intake*

As described by Nguyen-Ba et al. [10], we hypothesize that there is an ideal trajectory curve of feed intake, which is the amount of feed that a pig desires to eat when it is not facing any perturbation. This curve corresponds to the requirement of an animal in the ideal situation. We have chosen to develop the targeted trajectory of CFI which, unlike daily feed intake (DFI), does not contain huge variations. In addition, the CFI informs us about the history of consumption of the animal. Unlike DFI, CFI (as a trajectory) allows for the effect of disturbance and the effect of compensatory consumption to be taken into account. The derivative of the targeted trajectory of the CFI (target CFI) represents the targeted daily feed intake (target DFI). The model of the target CFI must respect the following conditions (i) it must not capture the variations linked to perturbations, (ii) the target DFI is an increasing or constant linear function (to respect the biology of growing pig), which implies that the target CFI is described by a quadratic-linear function. To estimate the target CFI, a statistical procedure was developed to perform several successive linear regressions and to temporarily eliminate all data that could originate from perturbations (i.e., data with negative residuals) from a dataset. This procedure results in a target CFI that does not include perturbed data. Consequently, the derivative of this function is the target DFI.

### *C. Automatic feeding system*

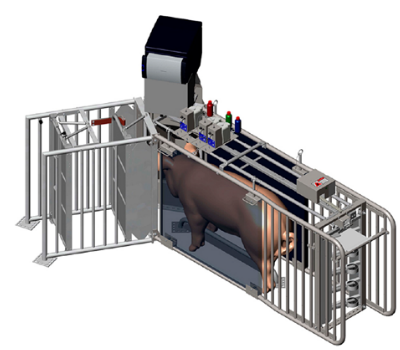


Fig. 1: An example of an automatic feeding station with controlled access for pigs [5].

Detailed descriptions of different types of automatic feeders were reviewed by Maselyne et al. [5]. First, each individual pig in the group has to be identified by attaching a Radio Frequency Identification (RFID) ear-tag to the pig. These ear-tags carry a unique code and a transponder for each pig. The feeder needs to be equipped with an antenna or reader system to recognize these codes. When the pig enters the feeder, the antenna captures the signal of the RFID ear-tag and information of this pig is registered to the computer control system. Feeding stations are often equipped with entrance and exit gates, protective crate and one or more feed troughs (Figure 1). They ensure only one pig can enter at a time. After a pig enters the feeding station, a limited amount of feed is distributed to the trough either upon request by the pig (e.g. by lifting a lever) or automatically if the trough is mounted on a load cell. Based on the registration of the unique RFID ear-tag, the nutrient compositions of the diet can be formulated according to the requirements of that pig. After each visit, the quantity and duration of feed consumption is registered for each pig. A pig may visit feeders a few times per day. The raw data of all visits and feed distributions can then be processed further into more aggregated traits (e.g. daily feed intake, feeding rate, number of visits).

## III. Simulation of precision feeding systems for swine

### A. Model

The agent-based model simulated a pig pen with a precision feeding system that was capable of tracking individual pigs. In the model, process of each pig being fed a certain amount of feed from the smart feeder was simulated. Growth capacity of pig was assumed to be dependent only on the amount of feed it was fed. Pigs entered the feeding system in a queue according to FIFO rules: the first one could eat first and if this pig finished, it would be the next pig's turn. The computer simulation system collected, processed and analyzed all the data related to the individual pig's meals and sent them to the computer simulation system. The model also defined some areas in the pig pen as follows:

- Life area: The area where pigs stayed when not eating
- Weighing area: An electronic weight scale was attached to the door of the feeder system, linked to a screen that showed the weight of each pig when standing on it. On the scale, there was a part that identifies each pig's ID through an RFID chip and transferred this identity to a computer. The weight of each pig was recorded to compute its nutritional requirement.
- Feeding area: An automatic feeding station consisted of several troughs, each trough could only keep one pig at a time, and an exit door for pigs to return to the Life area from the Feeding area. When a pig entered the trough, the RFID ear tag attached to the pig sent its ID, nutritional requirement and historical CFI to the computer system. Upon receiving the request, the computer system started mixing feed types with a calculated ratio to give a reasonable feed amount for that pig. When finished eating the pig left the Feeding area and could not go back. At this point, the pig stayed in the Life area and waited until the next visit.
- Sorting pen: the area that sorted sick or infected pigs, these pigs needed to be isolated from the rest of the herd.

In addition, an agent corresponding to an individual pig had the following attributes:

- ID: was the identify number of a pig which was attributed by the RFID ear tag mounted on the pig's neck.
- Sex: represented the sex of the individual pig (male or female).
- Age: was the age in days of the individual pig.
- Size: was the size of the individual pig.
- Weight: was the weekly weight of each pig.
- Daily feed intake: represented the daily amount of feed that an individual pig was loaded with.
- Cumulative feed intake: represented the accumulation of feed intake from the start of using the smart feeding system until the simulated day of an individual pig.

In addition, individual pigs could also perform some basic actions such as moving, entering the trough, eating, and coming out of the feeding system. Target daily feed intake of a pig was pre-calculated through the target CFI equation proposed by Nguyen-Ba et al. [10]. The pig body weight (BW) in a week **W** was estimated based on the mono-molecular equation of Thornley et al. [9]:

$$W = W_f - (W_f - W_0)e^{-kI} \tag{1}$$

where I is CFI (kg), k (/kg) is a positive rate parameter, $W_f$ is the final weight, and $W_0$ is initial body weight of the pig.

### B. Dataset

Details of the dataset was described by Nguyen-Ba et al. [10]. The dataset with 13954 entries was recorded by electronic feeders similar to those described by Labroue et al. [11], which included information regarding the identification, daily feed intake, and weekly weight of each of 116 growing-finishing pigs. The data were collected completely objectively by the system without the intervention of the farmers. From the dataset, twenty pigs selected from the same lot (i.e., they were born on the same farm and on around the same day) were used in our simulations. At 69 days of age, the pigs entered the same farm and remained there until they reached slaughter weights (124 kg on average). The pig that stayed the longest in the herd was at 211 days of age.

### C. Implementation on GAMA

*1) Design of Graphical User Interface:* The graphical interface included a screen that showed a pig pen and an automatic feeder system with the ability to monitor the activity of each individual pig. This interface was shown in Figure 2. The area (I) corresponded to the Life area in the simulation model, which was the living area of the pigs, the area (II) was the entrance of the feeding area which attaches a weight scale, corresponding to the Weighing area in simulation model. The scale was only activated once per week for each pig, the area (III) was where the feeding system located. It consisted of 5 automatic troughs, each trough could only host one pig at a time. When a pig entered the trough, the other pigs must choose another trough, the area (IV) was the exit gate from the feeding area to return to the living area. In synchronizing to feeding, a computer system recorded the amount of food the pig has eaten. For the simulation purpose, we assumed there were four groups of pigs in the pen. The figure showed specifically that the first group was at the exit, the second

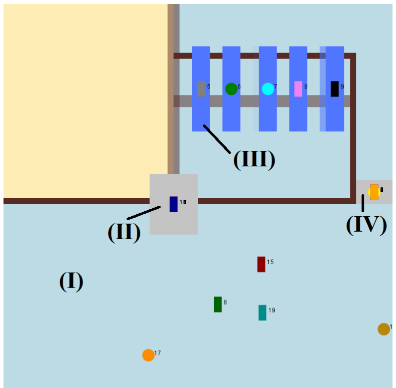



Fig. 2: The design of the graphical interface implementing the model of a precision feeding system on the GAMA simulation platform. Rectangles represent male pigs with the ID next to them, circles represent female pigs also with its ID nearby.

group was eating and the third group was at the entrance and was stepping on the scale. The remaining fourth group that had no feeding desire and was still in the Life area.

In addition, the interface also included a number of graphs showing CFI of each animal of the pig herd and comparing individual pigs with each other. Moreover, charts of BW of individual pigs in the herd were also provided.

*2) Workflow of the Simulation System:* Our proposed precision feeding model was simulated in GAMA platform [12], a development environment for building spatially explicit agent-based simulations. With the selected 20 pigs divided into 4 groups, the simulation simulated the process of each pig being fed a certain amount of feed from the smart feeder. The pig grew according to the amount of feed it was fed. Each cycle of the simulation corresponded to 3 hours of life for the pig herd. Since the dataset we used recorded the growth period of pigs from 69 to 211 days of age, the simulation had 1145 cycles.

Each time an individual pig entered the entrance of the feeding area:

- The simulated electronic scale connected at the gate weighed the pigs and sent the data to the computer system that simulates computations on GAMA, from which a chart related to the weight can be built.
- A daily feed amount was calculated and prepared by the computer simulation system in the trough for each individual pig to meet the target CFI volume computed in advance according to the equation of Nguyen-Ba et al. as mentioned in Section III-A.
- After stepping out of the entrance, the group of pigs went to the feeder system and left the entrance area for the next group of pigs. Upon entering the smart feeder, the pigs begun to eat and the DFI was added to the CFI. Body weight (BW) of a pig in a week was calculated by Equation (1) with the $k$ parameter varied between 0.0024 and 0.0027.
- After eating, the group of pigs went to the exit to return to the Life area.

These activities were repeated in the same way with the next groups of pigs and day after day until the simulation stops.

## IV. Experiments and Results

In the first experiment, we performed simulations on GAMA with the input was observations of the DFI and BW values of each pig taken directly from the dataset described in Section III-B. This scenario simulated the operation of classic automatic feed dispensers designed by Labroue et al. [11]. These automatic dispensers provided feed in the trough to pigs according to a fixed rate for the whole herd. In our experiment, the trough was being refilled up to 1.2 kg approximately if the amount of feed after the last visit of pig stays below 0.4 kg (similar to Labroue et al.). Figure 3 showed a graph of BW of 20 experimental pigs during the observation period. Due to the space limit, CFI lines of the 20 pigs were omitted. In the observation, there were some pigs that left the herd early due to various reasons (slaughter departure, quarantined, moved, etc.), the BW of these pigs from the time of leaving, shown in Figure 3, were no longer increased.

In the second experiment, we ran simulations with synthetic data on the DFI and BW of each animal, estimated according to the equation of Nguyen-Ba et al. [10] and Equation (1) of the precision feeding model, respectively. With the application of these formulas, each pig was limited to the maximum amount of feed intake per day according to the threshold calculated for each swine from the target CFI function. In this experiment, pigs were assumed to stay in the herd until 211 days of age (corresponding to the day $142^{nd}$ of the simulation). We ran each simulation 10 times and averaged the results. The simulation results of CFI of the pig that stayed the longest in the herd were shown in Figure 4a (the pig ID 9 left on the day $142^{nd}$) and of the pig that left the herd earliest were shown in Figure 4b (the pig ID 11 left on the day $127^{th}$). The time of leaving the herd of these pigs was taken from the observation used in the first experiment. It was shown that until the pigs left the herd, the simulation results with the synthetic data were similar to the simulation results with the real data. After leaving the herd, it is a fact that the animal's CFI did not increase. However, in the simulation with synthetic data, because the pigs stayed until the last day of the experiment, the CFI curve continued to increase. As a result, we can obtain a prediction of the CFI of the animals if kept until the last day of the experiment. For instance, the pig ID 11 would be able to eat an average of 20 kg feed more if it stayed for another 15 days.

Figure 5 showed the simulation results of the BW of the precision feeding model on the day of slaughter (the last experimental day) of all 20 experimental pigs. We found that the precision feeding approach resulted in a uniform weight in the range of 102 to 112 kg. To be able to provide maximum numbers of animals in an appropriate BW range, and to prevent too large variation in the slaughter weight (which in turn impair their carcass sale), the control of the BW

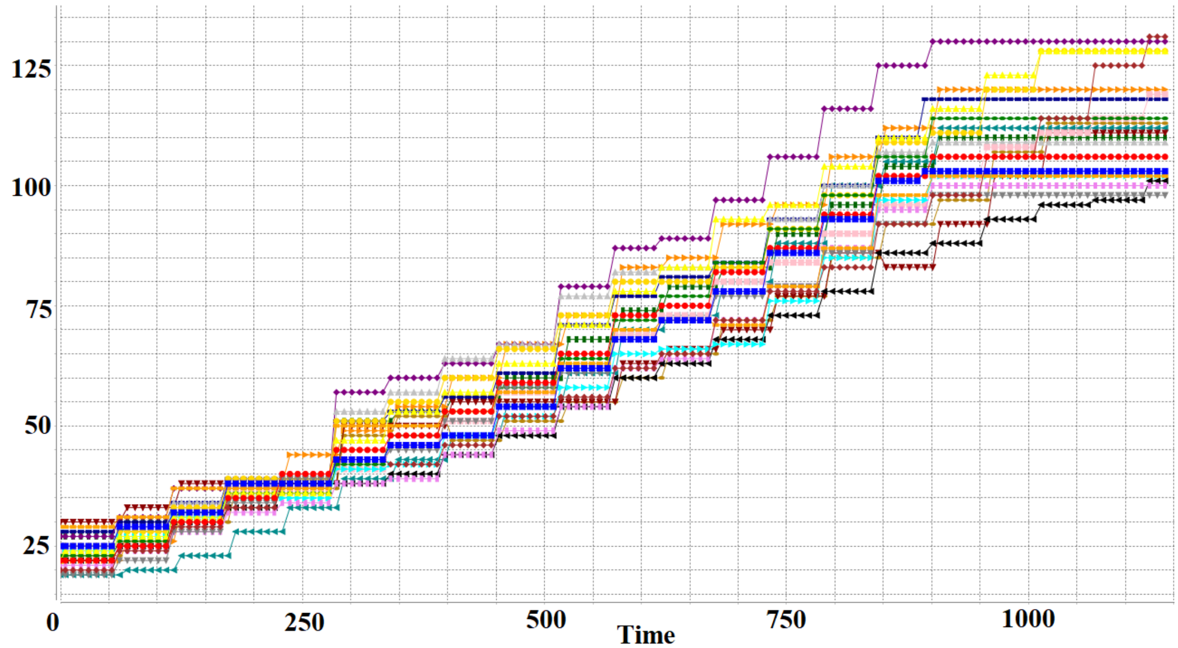
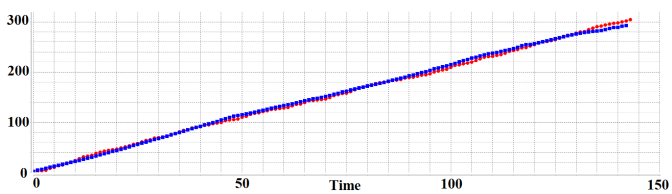
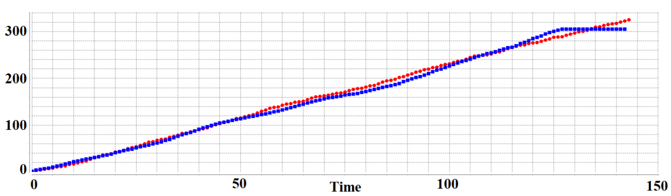



Fig. 3: BW of 20 experimental pigs during the observation period according to Labroue's classic feeding model.




(a) CFI - ID 9




(b) CFI - ID 11

Fig. 4: Simulation results comparing the CFI of the same pig leaving the herd a) the latest (ID 9) and b) the earliest (ID 11) in the two scenarios of classic feeding (blue line) and precision feeding (red line).

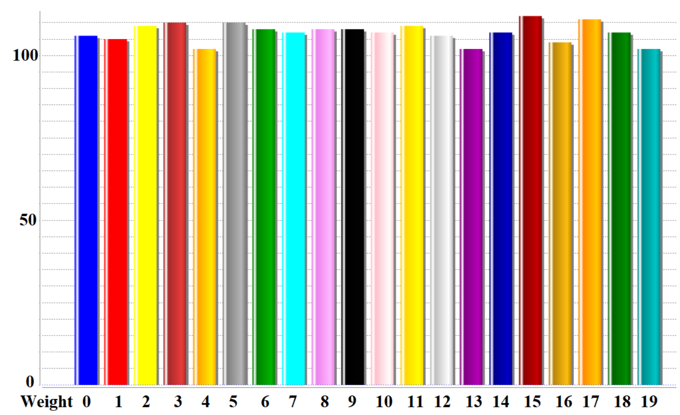



Fig. 5: Simulation results of the BW of all 20 experimental pigs with the precision feeding model on the day of slaughter (last experimental day).

variability at slaughter was crucial. This experiment indicated that simulations were necessary to anticipate the level and variability in the performance of group-housed pigs and that variability may be controlled by feeding strategies. Future studies involve evaluating the scalability of the system as the number of target pigs as well as the number of smart feeders increases in both computational and physical aspects.

## V. Related Work

Using modeling and simulation to support decision making is a fairly common approach in precision breeding. The benefits of such systems are often focused on improving animal productivity/welfare or reducing Greenhouse gases (GHG) emissions. To be able to achieve these purposes, three types of simulation are commonly used: discrete-event simulation (DES), continuous simulation (CS), and agent-based modeling (ABM). Some studies use DES to model system operations as a sequence of events over time, such as the work of Bruijnis et al. [13] and Sorensen et al. [14]. Studies using CS can solve problems of dynamic systems by analyzing feedback information between qualitative and quantitative factors through continuous loops. With this research direction, the authors have built mechanistic simulation models of small ruminants [15], and goats [16]. In the same vein, Parlavantzas et al. [17] and Pham et al. [18] developed epidemic models on dairy herds.

Agent-based modeling not only solves the dynamic problems of the system, but also helps the system designer to understand thoroughly about the components as well as the interactions between the components of that system. In order to decide on cow replacement, Al-mamun et al. [19] have created a multiscale ABM of simulation for a dairy herd, integrating inputs from individual animals and the whole population. Matthews and Bakam introduced the PALM model in 2007 [20], which combines biophysical modeling with an ABM approach for GHG reduction through economic strategies, such as incentives for low emission land use or taxation. The simulation results are used to discuss the consequences of the policies on farmers' lives.

Only Pomar et al. [21] has built an ABM simulation framework to implement virtual prototypes for precision feeding systems for domestic pigs using NI LabView's G programming language. Although the application of the framework shows the detailed operation and interaction of the reusable components in the operating model of the devices, the simulation of individual pigs is not covered. Our approach to simulating a PFS for the pig herd not only simulates the activities taking place on the hardware devices, but also shows the pig herd's own interaction with the system and vice versa.

## VI. Conclusion

Precision feeding systems will be the future of the pig industry. With such a system, farmers can save feed costs, increase productivity or commercial meat quality, and reduce emissions to the environment. However, to be able to implement, such a system requires a lot of investment that will be a burden for smallholder farmers or small research groups. Therefore, the simulation system based on ABM models is the proper solution helping to show the dynamics of the system from the movements of animals to their continuous interactions with the system compositions. Actually, simulation not only reduces experiment and test expenses, but also improves design quality, as knowledge on the system's conduct and performance is accessible early in the development process. Our simulation system built on GAMA using herd and individual feeding models have contributed to demonstrating the usefulness of precision feeding systems and has also produced a number of predictions helping the decision-making of farm managers.

## Acknowledgment

The authors would like to acknowledge Asia Research Center, Vietnam National University, Hanoi (ARC-VNU) and CHEY Institute for Advanced Studies (CIAS) [grant number CA.20.9A] for financial supports.

## References

[1] FAO 2009. How to feed the world in 2050. Retrieved on 16 July 2021, from http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf

[2] Brossard, L., Dourmad, J.Y., Garcia-Launay, F., Van Milgen, J., 2017. Chapter 10 – modelling nutrient requirements for pigs to optimize feed efficiency. Achieving sustainable production of pig meat Volume 2. Burleigh Dodds Science Publishing, 2018. 207-230.

[3] Pomar, C., Hauschild, L., Zhang, G. H., Pomar, J. and Lovatto, P. A. (2009), 'Applying precision feeding techniques in growing-finishing pig operations. L'utilisation d'une alimentation de precision chez les porcs à l'engrais', In Proceedings of 45th Eastern Nutrition Conference of Canada, pp. 103–16. Animal Nutrition Association of Canada, Quebec, Canada.

[4] Andretta, I., Pomar, C., Rivest, J., Pomar, J. and Radünz, J. (2016), 'Precision feeding can significantly reduce lysine intake and nitrogen excretion without compromising the performance of growing pigs', Animal, 10(7), 1137–47.

[5] Maselyne J, Saeys W and Van Nuffel A 2015. Quantifying animal feeding behaviour with a focus on pigs. Physiology & Behavior 138, 37–51.

[6] Law on Veterinary Medicine 2015, No. 79/2015/QH13, National Assembly of Vietnam.

[7] Casti, J.L.: Would-be worlds: how simulation is changing the frontiers of science. J. Wiley, New York (1997).

[8] Pomar, C., J. Pomar, J. Rivest, L. Cloutier, M.-P. Letourneau- Montminy, I. Andretta, and L. Hauschild. 2014. Estimating real-time individual amino acid requirements in growing-finishing pigs: Towards a new definition of nutrient requirements in growing-finishing pigs?

[9] Thornley, J.H.M., France, J., 2007. Mathematical Models in Agriculture, second ed. CABI Publishing, Wallingford, UK, 923 pp.

[10] H. Nguyen-Ba, J. van Milgen, and M. Taghipoor, "A procedure to quantify the feed intake response of growing pigs to perturbations," Animal, vol. 14, no. 2, pp. 253–260, 2020.

[11] F Labroue, R Guéblez, P Sellier, M.C Meunier-Salaün, Feeding behaviour of group-housed large white and landrace pigs in french central test stations, Livestock Production Science, Volume 40, Issue 3, 1994, Pages 303-312, ISSN 0301-6226.

[12] GAMA platform, urlhttps://gama-platform.github.io/wiki/Tutorials

[13] Bruijnis, M. R. N., H. Hogeveen, and E. N. Stassen. 2010. "Assessing Economic Consequences of Foot Disorders in Dairy Cattle Using a Dynamic Stochastic Simulation Model". Journal of Dairy Science 93(6):2419-2432.

[14] Sørensen, A. I. V., N. Toft, A. Boklund, C. Espinosa-Gongora, K. Græsbøll, J. Larsen, and T. Hisham Beshara Halasa. 2017. "A Mechanistic Model for Spread of Livestock-Associated Methicillin-Resistant Staphylococcus Aureus (LA-MRSA) within a Pig Herd". PLoSOne 12(11):1-18.

[15] Tedeschi, L. O., C. F. Nicholson, and E. Rich. 2011. "Using System Dynamics Modelling Approach to Develop Management Tools for Animal Production with Emphasis on Small Ruminants". Small Ruminant Research 98(1):102-110.

[16] Guimarães, V. P., L. O. Tedeschi, and M. T. Rodrigues. 2009. "Development of a Mathematical Model to Study the Impacts of Production and Management Policies on the Herd Dynamics and Profitability of Dairy Goats". Agricultural Systems 101(3):186-196.

[17] Parlavantzas, N.; Pham, L.M.; Morin, C.; Arnoux, S.; Beaunée, G.; Qi, L.; Gontier, P.; Ezanno, P. A Service-based Framework for Building and Executing Epidemic Simulation Applications in the Cloud. Concurr. Comput. Pract. Exp. 2020, 32, e5554.

[18] Pham, M.L.; Parlavantzas, N.; Morin, C.; Arnoux, S.; Qi, L.; Gontier, P.; Ezanno, P. DiFFuSE, a distributed framework for cloud-based epidemic simulations: A case study in modelling the spread of bovine viral diarrhea virus. In Proceedings of the 2017 IEEE International Conference on Cloud Computing Technology and Science (CloudCom), Hong Kong, China, 11–14 December 2017.

[19] Al-Mamun, M. A., and Y. T. Grohn. 2017. "Mabsdairy: A Multiscale Agent Based Simulation of a Dairy Herd". In Proceedings of the 50th Annual Simulation Symposium, April 23rd-26th, Virginia Beach, Virginia, 1-12.

[20] Matthews, R., and I. Bakam. 2007. "A Combined Agent-Based and Biophysical Modelling Approach to Address GHG Mitigation Policy Issues." In Proceedings of the MODSIM International Congress on Modelling and Simulation, edited by L. Oxley and D. Kulasiri, 10-13. Christchurch, New Zealand: Modelling and Simulation Society of Australia and New Zealand Inc.

[21] Pomar, J., V. López, and C. Pomar. 2011. "Agent-Based Simulation Framework for Virtual Prototyping of Advanced Livestock Precision Feeding Systems". Computers Electronics in Agriculture 78(1):88-97.