Farm Ontology: a System Thinking approach for planning and monitoring farm activities

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ABSTRACT

Farm Ontology (FO) defines a new and flexible conceptual model used as unique standard in every task of farm modelling. FO considers the farm-system as a whole to achieve its structural and functional aspects in an integrated view. Planning and management tasks are included for a comparative analysis between expected and actual activities. Planning includes simulations of alternative scenarios, whilst management enables practical applications (e.g. operational monitoring, automated controls). FO considers the hierarchical decision levels (strategic, management, operational) and provides information for both ex-ante (comparative behaviour of alternative farming systems) and ex-post evaluations (satisfying traceability and process certification purposes). An efficiency index is computed comparing actual and expected performances, providing an appraisal of different types of Sustainability aspects. FO structure allows to consider, for example, precision agriculture as technological enabler to optimize global farm performance, or the global performance of farming systems in a given region.
Keywords: Farm sustainability, Farm modelling, Precision Agriculture, Decision Making

BACKGROUND

Despite historical difficulties of ICT acceptance in the agriculture, farmers appear now more available on an opening to these technologies. These the reasons: 1) the revolution of Industry 4.0 is conditioning many approaches of the agricultural sector, in particular as far as the adoption of Precision Farming techniques is concerned; 2) the awareness that digital methods can lead to economic advantages over the medium term, as well as reduce the charge of some bureaucratic tasks (eg certification and traceability); 3) the new entrepreneurial generations are more familiar with ICT and less scared by SSD and MSS digital tools; 4) the need of integrating environmental aspects into many farm decisional processes through tools able to provide the necessary cognitive supports, without the claim of being an expert in the field; 5) the growing interest of local administrative governments in the automated monitoring of farm performances in a territory for policy planning of preventing controls. ICT solutions currently available to farmers for the most part are designed to meet a specific need (e.g. warehouse or livestock management, farm site-specific distribution, etc.) (Pierce and Elliot, 2008). However, they generally preclude the possibility of integration in case the use of more farm management procedures is required. The need to define a more "flexible" conceptual model to be used as unique standard reference in every task of farm modelling is nowadays felt more than ever.

SCOPE

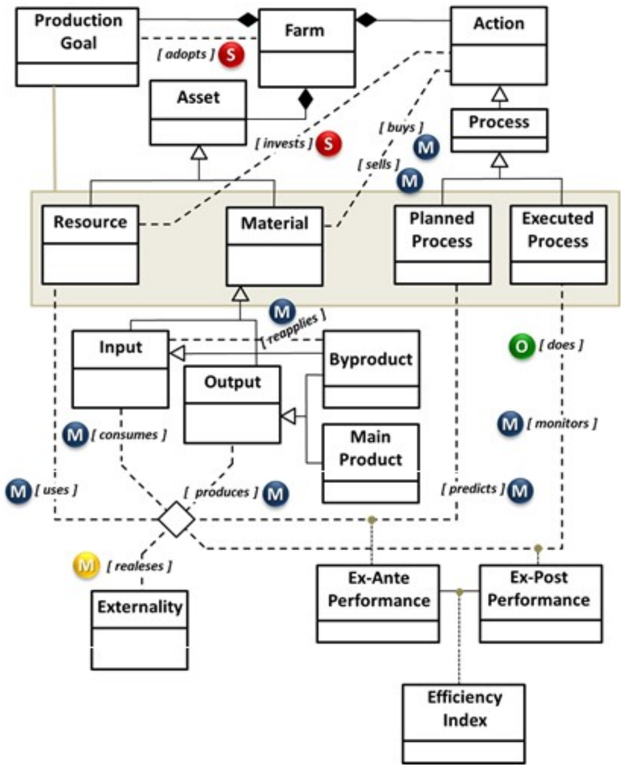
The paper suggests an approach to share a new "*Farm Ontology*" (FO) able to define a farm configuration that considers the farm-system as a whole, so one can achieve all its aspects, both *structural* and *functional*, in an integrated and holistic view (Mazzetto et al., 2004; Ushold et al. 1998; Martin-Clouaire and Rellier, 2009). In addition, it enables the farmers to include both *planning* and *management* aspects (*nominal* plans vs *executed* plans), in order to enable a comparative analysis between <u>expected</u> and <u>actual</u> performances within the same computational framework and database. Planning procedures may also simulate scenarios that are alternative to a reference situation, whilst management procedures enables several applications such as the control of the way an operation is performed, the filling of field registers, or the automatic control of some machines (typical of many precision farming applications).

FO is also able to formally express the nature of a decision-making process, distinguishing between the hierarchical decision levels (*strategic*, *management* or *operational*). Each decision type presupposes relationships among different classes of entities. The FO defines the general pattern that binds all the main relationships and entities, regardless of the type of hierarchical decision to be evaluated. FO flexibility lies in the possibility of implementing classes according to increasing levels of detail, according to the hierarchical decision at hand. Major details are typically required by operational decisions (e.g. planning of tractor paths), while taking more nuanced outlines in strategic decisions (investment for a new tractor or adoption of new farming system).

The related farm configurator can be then used to provide information both for ex-ante evaluations to assess the comparative behaviour of alternative farming systems (even supporting the inventory analysis of any LCA application), and for ex-post evaluation for satisfying traceability and process certification purposes.

APPROACH

The entity **Farm** can be seen as a collection of **Production Goal**, **Asset**, or **Action** classes, in accordance with the scheme shown by Figure 1 and the definitions given in Tables 1 and 2. The **Production Goal** generally focuses on the main product targets and the related production protocols, including any possible environmental and/or administrative restriction (e.g. biological apple orchards, grazing system, winery, milk farm etc.). Its definition is the typical result of a strategic decision, but the related implementation requires further details, being a complex interaction among components of the **Asset** and **Action** classes. The class **Asset** defines the *Farm Configuration*, say the structural composition of any mean used (or produced) at the enterprise.



[Figure 1] - *General design pattern of the Farm Configuration supported by the FO here proposed. Continuous lines indicate functional or structural relationships. Dashed lines are relationships representing actions (S = strategic: M = management; O = operative) that result from decisions that involve one or more entities. The yellow background of Externality class indicates that the [realeses] action can only be partially controlled by the Management, since it cannot be completely eliminated depending also on external factors.*

Assets are then split into **Resource** and **Material** classes, and the latter are in turn divided into **Input** and **Output** classes, depending on the type of relationship an instance of **Material** and/or **Resource** has with an instance of the **Process** class. In addition, **Output** are further divided into **Main Product** and **Byproduct** classes. The formers provide instances destined to the external market, while the latter even includes properties from the **Input** class, thus enabling to consider the recycling of materials within the farm. The class **Action** defines entities and relations resulting from a decision-making process. Some actions regard changes in the availability of new **Resources** and **Materials**. Others focus on the farm behaviour generated by a set of instances of the **Process** class. There are two types of processes: **Planned** and **Executed**, depending whether the task sequence of the process is simply foreseen or has been already actually executed, respectively. Whatever the case, any **Process**'s instance is expected to have one or more relationships with **Asset**'s instances. By definition we can have a **Process** that: a) *[uses]* a **Resource**; b) *[consumes]* or *[produces]* a **Material** (according to its availability status prior and after the process), and c) *[releases]* an **Externality** into the environment, occurring every time a negative impact on the surrounding environment is generated (eg release of harmful or undesirable substances or the creation of noxious effects).

[Table 1] – *Main entities provided by the Farm Ontology with related definitions.*

ENTITY	DEFINITION
Farm	Geographical and administrative context identifying the farm enterprise
Production Goal	Production orientation defined both by the main target products (what to produce) and by the ways in which production is made (how to produce). It is influenced by climate, environmental and regulatory contexts, sometimes also supported by production regulations and protocols that provide constraints and must guide the subsequent definition of nominal plans.
Action	Any virtual entity, implying a dynamic procedure and determining somebody's or something's behaviour, produced by a decision-making process at the farm.
Process	Action that implements a single treatment (= operation) within the production cycle, aimed at achieving the final product or supporting the farm behavior within predefined environmental or regulatory requirements.
Asset	Any entity with monetary value in charge to the farm administration.
Resource	An asset always available at the farm that can be used by a Process.
Material	An asset that is consumed (Input=factor) or generated (Output=product) by a process. In turn, a product can specialize in a Main Product (when defined as a target by the Production Goal and destined directly to the external market) or in a Byproduct (when it represents an inevitable secondary product not salable - eg crop residues - or an intermediate product to be transformed (reapplies) into a final Main Product - eg milk cheese).
Externality	Chemical or physical event occurring during the execution of a Process generating negative impacts on the environment external to the farm system.
Performance	A numerical index expressing a quantitative evaluation on the behaviour of the farm in relation to a particular domain of interest. It can regard both ex-ante or ex-post behaviours.
Efficiency Index	Dimensionless index quantifying how an ex-post performance meets the prefixed target established by an ex-ante performance.

[Table 2] – *Main type of actions defined by the Farm Ontology with related definitions.*

ACTION	DEFINITION
Farming System	Strategic action selecting the list of all the possible Production Goals to be realized at the farm.
Nominal Plan	Management ex-ante action selecting the list of all the Process needed to fully achieve a Production Goal. Conceptually, it can be treated as a POS (*partially ordered set*).
Scheduled Process	Management ex-ante action by which the allocation of a pre-defined Process is completed also in terms of responsibility (the executor, a person responsible for the process), space (where it is expected to take place) and time (when it is expected to start).
Scheduled Activity	Part of a Scheduled Process delimited by a specific time range.
Monitored Activity	Activity documented throughout a monitoring procedure, thus always related to an *already executed* scheduled process. Conceptually the execution can be performed both actually at the real farm or by a simulation model. In the first case, the monitoring procedure can be carried out both manually (direct observations) or by data-logger (automated monitoring).

INDICES OF PERFORMANCES

The farm behaviour can be finally evaluated throughout some *indices of performance (***IoP***)*, instances of the classes **Ex-Ante_Performance** or **Ex-Post_Performance**, according to we are dealing with planned or executed actions, respectively. Different types of IoPs can be taken into account, according to the domain of interest that can affect the various decision-making processes that must be performed at the farm enterprise. A summary of IoPs frequently used (*economic, environmental, energy and operational*), with related domain of interest and most applied indicators, is provided in Table 3. **Ex-Ante Performances** are generally estimated through planning tools, able to simulate the dynamic behaviour of the target farm scenario all along the year, once a "desired plan" - rather than a "best practice" - is fixed by the decision-maker as target nominal plan (to be considered also as a reference plan). On the other side, **Ex-Post Performances** can only be achieved through measuring and detecting (identifying) farm actions, performing a continuous and complete monitoring of parameters and agents that condition the main processes determining the productive behaviour of the farm.

[Table 3] - *Performances and related indicators used in the FO. Many indicators can be referred both to the yearly whole business activity - TX(y) - rather than to the i-th productive sector - TX(y,i). (*) The energy values may be even expressed in relation to the main form of energy supplied (thermal, electric or mechanical)*

TYPE OF PERFORMANCE	DOMAIN OF INTEREST	EXAMPLES OF INDICATORS	
		ACRONYM	DEFINITION
ECONOMIC	Farm profitability	TGPI(y); GPI(y, i)	Yearly Gross Production Income at the farm
		TPC(y); PC(y, i)	Yearly Production Costs
ENVIRONMENTAL	Quality of the ecological and physical environment in which the farm acts	TAW-N(y)	Total yearly amount of nitrogen per ha from animal wastes
		TCPhyt(y); CPhyt(y, i)	Total annual consumption of indirect energy related to chemical treatments for phytosanitary measures
		CFP(y,i)	Carbon footprint, calculated every year per each unit of production mass for the i-th productive sector
		WFP(y,i)	Water footprint, calculated every year per each unit of production mass for the i-th productive sector
ENERGY	Quality and efficiency of the energy supply of the productive system (*)	TFE-ST(y); FE-ST(y, i)	Primary energy consumption from fossil sources for stationary user points
		TFE-MB(y); FE-MB(y, i)	Primary energy consumption from fossil sources for mobile user points
		TPRE(y); PRE(y, i)	Percentage of energy needs covered by renewable sources
OPERATIONAL	Quality of the farm mangement and efficiency of the work organization	Hpeek(y)	Work hours during which the number of workers required is graeter than the number of permanent workers available at the farm
		WHP(y,i)	Work hours per unit of product
		MH(y)	Work hours spent in management tasks

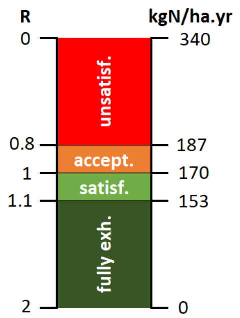
A key point of the FO is that ex-ante and ex-post IoPs are determined referring to a farm abstraction model that is represented by the same level of details through common data-structures. The latter are thus able to support both simulation/computing tools working on planned data and inferring/interpreting models treating surveys from monitoring tasks. In Figure 1, the actions typically connected to the simulation and reference tasks are the ones indicated as *[predicts]* and *[monitors]*, both classified as *management* actions. Ex-ante IoPs derived from the simulation

of alternative planned scenarios are useful also to support *strategic* decision related to the *[adopts]* and *[invests]* actions (e.g. selection of new production goals or the achievements of new machines).
The main function of IoPs is enabling comparative evaluations in order to get an appraisal of planned and/or executed plans. Comparisons can be firstly done between expected (ex-ante) and actual (ex-post) IoPs, using different computation methods provided by the class **EfficiencyIndex**. Thus, for example, the overall profitability index (PI) for the *y-th* year is then calculated as: $PY(y) = TGPI(y)_{ex\text{-}post}/TGPI(y)_{ex\text{-}ante}$.
In the same way, the overall efficiency index (FEI) in the fuel use to supply all the tractors at the farms all along the year is given by: $FEI(y) = TFE\text{-}MB(y)_{ex\text{-}post}/TFE\text{-}MB(y)_{ex\text{-}ante}$.
In the case of environmental performances, in addition to the parameters got from the use of the farm assets, the IoPs must also refers to all the undesired effects, which values are provided by the afore mentioned class **Externality**. The related management action *[releases]* can only be partially controlled by the farm decision makers, e.g. through the choice of proper technologies minimizing the negative effects or adopting efficient control systems. Nitrogen leaching, chemical drift or GHG emissions are typical examples of negative impacts.
The various IoPs can be put also in relation to a target reference value $\mathbf{IoP_{goal}}$. Such a value could be set according to: i) external constraints fixed by institutional rules (need to adapt to mandatory regulations or virtuous behaviours); ii) threshold values typically resulting from reference best practices; iii) specific customized goals of the farm management and/or strategic decision makers.
When performing a planning activity, the related $IoP_{ex\text{-}ante}$ should be set in order to fall within a *suitable* range (Δ, decimal) around IoP_{goal}, so that (in case of *benefit index*, say higher IoP better results):

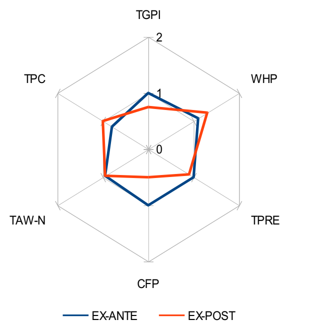
$$(1 - \Delta) < \frac{IoP_{ex-ante}}{IoP_{goal}} < (1 + \Delta)$$

Ratios < 1 indicate a *prudential* planning; ratios > 1 show definitely *optimistic* forecast.
The same approach can be followed also for evaluating the actual performances. According to the values of the ratio $R = IoP_{ex\text{-}post}/IoP_{goal}$, the following evaluations in relation to the external goal can be formulated: 1) *Unsatisfactory*, when $R < 1\text{-}\Delta$; 2) *Acceptable*, when $1\text{-}\Delta \le R < 1$; 3) *Satisfactory*, when $1 \le R < 1+\Delta$; 4) *Fully exhaustive*, when $R \ge 1+\Delta$.The on-farm evaluation is finally completed integrating ex-ante and ex-post results.

SUSTAINABILITY VIEWS



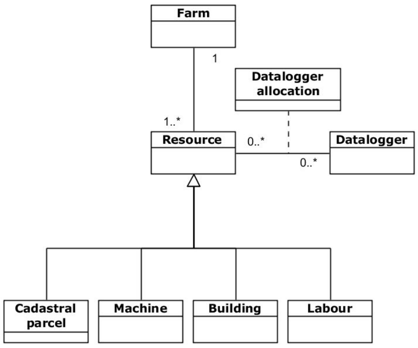
[Figure 2] – *Nitrogen load example for IoP sustainability, with the goal of 170 kgN/ha.yr*



[Figure 3] – *Overview of overall performance*

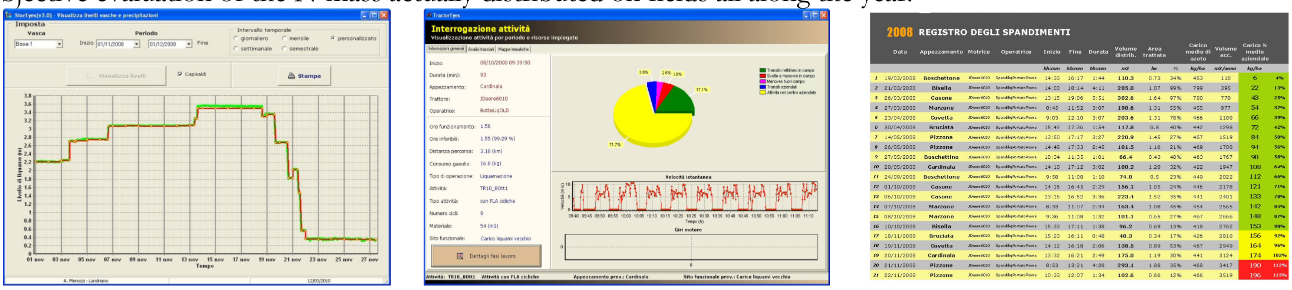
The satisfaction levels established by R can also be assimilated to the more generic concept of **Sustainability**. Depending on the type of domain of interest at hand and its related objectives established by IoP_{goal}, different types of sustainability can be thus defined (*economic, environmental, energy, operational*). As an example, in a livestock farm an aspect of *environmental sustainability* can be expressed by the total nitrogen load distributed every year on lands (**TAW-N** in Table 3, in *kgN/ha.yr*) through organic fertilizations based on animal wastes. The EU Nitrate Directive (91/676/CEE) sets this limit at 340 kgN/ha.yr, which is halved in the case of vulnerable areas. In these last conditions, therefore, it is appropriate to fix $\mathbf{IoP_{goal} = 170}$ **kgN/ha.yr** and - as we are dealing with a *Cost-criterion* - the calculation of R can be expressed as: $R = 2 – IoP_{ex\text{-}post}/IoP_{goal}$. If finally we set the value of $\Delta = 10\%$ of IoP_{goal}, we have the score situation described in Figure 2. Typically, when assessing a farm behaviour all along a period many sustainability aspects can be taken into account simultaneously. The number of aspects is established time-by-time by the farm decision makers and could be even associated to different priorities. Simple aggregation algorithms or multicriteria approaches can be performed with the aim of evaluating an Overall Sustainability Score (OSS) of the farm (the related computation methods are again provided by the class EfficiencyIndex). An example is given in Figure 3.

FARM INFORMATION SYSTEM



[Figure 4] – *Detail of farm model on resources and machine monitoring classes.*

All of the above can be put into practice only through the creation of an appropriate *Farm Information System* (**FIS**) able to process all the information flows through the data structures here described and to support a robust *Operational Monitoring System* (**OMS**) designed to collect automatically all the essential details required in the management of the main production processes (Calcante and Mazzetto, 2014). This is the only guarantee to obtain reliable $IoP_{ex\text{-}post}$ indexes and to get complete and objective reports of the farm's activities. An OMS requires the use of a data-logger (**DL**) equipped with proper sensors, positioning and identification systems able to monitor the behaviour of the main farm entities related to the class **Resources**. Typical farm resources regard *lands, building, machinery, plants* and *labour*. In the FO each resource type is modelled through a specific child-class descending from the **Resource** mother-class and specializing its own properties and methods (Figure 4). Further classes (**Datalogger** and **DataloggerAllocation**) and related tables in the Farm-DB enable to manage all the basic information for the resource automatic identification, if any. Machines are the most frequently resources submitted to an automated OMS. In Figure 5 an example of integrated OMS in a dairy farm slurry tanks and slurry spreading is presented (Mazzetto et al., 2009). Merging the information enables an objective evaluation of the N-mass actually distributed on fields all along the year.



A B C

[Figure 5] – *FO Example of integrated use of a fully automated monitoring system supporting the slurry waste management in a dairy farm.* ***A)*** *Continuous monitoring of slurry levels in slurry tanks (detection of filling and unloading operations, with the balance of organic matter masses and related N-contents.* ***B)*** *Automated monitoring of slurry spreading operations in the farm fields (with related details on worktimes, operational efficiencies and fuel consumptions).* ***C)*** *Yearly slurry spreading register obtained by merging the information in A and B. The columns provides all the details of each field spreading activity. The last two columns (right side) indicate a summary of the kg of N distributed per ha, with a early warning (in yellow) when approaching the threshold limit of 170 kgN/ha.yr. In this case such a limited was sensibly overcome reaching the value of 196 kgN/ha.yr (* ***R = 0,85*** *→ slightly unsatisfactory).*

FINAL REMARKS

The integrated architecture of the FO shows future promising applications in terms of adaptability to many type of farming systems, even including forestry enterprises. Such a flexibility also makes the FO-model, with related data structure, suitable to be considered as proper tool to carry out inventory analyses in agricultural LCA-related issues, as well. In addition, its structure allows applications to be carried out at the level of both single farms and multi-farms organizations.

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