Simulation of vegetal raw materials utilization in poultry production chains: a multi-agent modelling approach

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Regulation and technology evolutions may impose a better control of the poultry feed production system to deal with the variation of vegetal raw materials uses. Consequently, it is necessary to develop learning and decision-aid tools that can be used by domain experts (scientists and professionals). The aim of this work is to propose a new simulation method that can represent, on the one hand, the dynamics of raw materials as a feed compound as well as poultry markets, and on the other hand, the evolution of individual and collective decision-making processes within poultry firms. Our simulation model, called AviSim, aims at evaluating the raw materials uses following individual psychological behaviours in respect to the use of feedstuffs i.e. the agent has careful, moderate or optimistic behaviour regarding a given raw material and relates it to its level of inclusion. AviSim also includes social influence parameter to estimate the impacts of the social layer on the evolution of the production process i.e. each agent’s decision depends on his relationship with the other ones either as leader, follower or pragmatic person.

Several utilizations of this model are performed or scheduled: within firm discussions around the simulations to stress behavioural influence on the firm dynamics, utilization at the poultry production chain level to quantify the effect of a feedstuff reputation on its fate.

Keywords: poultry production chain; multi-agent system; feedstuffs utilization;

Introduction

Regulation and technology evolutions may impose a better control of the poultry feed production system to understand the quantitative variations of vegetal raw materials uses. Existing approaches to estimate the use of raw materials within poultry firms are only based on feed formulation using linear or nonlinear programming. The first category is a least-cost method and the second one is based on stochastic programming where the variability of nutrients is considered.

Understanding the evolution of the use of raw materials in the production of poultry feed is an issue raised by several public and private firms. In fact, the elaboration of alternative production and supply strategies involves the building of new learning and decision-aid tools used by domain experts (scientists and professionals).

To be supplied with raw materials, poultry firms consider formulation methods. Supply strategies are mainly based on economical and/or nutritional parameters. According to these parameters, poultry feed formulas may change following a variation in the cost ranking between materials, or due to large variations of their nutrient characteristics. Formulation methods try to find solutions that maximize the economic profit of firms, insure the best product quality, and satisfy the nutritional constraints.

Adaptation of poultry diet formulas follows several decisions rules applied on the feed formulation process. For instance, using linear programming, the problem of the variability of nutrients has been addressed by the inclusion of a margin of safety (Nott and Combs, 1967). This method may over-corrects the amounts of nutrients in the poultry feed (Roush et al., 1996), and consequently can include

1 Multiple-Objective Programming (Zhang and Roush, 2002) and chance constrained programming are also considered as stochastic approaches (Roush and Cravener, 2002). “Stochastic” refers to the variability of nutrients and the probability of meeting the nutrient requirements.
a more expensive diet and a possible wastage of nutrients, leading to environmental pollution (Roush and Cravener, 2002). Stochastic approaches have been proposed to deal with this issue, and assume that nutrient variability infers a risk in the diets formulation. Contrary to linear programming, stochastic approach allows to consider several objectives (such as diet price and nutrient precision) when formulating diets. However, stochastic programming and linear programming (issued from operational research techniques) propose to build a system of equations and constraints (such as the system 1, presented below), which must be solved. These approaches are means to compute feed formulas, without considering the fact that the different equations and constraints are dynamic and result from the decision-making processes of firms’ actors. Collective decision-making processes define a mechanism of interactions between various disciplines (economic, nutrition, animal husbandry, etc.). Finally, to understand the use of raw materials, it is necessary to analyze how the formulation matrix is built, and to identify the factors that can influence its content. In this work, we consider that the formulation matrix defines a dynamic balance of the activities of a network of actors.

The aim of this work is to propose a new simulation method that can represent, on the one hand, the dynamics of raw materials for feedstuffs as well as poultry markets, and on the other hand, the evolution of individual as well as collective decision-making processes within poultry firms (Hamel et al., 2005). We propose to develop a method and a learning tool to understand the consequences of individual behaviours on the use of raw materials in poultry feed formulation process, following several production conditions. Our approach is a multi-agents based simulation. In this paper, first of all we briefly introduce a description of least-cost formulation principles and multi-agents systems background, which leads us to motivate this study. Secondly, we present the proposed multi-agents model’s architecture and define its functioning concepts. The last section proposes an example of possible case studies, and finally discusses the advantages and limits of our approach.

**Least-cost feed formulation principles**

Feed formulation is a process by which different feed ingredients are combined in adequate proportions necessary to provide the bird with proper amount of nutrients needed at particular age. Experts in nutrition use usually linear programming to formulate feed diet by calculating a least-cost formula. The standard form of the feed formulation problem is as follows:

\[
\begin{align*}
\text{Minimize} & \quad Z = \sum_{j=1}^{n} p_j \times x_j \to (j = 1,2,\ldots,n) \\
\text{Subject to} & \quad \sum_{j=1}^{n} a_{ij} \times x_j \leq (\geq) b_j \quad \text{and} \quad x_j \leq (\geq) c_j
\end{align*}
\]

where \( p_j \) = prices; \( a_{ij} \) = nutrient characteristics; \( b_j \) = poultry requirement and \( c_j \) = inclusion constraint

The aim of this model is to minimize the economical function (feed cost), according to economical constraints (raw materials prices) and nutritional constraints. This graphical representation of this problem is presented in figure 1 (right side of the figure).

**Multi-agents systems**

Multi-Agents Systems (MAS) are tools derived from Distributed Artificial Intelligence (DAI). MAS represent a real system as a set of autonomous entities, called agents, which can interact to achieve collective objectives. This modelling approach is used to simplify problem-solving processes by dividing the necessary knowledge into subunits, by associating an intelligent agent to each subunit, and by coordinating agents’ activities (Bousquet and Le Page, 2004).

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2 From there, we call this system the « formulation matrix ».
MAS have been used in several fields, such as Artificial Life, where several studies have been conducted on animal behaviours and animal societies. The ant hill metaphor provides a much-used illustration (Drogoul, 1994), bee colonies ( Hogeweg and Hasper, 1983), and “Boids” (Reynolds, 1987), which imitate the behaviour of groups of migrating birds. Other applications have been developed in several domains, such as telecommunications, internet, robotics and monitoring industrial processes.

**Understanding the use of raw materials**

As stated above, economical and nutritional parameters cannot accurately represent and explain totally variations of raw materials use. Considering this lack of understanding, we propose to study how human decision-making strategies may influence the formulation matrix. This study has to address the cooperative processes between the firm experts, to propose a modelling approach of multidisciplinary knowledge as well as mechanisms to use, to combine and to update this knowledge.

Each formulation process is characterised by the constraints used to compute the diet. In this process, nutritional and inclusion constraints are distinguished. In the one hand, advances in nutrition research (synthesis of several experiments) allow to define adequate nutrient requirements, such as the values defined by the NRC (1994). In the other hand, inclusion constraints depend generally on nutritionists’ experiences, technological constraints of manufacturers, and so on. Consequently, these constraints result from decision-making processes, subject to human influence.

**Proposed simulation model: AviSim**

To simulate the production process within poultry chains, we identified five classes of agents that represent several functions of the production system (Hamel et al. 2005, Figure 1). The proposed model provides a generic representation of the production process based on a simplified view of poultry chains. An agent is a computer program that encompasses specific domain knowledge, simulates and plays the activities of a set of experts (Table 1), which can specify decision-making strategies of the agent. Our simulation model, called AviSim, aims at evaluating the raw materials uses following individual psychological behaviours in respect to the use of raw materials and social behaviours. The purpose of AviSim is not to define a new formulation technique, but to represent the dynamics of human activities and decision to establish the formulation matrix.

**Table 1 : AviSim’s domain agents and their roles.**

<table>
<thead>
<tr>
<th>Agent</th>
<th>Roles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formulator</td>
<td>Provides cheapest diet formula following nutritional, technological and economic constraints</td>
</tr>
<tr>
<td>Integrator</td>
<td>Manages the relationships with chicken breeders and retailers</td>
</tr>
<tr>
<td>Purchaser</td>
<td>Looks for new raw material opportunities and negotiates the procurement agreements</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Manufactures animal feed and manages raw materials storage</td>
</tr>
<tr>
<td>Manager</td>
<td>Proposes global strategies and coordinates agents activities</td>
</tr>
</tbody>
</table>

AviSim simulates the poultry production process following four firms functioning layers, which consist of the simulation of (i) the upstream dynamics (raw materials market) and raw materials purchase processes (ii) feed formulation (iii) feed manufacturing and the management of raw materials storage (iv) and finally, poultry production planning evolutions. As defined in table 1, each agent simulates the activities of corresponding functioning layer. To simulate the dynamics of firm environments (raw materials poultry markets) we defined a conceptual agent, called EMA (Event Manager Agent). EMA generates randomly external events (such as raw materials opportunities), and firm agents react to these events. AviSim is based on a discrete simulation mode, where each simulation step represents one week of production. The simulation process evolves according to firm production objectives and domain agents behaviours.

The dynamics of the activities and decision-making processes of the domain agents have direct impacts on the content of the formulation matrix, and consequently on the raw materials use.
Agents’ roles and behaviours

To simulate the activities of a functioning layer, each domain agent can play a role in respect to a simulated scenario. A scenario defines a collective process between interacting agents to solve a specific problem. As an example, how to decide if a new raw material opportunity is relevant according to our goals? How to modify poultry feed formula following a decrease of animal’s growth? An agent role is defined using a set of activities, decisions and domain knowledge used by the agent to cooperate with the other firm agents.

Example: to decide if a new raw material opportunity (e.g. wheat) is relevant, the formulator, manufacturer and purchaser agents cooperate in an interactive decision-making process. Each agent uses his knowledge and intervenes to elaborate the final decision according to his functioning rules and constraints (see Table 2).

Table 2: New raw material opportunity scenario. Three agents participate. Formulator evaluates economic profit of the opportunity and the needed quantity, manufacturer manages the storage resource and purchaser negotiates the purchase modalities (price, quantity and delay).

<table>
<thead>
<tr>
<th>Sender</th>
<th>Receiver</th>
<th>Message content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchaser</td>
<td>Formulator</td>
<td>PROPOSE. Opportunity (wheat, price, wheat characteristics). Can we use it?</td>
</tr>
<tr>
<td>Formulator</td>
<td>Manufacturer</td>
<td>PROPOSE. A new wheat opportunity. Planning and stock possibilities?</td>
</tr>
<tr>
<td>Formulator</td>
<td>Manufacturer</td>
<td>COMMIT. I cannot use it before 07 days.</td>
</tr>
<tr>
<td>Formulator</td>
<td>Purchaser</td>
<td>OK! Formulator computes operation profit using the optimisation program.</td>
</tr>
<tr>
<td>Purchaser</td>
<td>Formulator</td>
<td>COMMIT. Yes, we can buy it, but wheat can’t be received before 07 days</td>
</tr>
<tr>
<td>Purchaser</td>
<td>Formulator</td>
<td>ACCEPT. OK! I negotiate the delay (final decision).</td>
</tr>
</tbody>
</table>

Playing a role, each agent may exhibit specific behaviour regarding some raw materials. These behaviours define the mechanisms used by the agents to undertake their decisions. In our study, we identified psychological and social behaviours (Hamel, 2006).

a. Psychological behaviour

The use of a feedstuff in feed formulation processes is influenced by its reputation which may support or decrease its utilization. Several factors may have a direct impact on the use a raw material, such as its nutrients variability, storage conditions, etc.

A psychological behaviour defines a psychological state that can be adopted by an agent regarding a feedstuff. In AviSim, an agent can adopt a careful, moderate or optimistic behaviour regarding a feedstuff, which relates its level of inclusion (maximal incorporation constraint).
b. Social behaviour

Definition: Individual decision-making processes of a firm agent are based on his psychological behaviours and his personality function.

A collective decision-making process involves the participation of several autonomous agents to establish the decision. The autonomy property means that an agent is able to build his own individual decisions (e.g. the manufacturer can accept or refuse to use a feedstuff in relation with storage resources) and have his own behaviours. From the social psychology theory, it has been showed that in collective contexts, the interactions between cooperative agents infer an influence between them (COSTA and McCRAE, 1992). The influence level depends on the personality of each participant. In our case, a firm agent can influence the other agents because they are interacting and due to the existence of dependency relationships (e.g. hierarchical dependency between the manager and the other firm agents). We define the personality function of an agent as a mechanism allowing him to make decisions regarding a feedstuff, following his own behaviours and the other agents’ behaviours (Figure 2). Three personality categories have been identified:

1. leader: the agent applies his own behaviours and doesn’t consider the others;
2. follower: the agent applies the behaviours of the other ones and ignores his own behaviours;
3. adaptive: the agent applies the optimized behaviours according to the economical and technical contexts. In this case, a reasoning procedure is necessary.

Experiments and case studies

Our simulator has been implemented using Java language. AviSim is a simulation software that can be used by poultry science experts (scientists and professionals) as a role-playing game (Hamel, 2006). Different participants to a simulation round have to define the simulation hypothesis and to run the simulation. AviSim simulates the production process and provides the results (feed rations, formula prices, used quantities of feedstuffs, an indicator of feed conversion ratios). The details of the simulation run (exchanges between agents, external events, undertaken decisions, etc.) can also be viewed. The purpose is to propose a pedagogical tool to understand the impacts of human behaviours on the evolution of the production process. Several utilizations of AviSim are performed or scheduled: within firm discussions around the simulations to stress behavioural influence on the firm dynamics, utilization at the poultry production chain level to quantify the effect of a feedstuff reputation on its fate. The use of AviSim can be focused on several case studies. For example, several public and private French organisms are willing to promote the use of rapeseed meal in poultry diets. This objective is argued by the inconsistency of existing approaches to estimate and explain accurately the variations of the inclusion levels of this feedstuff. Our study demonstrates that the reputation of the rapeseed meal in poultry feed formulation has an important effect on its fate. According to nutritionists this raw material infers a risk on animal’s growth. AviSim allows us to estimate the influence between firm actors, especially in the case of rapeseed meal, the social influence of nutritionists as well as their psychological behaviours. AviSim allows also the study of nutrient variability of rapeseed meal on
firm dynamics and consequently on its use. This function allows AviSim’s users to study the impacts of choosing hazardous strategies regarding the use of some feedstuffs.

**Discussion and conclusion**

AviSim proposes a new approach to estimate the consequences of the individual as well as collective decision-making behaviours on the use of raw materials in poultry feedings. It uses the notions of raw material reputation, psychological as well as social behaviours. These parameters were until now ill-represented in poultry feed modelling. AviSim also uses the notion of nutrient variability of feedstuffs, which provides necessary data for stochastic analysis studies.

The use of AviSim as a simulation platform based on role-playing games is the first contribution of this system. Indeed, this kind of simulation is used as a discussion mean, which allows domain experts to stress the impacts of several factors on raw materials utilization. Such discussions are supported using the temporal dimension of the production process, and the simulation details. The future AviSim’s challenge is its integration within poultry firms. This purpose may raise several difficulties, especially the definition of the best strategies to elaborate game-configurations (participants, initial hypothesis).

The development of AviSim pointed out the advantages of multi-agents systems to deal with various problems related to animal production chains. So, the study of poultry chains may be used as an example for a better integration of modelling techniques within agricultural organisations.

**References**


