Specifying a strategy for deciding tactical adjustment of crop protection using CPN tools

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Abstract

Crop protection is a key activity for farmers. There is a need to improve the practice and use less chemical pesticides. We hypothesized that farmers may be overwhelmed by the amount of data available. Therefore we proposed the concept of crop protection decision workflow system (CPDeWS) to guide them in interpreting the information in tactical adjustments of treatment decisions. We provide here a short introduction to Petri nets, and show how the CPDeWS concept was mapped onto Petri nets, in the case of wheat. Finally we adopt a broad view to discuss our design and modelling choices, that are applicable to a wide set of crop protection and crop management problems.

Keywords: Farm management, Crop protection, Workflow modelling, Decision support system, Coloured Petri net

Introduction

Modern agriculture is confronted with the seemingly paradoxical challenges of both increasing quantity and raising quality of food production (while the prices should be kept low and the financial aids reduced). Here quality encompasses preserving the environment and the people in order to sustain production infinitely while producing highly healthy and nutritive food. These challenges greatly question the agronomic know how of the whole community. But it is also a driver for a more optimised agriculture, where production factors are used in a rational and justified way, consistent with objectively assessed risks.

In these challenges, the ICT community has already taken up its share, integrating novel technologies from the field scale using data provided by precision agriculture (Steinberger *et al.* 2009) up to the farm information management systems scale and extending further upscale toward the larger agro-business environment using service oriented approaches (SOA). For instance Ntaliani *et al.* (2010) illustrate this drive in the implementation of a business process management in e-government. Several case studies from the LEI Wageningen group (Verdouw *et al.* 2010; Wolfert *et al.* 2009; Wolfert *et al.* 2010) illustrate how SOA helps tighter integration of the various levels of the agro-food supply chain.

Another trend is the large effort toward providing Agri-ICT professionals with standards for modern agricultural information systems and data interchange formats between more and more scattered resources – see the Future Farm project1, agroXML2 or Agro EDI Europe[3].

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1 http://www.futurefarm.eu/
2 http://www.agroxml.de/
3 http://www.agroedieurope.fr/

All these authors show a drive toward a more data intensive agriculture which aims at a more knowledge intensive agriculture. They insist on using information and communication technologies (ICT) to leverage change and innovation among users and on developing reusable business process models. They show that systems analysis and ICT born specification formalisms are very helpful to farm management reengineering (Fountas *et al.* 2006; Sørensen *et al.* 2010; Nash *et al.* 2009).

Our own research effort is situated along a similar line. For instance, we have shown (Léger & Naud 2009) that ICT specification languages such as Statechart (Harel & Kugler 2004) can be used to leverage expertise from a pathologists' group. Our general aim is at designing operational decision support systems in crop protection. Clouaire & Rellier (2009) have underlined that, compared to the many simulation tools built to study isolated agronomic and technological aspects of the production processes, few works have dealt with the modelling and simulation of farmers' management and work practices.

We adopted a design approach which investigates this point of view: "how to design a decision support system as a process, with emphasis on work organisation, given the requirements of the crop?" We name our proposition: Crop Protection Decision Workflow System (CPDeWS). We consider that in many cases in modern crop protection, the main difficulty for farmers to achieve low input protection lies in a lack of methods to organize and interpret the large amounts of available information. Therefore we have proposed to develop tools on the basis of crop protection expertise that will guide the farmer throughout the season to make operational decisions about crop protection sprayings against several target diseases. Fountas *et al.* (2006) proposed to document the farmer's data flow for each decision. Similarly we integrate crop protection decision making as a decision workflow from the beginning of the season to its end (Léger, *et al.* 2010).

Protecting a crop is a control problem which can be decomposed into a production system, an environment and a control system. Although the overall system is by nature a hybrid system, the controller, i.e. the decision system we designed, can be modelled as a discrete event system (DES) (Naud *et al.* 2008). The DES modelling paradigm has the great advantage of being simpler to analyse than hybrid systems. We have also discussed in (Léger 2008, ch.2) that in the current state of knowledge and under the objective of low input crop protection, optimal control for the crop protection problem cannot necessarily be computed. This means that crop protection experts will be able to propose adjustment strategies that may prove as efficient as any optimal crop protection strategy but may lead to fewer treatments. Indeed the experts may be able to manage risk in a more subtle manner than what is nowadays possible to achieve through quantitative computation. The experts have an intimate knowledge of the epidemics and the crop needs that fundamental epidemiology is yet unable to quantify at operational scale within a farm.

The design process begins with an expert design which is elicited from the experts as a decision process specification. In the grapevine case study the elicitation was carried out using UML Statecharts as mentioned previously. This article investigates how coloured Petri nets (CPN) have been used to formalise specifications for a wheat case study. The overall approach for design is presented in (Léger 2008; Léger, *et al.* 2010b) and is similar in both grapevine and wheat cases.

The rest of the article is structured as follows: the following section provides a quick refresher on Petri nets (PN) and CPN, then describes the overall architecture of the wheat CPDeWS and provides definitions; the Results section consists in an overview of the transcription of the

design features into CPN; the last part discusses the choice of decision process modelling to design a crop protection decision support system.
Formal framework and design

Coloured Petri nets

Petri net is a discrete event system modelling formalism presented by Carl Adam Petri in 1962. Petri nets are traditionally used for describing and analysing systems that are characterized as concurrent, asynchronous, distributed, parallel, non deterministic and/or stochastic. Due to their graphical nature, Petri nets (PN) can be used as a visualization technique like flow charts or block diagrams but with much more scope on concurrency aspects.

We have used Timed Hierarchical Coloured Petri nets with the CPN tools software. A detailed presentation of the formalism can be found in (Jensen & Kristensen 2009). Figure 1 illustrates on some of its principles: places (circles) associated with tokens (which have a data structure, see rectangle), and transitions which depict events and actions (squares). *Needs short explanation on "colour"*

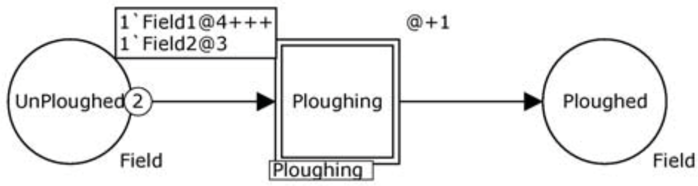

Figure 1. ploughing two fields, modelled as timed hierarchical coloured Petri net

DeWS Design

In this section we will present the architecture of a CPDeWS, illustrated with the example from the wheat CPDeWS: BLé3 and BLé2. Figure 2 presents the architectural organisation of the system. It is composed of three layers: the outermost containing external ressources, an intermediate level allowing to store certain key variables, and the core of the system itself which holds the experts' decision process modelled as a Petri net.

Although a discrete event system, the CPDeWS requires a persistence mechanism to hold the latest state of the environment. This mechanism is provided by the "neighbourhood" layer. It is composed of a set of discrete variables. The decision system has full access to these resources in real time. This persistence layer is necessary as the input data for the decision system may be costly to acquire (e.g. field observations) or may be the result of direct input from the user (i.e. not persistent elsewhere). The second reason for this is that the variables hold a discrete interpretation of continuous underlying variables. For instance, in the case of the BLé3 CPDeWS Septoria is monitored using a forecast model. Each time the model is updated, the internal variable (called ILS) is computed on the basis of thresholds which depend on the phenological stage of the plant. At each computation, our system computes the discrete value and saves it. The continuous value needs not to be accessed again for the decision.

The third layer of the system is its environment. The environment updates the neighbourhood variables, but can also send real time input events which are directly handled by the decision system (e.g. rain forecasts). This architecture is in essence similar to that presented in (Wolfert *et al.* 2009) for the three layered SOA Architecture.

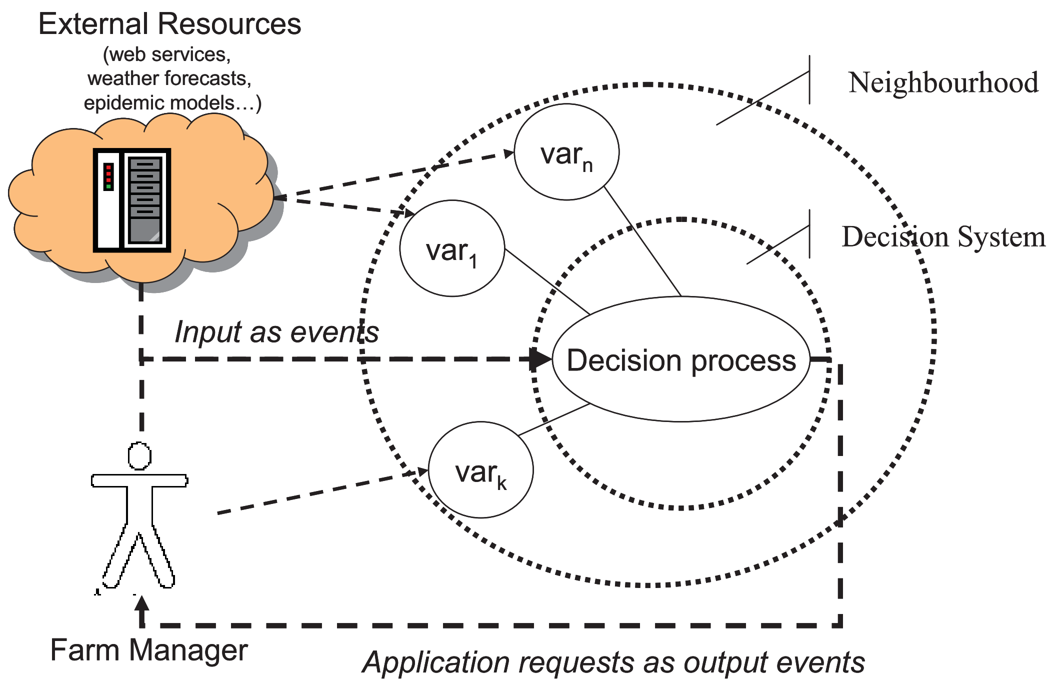

Figure 2. Overall architecture of the wheat CPDeWS

<u>The decision system</u>

Because the decision system is the formal transcription of an expertise, the structure of the model is therefore strongly linked to the design choices made by the expert team and by the elicitation method (Léger, *et al.* 2010; Léger 2008)

CPDeWS are organised to control pest management decisions at the plot scale. To simplify the design process, the system was designed with a single plot in mind; however the system is required to be able to manage a whole farm or more.

CPDeWS are tactical adjustment tools which drive crop protection from the beginning of the season until its end. The season is partitioned in decision stages in order to handle the various development stages of the plant and the changes in the nature of the disease risks they face..

The aim of a stage is essentially to decide for each target disease whether a treatment is necessary or not and when to position it during the period. A decision stage is characterized by:

- Its position in the season defined by a start phenological stage or date and by an end date/ phenological stage or a duration.
- A set of active diseases (not all diseases can cause damages throughout the season).
- An objective: the objective is a higher level requirement formulated so as to help the expert define the stage's specifications. It defines what needs to be achieved during the stage. This allows the experts to link the overall CPDeWS crop protection strategy to the implementation of operational decisions.
- A set of decision indicators and triggers which can either be decision variables or

input events (see figure 2).

- A decision process: It specifies how to use the available information (decision variables) in order to reach the stage's objective. It specifies the need for more information (leading to field observation), details the synchronisation of the reasoning of several diseases (e.g. treat Septoria along with Eyespot), and establishes priority between different disease risks. The outputs of such decision processes are treatment requests against one or several diseases, and/or observation requests.

The number of stages depends on the crop, its diseases and possibly climate, but it also depends on some strategic production choices made by the farmer. For instance, BLé3 is broken down in 6 stages while the BLé2 CPDeWS has 5. The difference between the two is explained mostly by the work load the farmer wishes to invest in the protection of his/her wheat (i.e. the importance of wheat production in his farming system). (Allain and Plai, 1998)

Observations are also a key structure in a CPDeWS, because the information provided by a fresh observation from the field will gain priority over all model outputs provided the observation of a given disease can be a relevant estimator of the disease risk. Observations requests can be mandatory or conditional, i.e. triggered by specific states of the decision process.

The system also outputs requests which are sent to an operational sub-system which is responsible for the selection of the fungicide mixture (Hernandez *et al.* 2010) and the grouping of plots in order to realise spraying batches. This sub-system is out of the scope of this presentation. After a spraying the CPDeWS needs to be fed with the applied fungicide active period duration against each disease, as these variables constitute an important aspect of any direct control based crop protection.

Results - Encoding the structures of the DeWS

In this section we will present how the different structures presented were mapped into coloured Petri net specifications using the CPN tools software.

<u>Global structures</u>

The CPDeWS is a workflow and its stages are sub-workflows. Within the CPN modelling framework, stages are mapped onto hierarchical transitions with the stages' decision processes modelled as sub-processes.

The various plots in the system are mapped onto a unique identification colour (id colour). The id colour is used to retrieve the information relative to a specific plot whenever necessary. For instance, phenology is stored in a dedicated global place. Global places are a special type of places accessible within any sub-processes of the system. We use these to model global variables.

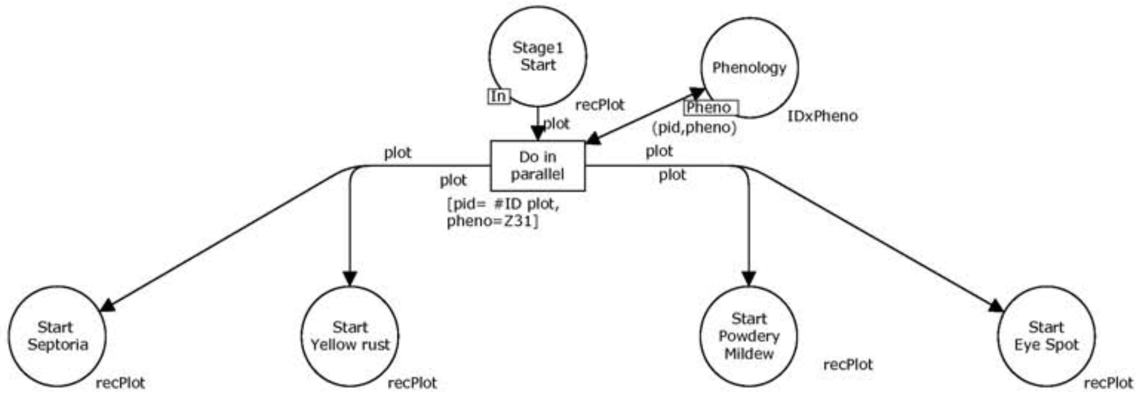

Figure 3. at the beginning of Stage 1, Phenology control the plots access to the stage concurrent processes

The phenological information for each plot is encrypted in a timed token composed of the plot id colour and the phenological stage colour. In simulation mode, each plot at each phenological stage is loaded into the phenology manager during the initialisation phase. Then the time mechanism ensures that no phenology token can be accessed before the simulation time reaches the date at which the phenological stage is reached.

Stages specific constructs

At the beginning of each stage's sub-process, the start condition is expressed as a guard condition on the stage's initial transition. As shown in figure 3, the transition will fire only if a phenology token with colour Z31 is "active". The transition's inputs are a plot and a phenology token. The transition outputs an identical phenology token and one plot token for each line of reasoning.

Mapping the reasoning.

In the Blé3 CPDeWS, each disease is managed along a line of reasoning which consists in the following ordered decision rules mapped as hierarchical transitions. *i)* checking the plot's strategic risk (the *a priori* risk); if the plot is susceptible to a given disease risk, the system *ii)* will wait until the active period of the previous treatment is over and then *iii)* it will activate regional risk monitoring. This monitoring leads either to *iv)* the request of a field observation or simulation of a forecast model or *v)* to the conclusion that no action was necessary during that stage, at the latest when the end time of the stage is reached. This concluding place is reachable from all the decision steps. Figure 4 illustrates this generic reasoning mechanism. Note that in this simplified expression, the reasoning given above is rather generic in crop protection. One important added value of CPDeWS and decision process modelling lies precisely in the possibility to depart from this general process to adapt to the period and the disease specifics.

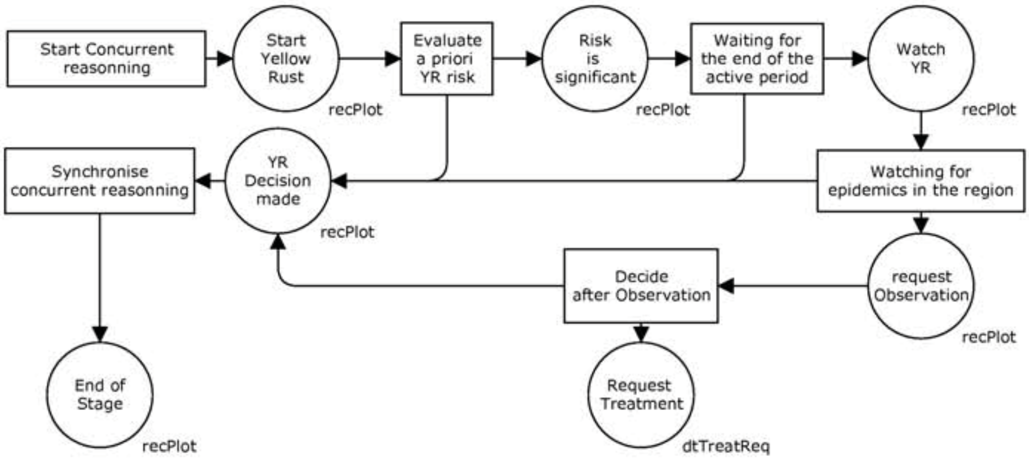

Figure 4. BLé3 Generic within Stage reasoning (yellow rust)

note: this diagram is not a formal CPN, several details are missing. For instance all (but the first) transition in this net are hierarchical transitions and the arc inscriptions are missing.

The *a priori* variables like the other decision variables (see table 1) are mapped as composite colour tokens identified by the plot id colour and a value colour, which can be either of colour type Boolean or from the colour set *{'low', 'medium', 'high'}*. Like phenology data, the decision variables are stored in global places which can be accessed anywhere in the net.

Handling decisions

A decision leads to two outputs. On the one hand the plot token moves in the net as its "decisional status" evolves until a final decision is reached for a given disease and a given stage. On the other hand, the decision may produce an observation request token or a treatment request token.

Observation requests are characterised by plot id token. Treatment requests are modelled as tokens which have a triplet for descriptor: *('plot id', 'current treatment stage', 'target disease')*. Observation and treatment requests are each routed to a specific global place. These two places are connected to the operational management sub-system which is responsible for managing the workload and planning operations. That sub-system is independent from the decision system. Therefore time and priority constraints would need to be specified through the requests tokens for it to be taken account of in the planning (but this remains part of our future work). Table 1 summarizes the information provided in this section for the entire BLé CPDeWS.

Discussion

The results given above describe how the CPDeWS concepts were mapped onto the CPN framework. We did not encounter technical limitations due to the framework. However, in the design phase of CPDeWS, we separate the decision part which is modelled, and the biological part which is not. We review in this section reasons and means for the cooperation of models and field experiment in this design stage.

As the proposed design of CPDeWS is the output of expertise (strongly rooted in scientific knowledge and know-how) it is important to assess the validity of the specified adjustment strategies. This should be achieved both through field experiments and through formal methods. Field experiments allow assessing the agronomic efficacy of the decision process (Naud *et al.* 2010; Naud *et al.* 2009). However field testing of the efficiency of the proposed crop protection is not sufficient, as we need to show that it is the CPDeWS which is responsible for the level of quality. Therefore, verifying the conformance between the implemented crop protection decisions made and those specified by the CPDeWS is necessary. This is achieved through process conformance checking (Rozinat & van der Aalst 2008; Cook & Wolf 1999). Two methods have been proposed to assess that the implemented decisions in the field respect the decision process specification (Léger & Naud 2009; Léger 2008 ch.6).

Blending field experiments and formal methods is necessary as there is currently a lack of epidemiological models handling the development of the full complex of diseases a crop is faced with and their control by fungicides (with the notable exception of the work carried out in the DESSAC suite : Parker 2003). In particular, predictive and quantitative modelling of the effects of fungicide sprayings on disease development at the field level is hardly available commercially. Therefore real life experimentation is the best "simulation" available. Unfortunately that solution is slow and expensive. Due to the number of variables and the length of the season, there is a combinatorial explosion that makes it impossible to test in the field all the potential configurations of a CPDeWS. This led us to turn to formal modelling techniques like CPN for their ability to undergo formal verifications. The idea is first to define formally some risk scenarios and some required safety properties for this class of systems. Then using technique such as model checking (Baier & Katoen 2008) it should be possible to objectively prove the reliability of the proposed CPDeWS under a set of precisely defined conditions.

	place transition	net Hierarchy	Time	Colour	global place	transition	transition guard	output arc inscription	transition label	place label
Stage	X	X								
Plot				X						
Disease				X						
Phenology	X		X	X	X					
Spraying persistance	X		X	X	X					
a priori variable				X	X					
Plot scale variables				X	X					
Regional variables				X	X					
Event (warning, rain forecasts…)						X				
User input						X				
Beginning of stage							X			
End of stage		X					X			
Decision rule	X	X				X			X	
Decision conditions						X	X	X		
Decision results				X	X			X		
Concurrent reasonning	X						X			
Synchronisation of 2 or more lines of reasonning					X	X				
Interstage communication					X					

Table 1. CPDeWS design features and the element used to map them into CPN

Conclusion

The design of decision support systems is an art in the sense that it blends together business knowledge, hard science, knowledge management science, a pinch of artificial intelligence and ergonomics. This makes the project of designing agricultural DSS long and costly (Matthews *et al.* 2008). We think that the integrative approach proposed in this article, which balances modelling of decision and field experiment, could quicken such design and integration of pest specific Decision support systems (e.g. pest forecasting models). It should help to establish structured best practice guidelines for pest management. Our work with CPDeWS modelled as Petri nets is an attempt to identify design tools suited to that purpose.

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