Using gaussian process metamodels for sensitivity analysis of an individual-based model of a pig fattening unit

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Pig livestock farming systems face economic and environmental issues. To cope with themand identify innovative strategies different models have been developed to predict performance of fattening pig production. However, most of them do not account for the interactions between feeding strategies, management practices, variability of performance and requirements among pigs. Recent studies have highlighted the added value of individual-based models to quantify the effects of feeding practices on technical and environmental performance of a group of pigs (Brossard *et al*., 2014).Our objective was to develop a pig fattening unit model able i) to simulate individual performance of pigs including their variability in interaction with the farmer's practices and decisions and ii) to evaluate the effects of these practices and decisions on the technical, economic and environmental performance.

The fattening unit model is a discrete-event mechanistic model, stochastic for biological traits (intake and growth potential of pigs, risk of mortality), with a one-day time step.The pig fattening system articulates three subsystems: a biophysical, an operating, and a decision system. The biophysical system contains the fattening pigs. The operating system includes the resources (feeds, fattening rooms), applies the manager's rules to the biophysical system and allocates resources to each activity in the farm. The decision system is represented by the manager (the farmer) who decides, manages, and controls the operating system, and indirectly the biophysical one. The manager receives information from the biophysical system and from the agenda of events each day. According to this information it updates the agenda through the addition/removal of tasks. Practices are inputs of the model, as well as feed composition.The practices include batch management, pen filling practices, feeding practices and slaughter delivery practices.Pigs are represented using an individual-based model adapted from the InraPorc model (van Milgen *et al*., 2008). This individual-based model simulates the feed intake, body protein and body lipid deposition, and the resulting growth and nutrient excretion of each pig, on a daily basis.

The model is here applied on a typical pig fattening unit in terms of size, batch management, and feeding strategy. The simulation run on 1000 days and performed the dynamic growth of 47 batches(i.e. from 4700 to 42300 pigs). The chosen interval of 21 days between two successive batches corresponds to the main figure in French pig farms. We considered 5 fattening rooms, with the use of an extra-room for the management of too-light pigs. The feed rationing plan simulated the *ad libitum* distribution of feed. The feed sequenceis a ten phase planmixing two feeds shifting progressively from a 100% grower to a 100% finisher feed. These plans were applied using the mean weight of pigs from the same pen as transition criterion. The range of slaughter body weight for carcass payment without penalties was between 105 kg to 135 kg, in whichthe optimal range for carcass payment was between 112 kg to 127 kg, when referring to the French payment grid for lean meat content and carcass weight. For these simulations we controlled the stochasticity by setting the seed in order to have the same scheme of mortality between the simulations. The pig profiles (5 parameters driving growth potential and intake curve)were given as inputs to the model from a dataset containing 1000 female profiles and 1000 male profiles(Brossard *et al*., 2014).

The model outputs used for the sensitivity analysis are average values forthe slaughter age, the slaughter weight, the amount of phosphorus and nitrogen excreted per pig over the fattening period, the lean content per pig, the feed conversion ratio, the total feeding cost per pig, the daily gain, the percentage of pigs in the slaughter weight range, and the one in the optimal range of slaughter weight. Considering the running time for one simulation (around 10 mins), we chose to use Gaussian Process Metamodels to reduce the time cost of the sensitivity analysis. One metamodel was built per output from 100 simulations of the model, using Latin hypercube sampling rescaled with the chosen parameter's distribution. Table 1 shows the 14 parameters tested in the sensitivity analysis and the distribution and bounds associated. The parameters feed, phosphorus, nitrogen and amino acid intakeare mainly for checking the behaviour of the model and its correct implementation by expertise. The area per pig and rate of pigs per room aimed to evaluate the sensitivity of the model to density of pigs in pen. The parameters cleaning-disinfectionand drying period, size of extra-room and maximum time fatten in extra-roomare mainly for evaluate the effect of the duration of the fattening period on the model. The number of place per pen and number of pen per room aimed to study the impact of the size of the farm on the model. The minimum number of pig per delivery to slaughterhouse and tolerance on the number of pig delivered compared to the announcement are mainly to evaluate the effect of the constraint on delivery on the model. The mortality rate aimed to check the effect of this part of the animals' characteristics on the model. The extended Fourier Amplitude Sensitivity Test (eFAST) method (Saltelli *et al*., 1999) was used to perform the sensitivity analysis on the metamodels, using N = 1500 scenarios for each trajectory, which indices 21000 simulations of each metamodel. We performed the sensitivity analysis using the *fast99* (Pujol*et al*., 2015) function in R 3.2.2.

Figure 1 shows the results of the sensitivity analysis. Figure 1.A gives the coefficients of variation of the model's studied outputs. This graphwas built using the metamodels output values obtained from the input sequences of the scenario considered above. The greatest variations were observed for the quantity of phosphorus and nitrogen excreted per pig, and the percentage of pigs delivered in the optimal weight of range. These variations of phosphorus and nitrogen excretion are explained respectively at 85% by intake of phosphorus, and at 84 % by the intake of nitrogen. Concerning percentage of pigs in optimal weight range, 38% of the variation is explained by the number of days of the drying period, 18% by the minimum number of pigs required to schedule a delivery, 14% by the quantity of feed intake, and 8% by the number of places per pen. Figure 1.B shows the average sensitivity indices of the 14 inputs investigated among all theoutputs. Feed intake explains 37% of the total variation of the model outputs, in particular lean content (88%), average daily gain (88%),feed conversion ratio (59%), feed cost per pig (43%), slaughter weight (25%) and percentage of pigs in optimal weight range (14%). The duration of the drying period explains 31% of the total variation of the model outputs, in particular slaughter age (75%), slaughter weight (52%), feed cost per pig (44%), percentage in optimal weight range (38%) and feed conversion ratio (32%). Phosphorus and nitrogen intake explaineach 11% of the total variation of the model outputs. The minimum number of pigs required to schedule a delivery explains 10% of the total variation of the model outputs, in particular percentage of pigs in weight range (34%) and in optimal weight range (18%). The other inputs explain less than 5% of the mean total variation among all the outputs. The maximum of variation explained by the number of places per pen was 16% through the percentage of pigs in weight range.

In conclusion, the sensitivity analysis allowed us to check by expertise that the response of the model corresponds to the results expected, to detect the last informatics errors and correct them, and to identify the less-sensitivity parameters which can be set for routine use.In this paper we used the first step development of a fattening unit model for the prediction of technical performance. The following step will be to predict the economic results and the environmental impacts at farm gate using LCA. In addition of the sensitivity analysis, an analysis by virtual experiments will be performed on the model.

Table 1. Parameters and associated distribution used for the sensitivity analysis of the model

Parameter	Lower boundary	Upper boundary	Distribution law
Feed intake (Proportion of InraPorc intake)	0.95	1.05	Uniform
Drying period (day)	0	6	Discrete uniform
Phosphorus intake (Proportion of InraPorc intake)	0.9	1.1	Uniform
Nitrogen intake (Proportion of InraPorc intake)	0.9	1.1	Uniform
Min. nb. Pigs/delivery (pig)	10	190	Discrete uniform
Nb. Places/pen (place)	10	30	Discrete uniform
Nb. Pens/room (pen)	10	30	Discrete uniform
Delivery tolerance (Proportion of number of pigs)	0	0.15	Uniform
Size of extra-room (Proportion of farm size)	0	0.15	Uniform
Amino acid intake (Proportion of InraPorc intake)	0.95	1.05	Uniform
Mortality rate (dmnl.)	0.01	0.05	Uniform
Rate pigs/room (Proportion of room size)	0.9	1.1	Uniform
Max. time in extra-room (day)	7	63	Discrete uniform
Area/pig (m²)	0.6	1	Uniform

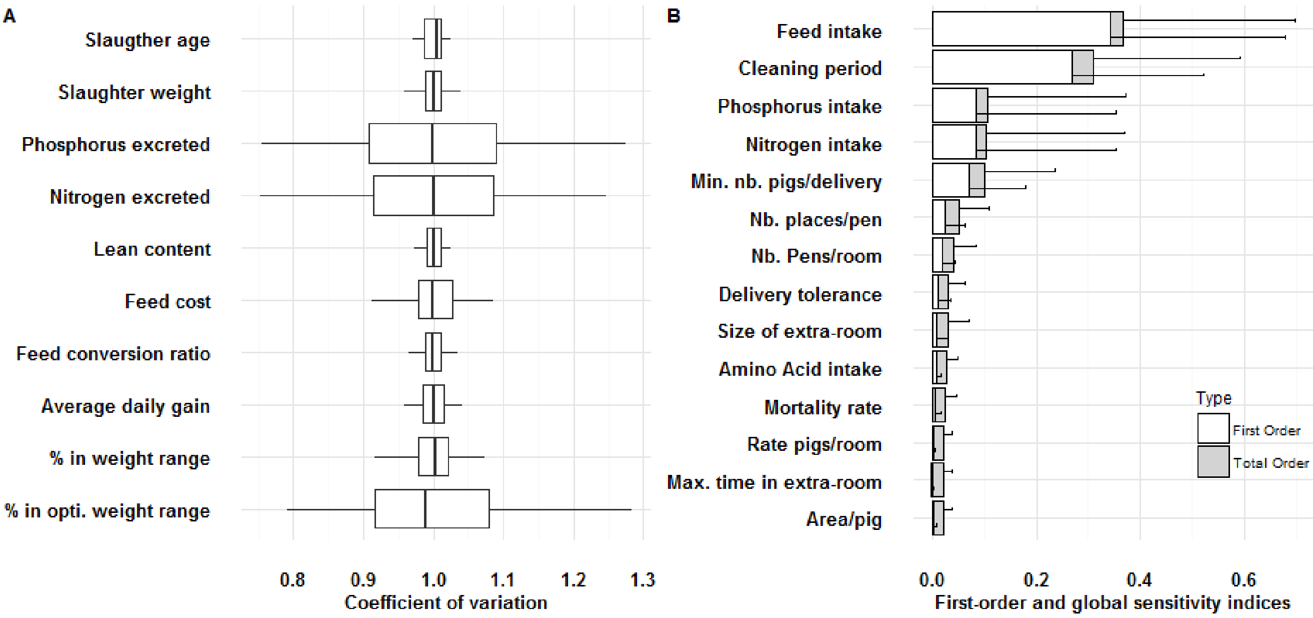

Figure 1. Results of the sensitivity analysis A) coefficients of variation of main outputs of the model and B) average sensitivity indices of the inputs investigated (among all the outputs)

References

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