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Modelling the Complexity of the Cropping Plan Decision-making

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Abstract: Every year farmers have to allocate their fields to different crops and crop management. These choices depend on multiple spatial and temporal factors, farmers' strategy and risk behaviour. To support farmers in these complex decisions and efficiently allocate scarce resources, we studied cropping plan decisions in arable farms with the aim of simulating contextual changes. A deeper understanding of these processes at farm level is then a start to model and design flexible and environmental-friendly cropping systems. We propose a stepwise approach to study and formalize the complexity of the decision-making processes based on farmer's interviews and on modelling approach inspired from software development methods. We made use of semi-structured farmer's interviews (n=30) to define farm constraints in relation to farmers strategies that affect cropping plan decisions. We identified objects/concepts that farmers use to decide their cropping plan and gathered them into an ontology. We sketched out individual decision model using abductive reasoning to capture the dynamic of the decision-makings. All individual decision models were used as so many hypothesis to build a more generic cropping plan decision models through an inductive and iterative integration. We took into consideration that farmers decisions involve anticipation, uncertainty and risk.

Keywords: Cropping plan, dynamic decision-making, model, BDI, UML

1 INTRODUCTION

Agricultural production systems of the past fifty years have been driven by the search for high yield, with the primary objective of increasing productivity per hectare and per worker. The resulting technological solutions were very efficient as demonstrated by the strong productivity increase in the past decades. But the rising environmental concerns and the climate change expectation make necessary to adopt innovative farming practices. These new practises have to be harmless for the environment, efficient towards natural resource uses and economically sustainable. In the mean time, problems and methods of agronomists involved in the study and design of new farming systems have to evolve to meet the challenges imposed by new concerns of sustainability of agriculture [Cox, 1996].

Computer based simulation models are commonly used since Wit [1965] to support the design and evaluation of innovative agricultural production systems. Simulation models developed by farming systems researchers traditionally focus on the biophysical entities of the farming systems usually in the form of interacting crop-soil models [Matthews et al., 2002]. The modelling of crop management practices in most crop models is mostly limited to the technical operations used to control few production factors such as the level of nitrogen and/or water. Farmers' practices are generally represented at field level through management rules using expert-based or optimisation-based threshold values [Bergez et al., 2010]. The low consideration of the management process

dynamic in most simulation approaches [Garcia et al., 2005] is a major limitation of model-based farming systems design [Keating and McCown, 2001]. The introduction of management (or decision) models as models of human action [Le Gal et al., 2009; Martin-Clouaire and Rellier, 2009] allows for more appropriate analysis of the farmer's practises evolutions due to contextual changes than standalone biophysical models [Bergez et al., 2010] and allows for improving farmer's managerial support [Cox, 1996]. A key feature of these models is that they link the biophysical and decision models in a single operating model often called bio-decisional models [Bergez et al., 2010]. Whether the use of bio-decisional models is now recognized to be an advance in farming system design [Bergez et al., 2010; Nuthall, 2010], we point out the lack of methodologies to study and formalized decision-making for modelling purpose in the field of agronomy.

The scope of our paper is to present how farmers' representations may be elicited, formalised and then used as basis for designing the decision models relying on a theory of the decision maker's behaviour. We present a stepwise approach to study and formalize the complexity of decision-making processes and illustrate it with the study case of cropping plan decision-making processes in arable farms. In the first section, we present the cropping plan decision-making problem, and justify the need to consider the dynamic of the decision-making to develop a bio-decisional model dealing with the cropping plan decision problem. In the second section, we explain the framework Belief-Desire-Intentions (BDI) that we choose as theoretical framework to structure the decision-making problem. In the third section we present the methodology we used to fill the gap between field observations to the conceptual management model. Then in the last section, we illustrated our methodological proposition by presenting some aspects of the cropping plan decision-making processes in arable farm using irrigation in France.

2 THE CROPPING PLAN DECISION PROBLEM

A cropping plan is the acreages occupied by all the different crops every year and their spatial distribution within a farming land. Cropping plan decisions mostly occur at farm level and are part of the global technical management of farm productions. As main land cover/use decisions in farming system, cropping plan decisions depend on multiple spatial and temporal factors, farmers' strategy, risk behaviour, and interact at different temporal levels of the farm management (strategic, tactic). In most modelling approaches, the cropping plan decision is represented as the search of the best land-crop combination allowing for the optimal use of farm resources [e.g. Dogliotti et al., 2003; Haneveld and Stegeman, 2005; Bachinger and Zander, 2007]. Objectives to achieve a suitable cropping plan are often based on complete rationality paradigm using a single monetary criteria optimization and in few cases, multi-attribute optimization [e.g. Annetts and Audsley, 2002]. Aubry et al. [1998] argued that these normative and static approaches failed to address the dynamics of mechanisms involved in the processes of farmer's decision-making. A first reason is that decision indicators such as water availability, prices, weather are changing almost every day, and a successful decision-making process is likely to be dynamic to proceed with the most accurate information [Nuthall, 2010]. A second reason is that farmers' decision-making involve both reactive and anticipatory phases [Bergez et al., 2004; Garcia et al., 2005].

Modelling decision-making to support farmers' decisions requires to explicitly consider the sequence of problem-solving imposed by the uncertain and changing context [Cox, 1996; Bacon et al., 2002] and to tackle decision-making problem as a dynamic decision-making problem (DDM) [Ohlmer et al., 1998]. The cropping plan decision problem combines the three common features of DDM as defined by Edwards in 1962 [cited in: Brehmer, 1990]: i) a series of decision taken over time to achieve some overall goal, ii) the decisions are interdependent, iii) the environment changes over time, both autonomously and as consequence of the decision maker's actions. The cropping plan decision-making is consequently seen as a process of achieving control over a dynamic system in order to produce a desired output, rather than as a resolution of choice dilemma [Brehmer, 1990]. According to this conception, simulation models based on the reasoning processes of decision-making agent are more suitable than static and normative approach to study and model such decision-making processes.

3 THE BELIEF-DESIRE-INTENTION (BDI) THEORETICAL FRAMEWORK

Simon introduced the concept of "bounded rationality" to express the idea that human decision-making is limited by available information over time and the information-processing ability of the decision-maker [Simon, 1947]. He stressed on the reasoning processes of decision-making based on procedural rationality of the agent [Simon, 1976]. The procedural rationality is about the rationality of the procedure used to reach a decision rather than the rationality of the decision itself as usually assumed in the decision theory. The novelty of considering the cropping plan decision-making problem in the light of the procedural rationality is the possibility to combine proactive and reactive decisions within a dynamic and uncertain environment. Reactivity means the decision-making agent perceives its environment and reacts to changes timely. Pro-activeness means that its behaviour is also driven by internal goals. The BDI framework is recognised as one of the most popular architectures for developing agents for complex and dynamic environments and provides a good theoretical background on decision-making processes [Bratman, 1987]. BDI is also a good framework for the modeller in the formalization of decision problems [Becu et al., 2003]. The BDI framework is organized into four components: beliefs, desires, intentions and events. Beliefs are the information and representations that the decision-maker has about the worlds (environment, context...). Desires are the objectives or situations that the decision-maker would like to achieve, this represent the motivation of the agent. Desires are quite often specified by goal. Intention are partial plans for actions that the decision maker is committed to execute to achieve one or more goals or part of goal. And last, the events are triggers for reactive decisions. An event may update one or more of the three other components.

4 MATERIALS AND METHODS

We used a stepwise approach to study and formalize the complexity of the decision-making processes based on farmer's interviews and on modelling approach developed for multi-agent modelling [Becu et al., 2003]. Following the cognitive paradigm based on Newell and Simon model [Pomerol, 1997], we based our approach on the assumption that accessing to farmers' knowledge and mental representations is a mean to better understand the complexity of the decision-making problem.

4.1 Sampling

We carried out a field survey in 2009 in three regions in France, Midi-Pyrénées (MiPy.), Poitou-Charentes (PCh.) and Centre (Ce.). We used semi-structured farmer's interviews (n=30) and non-structured interviews with key informants from local extension services (n=3). We used non probability sampling methods to choose crop farmers among lists provided by extension services and cooperatives. The choices were driven by the search of diversity using available key-variables likely to affect cropping plan choices, i.e. type of crops, farm size, water resources and soil types.

4.2 Knowledge acquisition

We used elicitation techniques coming from the knowledge engineering (KE) community as a mean to access farmer's representations of the decision problem [Wielinga et al., 1997; Milton et al., 1999]. We used KE techniques as a mean of transition between the interviews and the BDI framework for structuring the elicitation and analysis of the decision-making problem. The questionnaire for farmers was therefore structured into four complementary parts: 1) *Desire*: We questioned farmer about their productions (past, current and future) in relation to their objectives. We analysed how objectives (desire) and goals held impact on the decision-making processes to assess farmers modus operandi. 2) *Belief*: We characterized the on- and off-farm constraints that affect cropping plan decisions by accessing to farmer mental representations (their beliefs). We took care free rein to the evocation of factors that we could not identify in advance by preferring open discussion to closed questions. We complemented questions with different media (e.g. farm map, warning bulletin for irrigation) as a mean to efficiently collect data and facilitate the knowl-

edge elicitation. 3) *Intention*: We asked to farmer how they take decisions, what information they use and what are the operations to be done when an option is selected. We determined the sequences of decisions on an annual cycle and the description of medium and long term plans. We lived up interviews with scenarios on climate, prices and water regulations adapted to each regional contexts to capture different decision-making options for various situations. 4) Risk aversion estimation was estimated through revealed and stated preferences approaches.

4.3 Transcription and generalization

We used the Unified Modelling Language (UML) as formal language for the transcription analysis, because it provides standard graphical representations and good correspondences with knowledge objects (Table 1). We identified concepts that farmers used to decide their cropping plan using individual thematic UML diagrams. These diagrams were solely based on farmer's mental representations derived from the interviews. All farmer's representations models were used as so many hypothesis to build an ontology using inductive and iterative integrations. The ontology should represent in a generic way the farmers' knowledge involved in the cropping plan decision-making. UML class diagram was used to model the ontology as static model for depicting the classes of the domain and their relationships [Kogut et al., 2002]. In parallel, we sketched out individual dynamic decision models, using abductive reasoning to capture the dynamic of the decision-making. The sequences of decisions, as described by farmers, were represented with UML activity diagrams. These diagrams were used to describe the infra-annual dynamic of the decision-making and to identify events that disturb planned decisions.

Table 1: Correspondences between knowledge objects from Milton's classification [Milton et al., 1999] and UML formalism as proposed by Becu et al. [2003]

Knowledge object	UML formalism
Class	Concepts
Instance	Instance
Process (task, activity)	Operation
Rule	Methods
Relationship	Association, Aggregation or Inheritance

5 CASE STUDY: THE CROPPING PLAN DECISION-MAKING PROBLEM

5.1 Farm characterization

From the initial set of farmer interviews (n=30), we kept 28 arable farms in the analysis (MiPy=9, Pch=9, and Ce=10). Two farms were left because they were mixed farms and the cropping plan decisions-making driven by animal feed productions. The sample represents a great diversity of arable farm in the three regions as illustrated by the variation of their land areas ranging between 33 and 400 ha farm⁻¹, with an average of 157 ha (sd 91). Altogether, farmers grow 29 different crops with a majority of cereals on about 2/3 of their farming area. The main crops were the winter wheat (23% of the area), maize (19%), rapeseed (11%), durum wheat (9%) and fallow (7%). They grow on average 6.4 different crops per farm (sd 2.0).

5.2 Farmers objectives and strategies: desires and goals

All farmers reported incomes as main objectives for their farms (Table 2). However, only two farmers mentioned profit maximization as sole criteria and 71% searched first for good and secure income rather than profit maximization at any risks. The desire of income security were not always

associated with the same goals: farmers mentioned crop diversity and/or rotation (10/20), search for robust cropping plan (5/20), securing crop sales (contract and cooperatives) (5/20) and input cost minimization (4/20). The desire to increase and/or maximize income was mainly associated with the search of market opportunity and contract (8/14). The second motivation for farmers (42%) was the workload management, mostly recall as a simplification of their crop production systems (8/10) by e.g. the introduction of no-tillage practices, the decrease of irrigation but also by reducing the number of crops. The last proposal comes in contradiction with the search of crop diversity as mentioned above. This illustrates that objectives might sometimes be contradictory and that cropping plan decision-making is necessarily a trade off between a set of heterogeneous objectives and constraints.

Table 2: Main objectives of farmers (n=28) that drive decision making.

Category	Desires (objectives)	Frequency of response
Income	Secure good	20
	Maximization	10
	Increase	4
Workload	Minimization or decrease of the workload	10
	Spread workload	1
	Maintain satisfying workload	1
Survival of the farm	Maintain - heritage	2
	Survival of the farm	1
	Pass farm on to the next generation	1
Technical aspect	Experimentation (varieties, pesticides)	2
	Simplification of the production system	2
	Technical crop (vegetable)	1
Environment	Increase biodiversity	1
	Input minimization	1

5.3 Farmer representation: beliefs

We transcript farmer's representations into individual objects diagrams and used them to identify generic concepts. As illustration (Figure 1a), we show the transcription of the farm land representation of the farmer Ce2. We asked him to describe his farm land, and to explain factors that motivate the different crop allocation between plots. In this case, the first factor was the installation of irrigation equipment preferentially on large plots close to the homestead. Based on this distinction of irrigated and rain-fed area, the farmer allocates two different cropping systems here defined by their rotation. In both area, very small plot were left in fallow for work simplicity. We complemented this bottom up integration (from farmer) by a top down concept integration (from the modeller) to ensure model consistency all along the inductive processes. Following the same example, four concepts mentioned by the farmer Ce2 were integrated into the ontology as four generic classes (in grey in Figure 1b). Plots size and distance were introduced as attributes of the plot class (not presented in Figure 1b). The classes represented in white in Figure 1b were either derived from other farmer's interviews (e.g. Crop management block) or introduced by the modeller (e.g. management unit, composite management unit) to enrich and keep robust the model. The two management unit classes are a generalization of the plot, irrigated area and rain-fed area classes in the Figure 1b. In the final ontology, we have two more management units than presented in the Figure 1b; the CAP islet and irrigation block. Similar modelling exercises were performed on the different aspects of the cropping plan decision-making problems (socio-economic context, water resources, agronomic constraints, farm land characteristics, and equipment and labour). The farmer's knowledge involved in the cropping plan decision-making were therefore represented into more than 60 classes into the ontology.

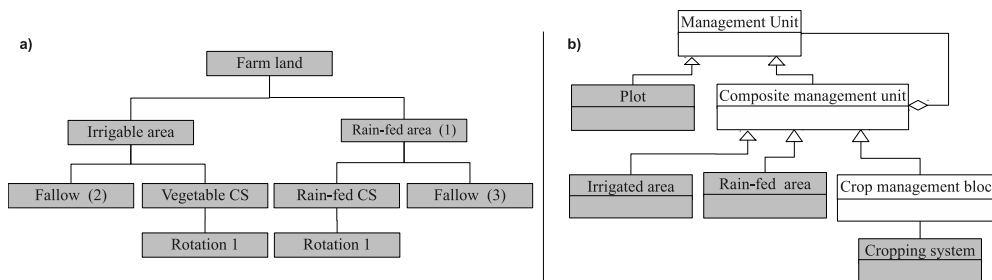


Figure 1: a) Organization of the farm land as described by the farmer Ce2. It shows the heterogeneity of the land that the farmer Ce2 considered when dealing with crop allocation: (1) small and remote plots, (2) part of plots not easily accessible by irrigation equipment, (3) very small plot. b) Part of the ontology that represent the management units used by the farmer Ce2 (in gray). In white, classes that come from other farmers' representation (e.g. crop management block) or that were create for model consistency of during the integration phases (e.g. management unit, composite management unit)

5.4 Farmer's plans: intentions

We studied how the cropping plan decisions of farmers were structured in time through reactive and anticipatory phases. We first questioned farmers on the way they anticipate their cropping plan. 53% of farmers revealed to have stable cropping plan over time and to not seek for changes. This was explained by use of rotation, the satisfaction of their current cropping plan and/or by the search of stability. 14% of the farmers looked 1.5 years forwards when setting up their cropping plan. Following a more adaptive strategy, 32% reported that they anticipate their cropping plan only during the year before the winter sowing period. Then we asked to farmer to describe the sequence of decision they take during the year before sowing (Figure 2). An important outcome of this dynamic analysis of the decision-making is that all farmers have a clear plan of the sequence of decisions they have to take. Their plans are very different from farm to farm and strongly depends on farmer strategies, socio-economic context and available information. Although the majority of farmers reported to seek for cropping plan stability, all except one mentioned at least one reason that encourage them to adapt their initial cropping plan during the year. Stated reasons were linked with uncertain factors related to market (contract 29%, crop price 29%), climate (water resource availability 20%, field accessibility for sowing 14%) and agronomy (seedling emergence, weed and pest issues 9%). For 71% of the farmers, changes from initial plan usually concern only a small portion of the cropping area, do not take place every years but most frequently concern crop with high profitability (contract, market opportunity...).

6 DISCUSSION AND CONCLUSION

Modelling the crop allocation decision-making processes occurring at farm scale requires to explicitly consider interactions between a set of constraints from very different natures, fitted into different time scale dynamics, and integrated into various spatial entities within the farming land. While each farmer has his own particular way of making decisions, we showed that they used many common concepts to make decisions. Identifying these common concepts and their relationships is already a great step forward in the structuring of the decision-making problem. However, the use of knowledge acquisition techniques to access to these representations are time-consuming. The development of the ontology by combining both bottom-up (from interviews) and top-down (from modeller and expert) approaches is a pragmatic way to develop consistent and reusable models based on shared concepts with farmers. The use of inductive techniques to integrate concepts make possible to extend (new concepts) and/or update (new attributes) the current ontology for other situations and/or other decision-making problems. As Becu et al. [2003], we argue that the use of formal language (UML) is an efficient mean to transcript and abstract

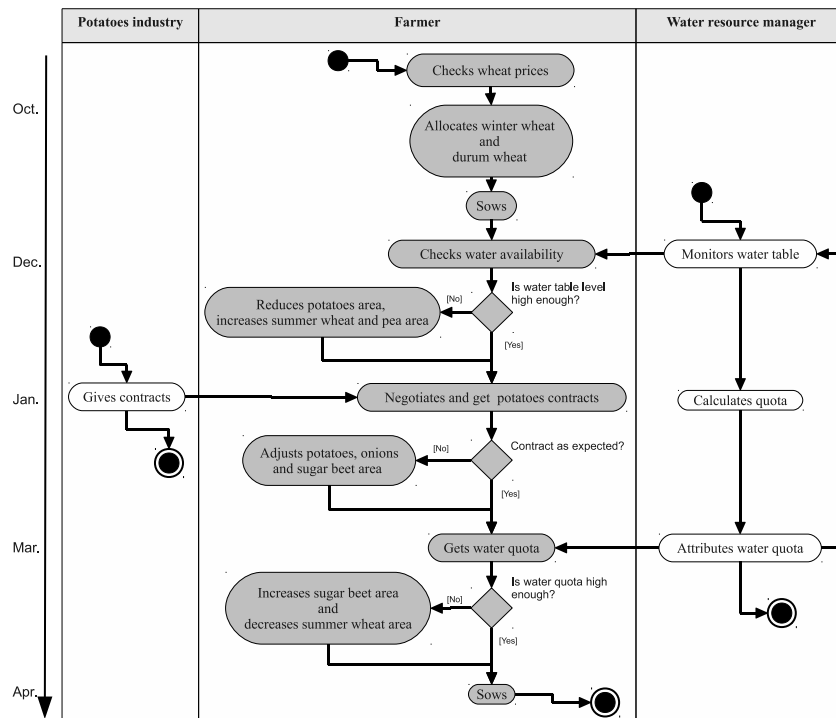


Figure 2: UML activity diagram that depict the planned sequence of activities and decision as described by the farmer Ce2. It show the decisions and the related events (prices, contract and information on water resource availability) that could disturb the initial cropping plan. In left side, the time scale is only indicative of the period at which decisions are taken. [Rounded rectangles represent activities, diamonds represent decisions, black circle and encircled black circle represent the initial and the final state of the workflow]

information for modelling purpose because of the similarity of knowledge objects and UML formalism. The UML language allows for representing the decision-making problem in a readily usable form for computer programming. The use of the BDI model as theoretical framework is helpful to formalize the reasoning of the farmer and serves as architecture to develop the simulation models. Based on this work, a simulation tool will be developed to support farmers in their annual and long term crop choices and allocation strategies, and to support the design of environmental public policies by simulating their effects on individual land use decisions.

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