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Nordic Innovation Centre

June 2008

InfoXT - User-centric mobile information management in automated plant production

Recommendations and guidelines for a novel, intelligent, integrated information and decision support framework for planning and control of mobile working units



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Title: InfoXT - User-centric mobile information management in automated plant production		
Nordic Innovation Centre project number: 05103		
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Abstract: Nordic knowledge and know-how in the area of agriculture and ICT was extracted and further developed in the joint Nordic project '<i>InfoXT - User-centric mobile information management in automated plant production</i>'. The aim of the project was to draw up basic recommendations and guidelines for a novel, intelligent, integrated information and decision support framework for planning and control of mobile working units. Project participants came from Aarhus University - Faculty of Agricultural Sciences, Helsinki University of Technology - Information and Computer Systems in Automation, MTT Agrifood Research Finland, Swedish Institute for Agricultural and Environmental Engineering and VTT - Technical Research Centre of Finland. The work was based on a systems analysis approach that utilised data from earlier and on-going Nordic research and new prototypes as a technology platform. An initial study among Swedish precision farmers revealed user needs in information- and technology-intensive farms. Against this background, a systems concept for information management in mobile plant production environments was designed. The concept was technically validated by implementing new parts in practice. The system usability of the concept was evaluated using scenarios and internet questionnaire in all Nordic countries. The resulting system concept functions as a common description of user-friendly information systems for all actors in the value chain.		
Topic/NiCe Focus Area: ICT & Electronics		
ISSN:	Language: English	Pages:
Key words:		
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Executive summary

The specific objectives of this project were to:

- Utilise recent developments in information and communication technologies, in particular global positioning, wireless communication and pervasive computing, to automate certain tasks in crop production.
- Facilitate the implementation of the precision agriculture concept in order to reduce the negative impacts of agricultural production on the environment.
- Develop basic recommendations for novel and intelligent planning and control of mobile working units in agricultural production, specifically crop production.

These objectives were achieved by:

- Extracting and developing Nordic knowledge and know-how concerning the use of modern ICT and information management in a mobile crop production environment.
- Identifying user needs and requirements for automation in crop production.
- Developing a detailed model of information needs and data flows in field tasks performed by mobile work units.
- Identifying available and relevant technologies for data storage, data transfer and data management.
- Designing system architecture for the concept according to user needs and available technologies.
- Evaluating the technical viability and systems usability of the concept designed through the creation of working prototypes and scenarios.

Method

The project utilised a systems analysis approach as its core method. In systems analysis, a problem is studied by building and exploring models that provide a description of the system under investigation. The systems analysis process requires data in all its phases from problem formulation via model building to model validation and problem solving. Data and background material were collected from the literature, from previous and on-going Nordic research and from interviews with technological development experts and users in the value chain of information technology and decision support for mobile work units. The problem solving followed the phases of Core-Task Analysis based on user demand modelling. The concept was evaluated by end-users through an internet-based questionnaire in conjunction with a video describing the concept proposed.

Main results

- The main difficulties in managing precision agriculture data in practice and in extracting useful information from the field for decision-making were identified.
- An information model that integrates different planning levels as part of the development process and specification of the core task was developed.
- The non-linearity of farmers' decision-making was included in the modelling of information systems.
- A systems usability development method for precision agriculture was developed, considering different demands expressed by users.
- The output of the information model and development method was utilised to create a prototype of the proposed architecture for the case of precision spraying in malting barley.
- Farm data were collected and stored in a central database, accessible via internet servers.
- Farm data were made available to authorised actors only (with authorisation decided by the farmer) to produce a more efficient production system.

Conclusions drawn from the study

The following list of recommendations and guidelines are applicable for all actors in the value chain:

- Efficient information management systems in mobile plant production environments should be internet-based with an open interface.
- Farm data saved in a central database should be accessible to the farmer via internet servers.
- Difficulties are often related to manual transfer of data and incompatibility between links in the information chain. There is therefore a need to harmonise or standardise data transfer formats, and to some extent data models, for better economic efficiency. The ISOBUS xml format is suitable for data transfer between mobile work units and databases.
- Farm Management Information System should be called Active Farm Management Information System, since the farm database must have features that support farming activities and knowledge management. There is a need to develop assisting interactive functions
 - such as automatically programmed features
 - to provide situation/context-aware advice
 - for use in work situations in the field, buildings or farm office
 - which have additional personal/farm-specific services attached.
- It is important that the communication media and the data transfer networks are reliable and sufficiently powerful to provide a high transfer capacity.

Recommendations for further studies

At a Nordic and European level of research and cooperation, it is necessary to develop:

- Standardised or harmonised open system interfaces, data formats and data models.
- Interoperability of the agricultural domain with other domains such as traffic, forestry, etc.
- Dependable and efficient wireless communication networks, even in rural areas.
- Further studies on farmers' decision-making processes as the basis for developing information systems
- Smart system features leading to smart environments to fully utilise the system concept.
- Accessible user interfaces to integrated devices.
- Larger scale pilot studies of the new system concept

Preface

The Nordic countries are well-known for their high quality agricultural products and good farm management. Family farms are the foundation of Nordic agriculture. Nowadays, external demands on agriculture are increasing, leading to pressures on farms that may become overwhelming. These external demands relate to efficiency, compliance with standards, the environment, ethics and human and animal health. Information management has an important role to play in coping with these demands. Modern ICT provides tools to solve problems and facilitate the development of sustainable agriculture. However, agricultural processes are diverse, comprising diverse systems, and thus a common understanding and concept of information management in agriculture, and in particular plant production, is needed. A common concept assists all actors in the value chain to develop their own processes and products to meet the demand. Availability of skilled labour is a challenge that has to be considered when developing information management concepts in Nordic agriculture. In addition, the information technology developed has to be acceptable to end-users. For that reason, this report adopts a user-centred approach.

This report presents results from a Nordic collaboration in which agricultural and ICT knowledge from the Nordic countries was combined to form a common system concept for information management in mobile plant production working environments, where automation can be used to bring more efficiency. The research work was carried out by Aarhus University, Helsinki University of Technology, MTT Agrifood Research Finland, Swedish Institute for Agricultural and Environmental Engineering and VTT Technical Research Centre of Finland. Research colleagues from the Norwegian Institute for Agricultural and Environmental Research and the Agricultural University of Iceland gave their input by commenting on the concept developed. Nordic farmers and technology companies made valuable contributions through numerous interviews and discussion sessions during the concept design phase. Feedback from practical actors and researchers during the concept evaluation phase was also invaluable.

As project manager, I would like to thank all parties for making a sound contribution to this work. On behalf of project participants, I would like to thank the Nordic Innovation Centre (NICE) for its financial and technical support. The joint work carried out within the project is quite new in the area and would not have been possible without the support of NICE.

We hope that the results obtained will lead to an open discussion among all actors in the value chain and help them to improve efficiency in their work.

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1 Introduction

Agricultural processes are diverse by nature and within the individual farm, a number of different production processes and their sub-processes operate in parallel most of the time. Actual work on farms consists of parallel and successive tasks. In the Nordic Countries the number of farms has been decreasing and the size of the farms increasing over recent decades. Fewer workers are now managing larger businesses and automation is being increasingly employed. At the same time, demands on the quality and traceability of production methods and raw materials are increasing. These demands are set by governments, the processing industry and customers and they relate to compliance with standards, the environment, ethics and health.

Information management plays an important role in how well farms are able to deal with increasing demands. In plant production tasks in the field, agricultural machinery now plays a key role in process acquisition and documentation of data. It is important that field tasks are carried out according to plan, and if sudden changes in plan are needed that these follow standards and regulations and help to improve the outcome.

2 Background and aims

New automation, ICT and GIS technologies provide solutions for steering and controlling mobile working units in site-specific production systems to fulfil the requirements for efficient, environmentally friendly, safe and traceable production. However, improving the quality and efficiency of work tasks requires user-centric on-line support system solutions. A missing link in the system is the lack of a refined and integrated analysis of the data acquired and transformation of these data into information and knowledge useful for decision-making. Currently, the majority of the information collected by sensors or by manual recorders is not used due to logistics problems in data handling. The costs of the time spent in managing the data in many cases outweigh the economic benefits of using the data. For example, the use of wireless communication and open system interfaces will be very much in demand in the future. However, the user-friendly system needed for this does not currently exist and development of this kind of open system is a challenging task for companies to carry out alone.

The overall aim of this project was to draw up basic recommendations and guidelines for a novel, intelligent, integrated information and decision support framework (system architecture, *etc.*) for planning and control of mobile working units. The approach involved extracting and developing Nordic knowledge and know-how concerning the use of modern ICT and information management in the mobile environment of crop production.

3 Method - Systems analysis approach

The work process in development of a system concept is presented in Figure 1. The right-hand side of the diagram shows the five phases of the system analysis work flow: problem identification, problem formulation, model building, model validation and problem solving, while the left-hand side shows the inputs used in the development process.

3.1 Problem identification and formulation

The foundations of the system concept development lay in the problem identification and problem formulation phases, in which the target and boundaries of the system were determined using the literature and interviews with farmers and technology companies. Farmers' attitudes to their work and profession were defined. Users' needs and technology companies' viewpoints were formulated into core task-based systems usability claims.

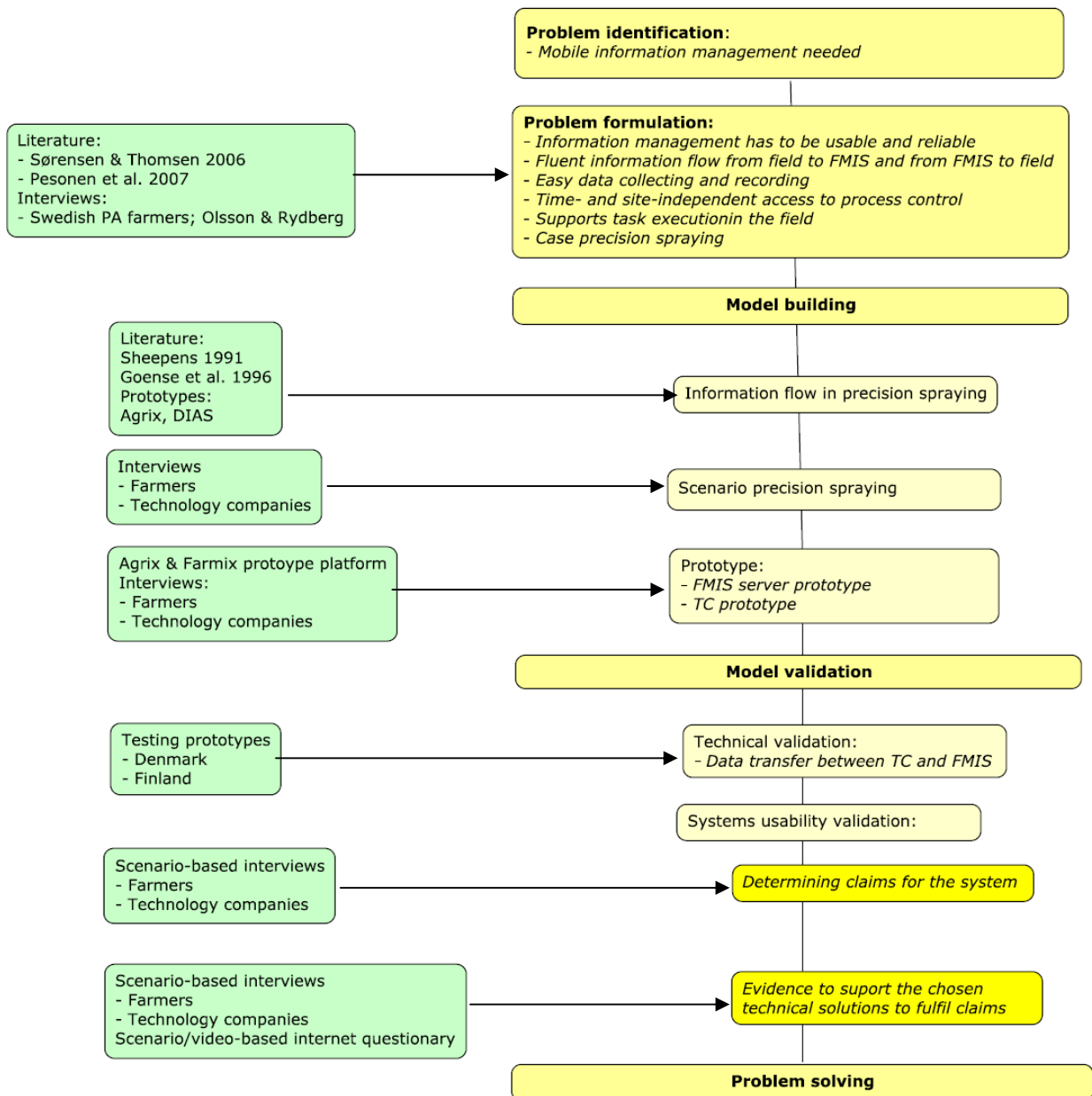


Figure 1: Overview of the different phases in the development of the system concept. The arrows indicate dataflow.

3.2 Model building

In the model building phase, system requirements were articulated and system solutions created. Precision spraying was chosen as a demanding case for a closer information management study. The principles of information modelling for the spraying case followed the principles derived in the general reference models for arable farming. The basis for the spraying case was a deliberation process identifying the relevant decision-making processes involved in the spraying operation, including strategic, tactical, operational, executive, and evaluation levels. A scenario was built to describe the work flow and information management in the precision spraying operation. This scenario was used as background material for interviews and questionnaires in order to obtain data for system design and evaluation. The system concept covers a large functional network. Prototypes were built of those system parts that were novel and thus needed to be verified.

3.3 Validation

During the validation phase, data were collected in different ways as indicated in Figure 1. Technical validation of the system concept included theoretical evaluation based on reported experience of known technologies, as well as tests using specially built prototypes. The prototype tests took place in Finland and Denmark. As indicated in Figure 1, these data and development steps may be considered as *technical validation*.

All these previously defined issues were interpreted from a Usability Case methodology point of view in the model validation phase. The system Usability Case was then articulated under the heading of ‘systems usability validation’. Two phases were identified; the *determination of claims* and the *finding of evidence* as to whether the system concept designed fulfils these claims.

In the *usability validation* phase, two sets of scenario-based interviews were carried out, the first in Denmark, Finland and Sweden with the aim of obtaining material to develop usability claims and the second collecting evidence for arguments supporting solutions that fulfilled the systems usability claims. In this phase the scenario was prepared as a video and made available on the website (<http://www.mtt.fi/infoxt>) for everyone interested. The scenario, including a questionnaire, was available in English, Danish, Finnish, Icelandic, Norwegian and Swedish. The questionnaire contained questions concerning the systems usability of the different aspects of information management in the scenario case.

3.4 Problem solving

The solution to the problem was constructed gradually in the form of a novel system concept design. The concept of the information management system was designed according to the human-centred design process (ISO Standard 13407, 1999). However, it was observed that an adaptation of the standard was needed in the sense that an individual *user's* point of view, to which the standard refers, was too narrow. We decided it would be more appropriate to focus on *usage* since in a *usage-driven* approach, the focus is on the system of practices in which the users are involved. Three methodological principles were considered important. First, the target product had to be placed in the *societal frame* in which it is going to be used. In the present case this meant that the system designed had to be placed in the context of precision agriculture, which as a whole influences the development of the system. To accomplish this, description or modelling of the domain is necessary. The second principle is that the *intentions and needs that the users express*

with regard to their work and business are taken as the starting point in the development of technology. In this case the users were the farmers. The results of these considerations had to become evident in the product requirements. Thirdly, users' ideas and reactions concerning the specific characteristics of the technology designed are collected and analysed during the *maturation of the design*. These new data are then fed back into the design process. The present report is a description of how these principles of usage-driven design were considered in the system concept development. In this project we did not reach the phase of the user interface design.

3.4.1 Core-Task Analysis

Following the usage-driven approach, the design process was carried out using a method called Core-Task Analysis (CTA) originally developed by the Technical Research Centre of Finland (VTT) (Norros, 2004). The central concept of the method is the *core task*, by which we mean the essential result-critical content of a particular work, defined primarily by the aims and purposes of the work. In order to act appropriately in a particular work, the demands of the core task must be maintained in all situations as physical laws and socio-economic general conditions must remain the same from one situation to another. When technologies develop, the former type boundary conditions may change. Changes may also take place in the socio-economic boundary conditions of work. It is clear that all these changes induce pressures on the core task so that it tends to change. One of the aims of CTA is to identify major changes in the core task that may act as obstacles to appropriate completion of the work.

The *core task* analysis of a particular piece of work comprises three different levels or perspectives (see also section 8.2). These are:

- Modelling of the work domain and generic core-task demands of the work.
- Modelling of work situations or work scenarios, which provide a process point of view to work (goals, resources and processes of information and action).
- Empirical analysis of actual work performance and opinions concerning work.

On the first level, a systems theory-orientated generic analysis of the work domain is used, *i.e.* arable farming (Vicente, 1999), together with the Engeström activity system model, which enables conceptualisation of socio-cultural processes in the system (Engeström, 1999). With the aid of these tools the work of the users, *i.e.* farmers, can be defined in a new systemic way. As a result, a definition of the core task demands is produced. This provides a basis for deriving claims concerning technologies that should support the particular work (Norros, 2004).

The second level of CTA focuses on understanding work processes. This is possible only if the focus is on particular situations in which work is typically carried out. Situations are considered as instances of the generic work domain and core task. As a result of this phase, specific goals, resources and constraints can be defined and information flows made explicit.

An empirical level of analysis is necessary to understand what people are actually doing when certain work is performed. This level of CTA may often be the starting point for analysis. The empirical analysis usually focuses on work as it is at present, but during the design process the analysis can also be focused on developing new work. In both cases the problem is that at least some generic concepts of the work domain and the core-task demands, and also understanding of the situations, are needed in order to make sense of what people are observed doing.

3.4.2 Adapting Core-Task Analysis to design needs

The Core-Task Analysis method was originally developed for analysis of people's performance in complex work. In a more design-orientated context, the method should be adapted to the analysis and evaluation needs of the on-going design process. Such a design-orientated application of the CTA approach was developed in a recent project focusing on barley growing (Nurkka *et al.*, 2007). In the following we present some of the arguments that guided us in adapting the CTA method to better fit the design aims, particularly in the farming domain.

The Human Computer Interaction (HCI) literature suggests that the cornerstone for user acceptance and usability of a novel system or product is involving the users in the development process. There are many approaches and forms of user involvement but all aim at direct contact between the users and developers (Kujala, 2002). Different methods are used to find out about the users and their capabilities, needs and demands concerning the product. The findings are taken into account and transformed into user requirements and finally to product attributes. The motives for user involvement in practical product development are therefore many: to define more accurate user requirements, to improve the quality of the system, to improve the development efficiency and to increase user satisfaction (Kujala, 2002). User involvement and identification of accurate requirements and analysis are particularly important in the early phases of the development, when the concept is created and changes are still easy to make.

The dominant objective in the development of a DSS/FMIS (Decision Support System/Farm Management Information System) has been an effective transfer of scientific knowledge to farmers in order to improve their decision-making (Fountas *et al.*, 2006). It seems logical that scientifically sound DSS should be useful for farmers, as they have a need for good planning and decision-making (McCown, 2002). However, researchers' assumptions that farmers would enthusiastically embrace their research findings have been proven wrong (McBratney *et al.*, 2005). The information offered has been considered by the farmers to be inappropriate for practical farming. Another reason for the low adoption of DSS is poor understanding of the system concept or its benefits in use. The systems may be too difficult and time-consuming to use, they do not fit the farmers' work patterns and different systems are difficult to integrate in practice (Roskopf *et al.*, 2003; Parker, 2005). As a result there appears to be a lack of trust in DSS, which constitutes the major barrier to adoption of the system.

It has been proposed by Fountas *et al.* (2006) that information systems should incorporate farmers' personal experience and management goals into data management. McCown (2002) postulates that farmers must undergo an iterative learning and practice-based process of change when confronting the future. The developers of new technology must be prepared to be involved in, lend support to and learn from this process. They should learn what the farmers are learning. Accordingly, we believe that to understand the practical needs and demands of the farmer in production of a high quality crop, there is a need to understand the farmer's general attitude towards farming, his/her conception of Precision Agriculture (PA) and how he/she is currently using PA at the moment in the farming process. Finally, we must understand the obstacles to uptake of systems to support PA.

The CTA method of Nurkka *et al.* (2007) was developed still further in the present project. Figure 2 shows the course of the research phases in this system concept development work. Recommendations and guidelines for concept implementation and further research and development work are derived from the concept itself and its development work.

Phases of problem solving included:

- Core task 1/ Science-based modelling of the work domain and core-task demands
- Analysis of present orientation of farmers
- Practice-based modelling of the emerging core task
- Integrated information modelling
- Scenario-based concept construction
- Analysis of interactions in use cases
- Core task 2 / Science-based modelling of the new work domain and core-task demands.

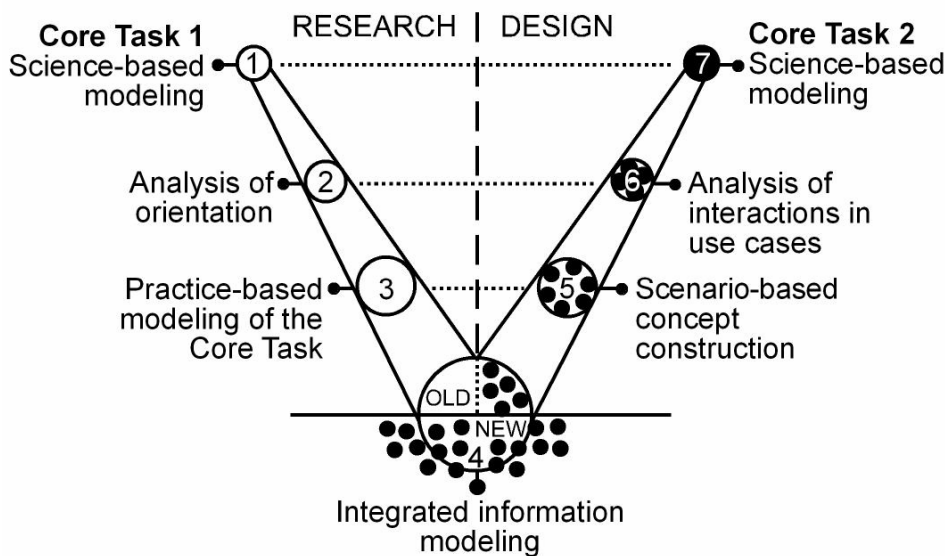


Figure 2: Phases of the Core-Task Analysis-based user demand modelling system (Nurkka *et al.*, 2007).

The human-centred design process aims to design a new information management concept that supports the farmer's core task. It is divided into two parts; research and design. The research part handles the problem at a general level, focusing on the core task of farming, the farmer's orientation to his/her work. The core task and associated information management are defined on both a scientific and practical basis. The science-based core-task model postulates the core task according to scientific and physical facts as a matrix where successive work processes form one dimension and the move from general to specific the other dimension. The practice-based core task is modelled after the farmer's understanding of his/her work.

The integrated information modelling phase changes the focus from general to specific, in this case from information management in farm production processes to information management in field task operations. In this phase results and demands from the research part are taken into account, data flow models of field task operations are created, available relevant technology for design is inventoried and specifications for a novel system concept are defined.

In the next phase, a suitable field task is chosen as a case for a specific technological design. A scenario describing usage of new concept-based task operation is created. The scenario consists of

a series of pictures and narrative of work flow and information management within it. This scenario is used as background material in interviews when defining claims that actors in the value chain have set for the system. The system concept is constructed to fulfil the claims and prototypes are built to validate the new technological parts of the system.

Systems usability of the concept is evaluated by analysing interactions in use cases. In this phase evidence is collected regarding whether the potential users find that the features of the new system concept fulfil the claims made for the system.

4 Science-based modelling of the core task of field work – the present situation and farmer orientation

4.1 Information management in farming

Farming in general, which comprises many different production processes, can be compared with management of any process. The management duties include controlling and monitoring the farming process, collecting and analysing statistics on the process and using the collected information in decision-making and strategic planning. Challenges in management increase as the farmer needs to confront changes for which his experience provides limited guidance. These challenges include the introduction of new farming techniques, since the main aims of agricultural production to date are not only profitability in terms of economic efficiency, but also the maintenance of a healthy environment.

The focus of agricultural production is changing from quantity to quality and sustainability (Jensen *et al.*, 2000). Precision Agriculture (PA) aims to achieve these goals. By generic definition, PA refers to agricultural techniques that increase the number of (correct) decisions per unit area of land per unit of time, with associated net benefits (McBratney *et al.*, 2005). When practising PA, a farmer manages crop production inputs (seed, fertiliser, lime, pesticides, *etc.*) on a site-specific basis to increase profits and crop quality, but also to reduce waste and maintain environmental quality. In order to make precise decisions in different phases of the farming process, he/she therefore needs to analyse information from different vast and sporadically located information sources. Management of the information and decision-making is the core issue for the farmer in successful PA, not the data acquisition process. A range of Decision Support Systems (DSS) and Farm Management Information Systems (FMIS) are available to farmers, but the adoption of those systems and of PA has been disappointingly low (Roskopf *et al.*, 2003; McBratney *et al.*, 2005; Parker, 2005). DSS and FMIS tools have a number of applications in farming, the most important being to support strategic and operational decisions and to enable better identification and shared analysis of problems (Loevinsohn *et al.*, 2002) by permitting access to and manipulation of information.

A project where the adoption of PA in Germany was investigated concluded that there was a need for better exploitation of the recorded data in order to reach the level of information required (Reichardt & Jürgens, 2006).

4.2 User demands according to previous research

A case study was carried out on previous research in Finland (2005-06) to understand and analyse farmers' actual information demands and farming practices in order to gather requirements for a novel information system using malting barley production as an example. The emphasis was on user demands. By approaching system development in a user-centred way, the usability and acceptance of the system is predicted to be better. The hypothesis of the study was that novel technology is more acceptable and applicable if it has the potential for use in current practices.

Core-Task Analysis was employed in the study (Figure 2). The development work focused on the research part of the human-centred design process (V-model), and the design part only extended to phase 5 (scenario-based concept construction). In phase 2, the orientation of 11 malting barley producers practising conventional farming was analysed. In phase 3, practice-based modelling was carried out on four farmers who had shown an orientation to improve control of farm processes in order to achieve better yield and quality of malting barley. It was concluded that these farmers were potential PA farmers, even though they did not have any PA technique employed in their farm processes.

The science-based core task consisted of two dimensions; 1) the temporal sequence of the growing process divided into successive tasks within a year; and 2) eight general function levels of the growing process. These function levels were:

- Farm management
- Production conditions on the farm
- Field conditions
- Plant requirements
- Growth process and growing conditions
- Control of interactions between nitrogen, starch and proteins
- Control of the effects of crop protection chemicals and fertilisers
- Use of feedback information

The means to control the above-mentioned functions and additional sub-functions were identified and arranged according to work schedule of the growing season. This model worked as a basis for interviews with farmers regarding their work and the core task demands of their work.

A joint scheme for the analysis of farmers' work orientation, *i.e.* their perceptions of work and their personal sense of work, was developed. Each farmer was classified according to 14 items on the basis of a contextual three-grade rating scale. The basic evaluation categories and items were as follows:

Perception of the object of activity

- Producer thinking: Considers him/herself part of the production chain
- Biological thinking: Interest in the growth process of the plant
- Service thinking: Commitment to the idea of entrepreneurship

Perception of the uncertain and unpredictable character of farming

- Coping with uncertainty by own active practice
- Awareness of reasons for uncertainty

Perception of knowledge and its construction

- Respect for experiential knowledge
- Use of information tools
- Societal nature of knowledge: Active participation in the farming community

Perception of good farmer – what is good, morally right and valuable in the profession

- Confidence in own decision-making and judgement

- Control and development of own activity
- Respect for nature and a communicative relationship with nature

Motivation for malting barley production

- Way of life, source of significance
- Professional challenge
- Exploitation of the economic possibility, profitability.

On the basis of the individual ratings achieved, the farmers were classified into three categories where one class contained farmers with the necessary orientation for adopting PA technology and thus most likely to be helpful collaborators in the design of new tools.

Practice-based modelling (phase 3) took place as a workshop, during which farming practices were simulated by inviting the farmers to draw their own conceptual models of the barley growing process based on the experiences of the preceding farming period. The model was intended to portray the actions they made and the tools they used during the process. The farmers were encouraged to make as many comments as possible on the content and type of the information they used and how they used it in different phases of the process. The work was facilitated by paper tags prepared with relevant information according to core task. The aim of this phase was to understand the obstacles to the use of the systems in supporting PA and the actual needs of the farmers regarding information systems.

In phase 4, the research results obtained on core task demands and farmers' needs were integrated and a detailed model of information needs was developed for the present conventional barley growing situation and for the future situation augmented with ICT-based precision agriculture technology. User demands were met by suggesting possible technologies to fulfil these demands. The technologies were suggested after inventory of available techniques and investigation of their suitability for farm processes and the farm environment.

In phase 5, the scenario describing information management in successive farming tasks during the year was drawn up using the new system concept. Two of the conventional farmers interviewed in phase 3 evaluated the proposed system concept and found it satisfactory. The study ended with this phase.

The main results of the project concerning user needs based on the review of user demands are listed below.

- Orientation-dependent demands:
 - Understanding the farmer's role in the malt/beer production process
 - Possibility to challenge the grain markets
 - Functional models for support in uncertain situations (plant protection, *etc.*)
 - Tools to evaluate the effect of different cultivation practices
 - Analysis of existing farm data
 - Tools to share information with other farmers, farmer co-operation
 - Tools to evaluate the influence of a certain cultivation practice on the whole farming business
 - Methods to improve farming
 - Towards sustainable farming; understanding reasons for environmental requirements (by government), tools to detect different factors
 - Understanding the meaning of farming, incentives
 - Understanding growth factors and their influence in the process

- Understanding the meaning and behaviour of inputs in the production process.
- Core task execution focused demands concerning:
 - Information generation
 - Immediate recording of observations and measurements
 - Precise information
 - Detailed information and knowledge about the effect of growth factors on product quality
 - Automatic weather data retrieval in farm area
 - Evaluation, interpretation and analysis
 - Influence of decisions in different phases on the final output
 - Awareness of the total on-farm situation
 - Better utilisation of farm potential
 - Understanding interactions between growth factors
 - Understanding realistic yield potential
 - Understanding the effect of a single act on output
 - Operational environment, where information tools should:
 - Support mobile work
 - Operate in rapidly changing physical conditions (bright light, dust, vibration, moisture, temperature)
 - Support execution of multiple parallel tasks
 - Adapt to restricting or enabling clothing
 - Ease time restrictions and tight timetables instead of causing extra stress.

In general, the most important needs for information management in plant production were:

- ⇒ Easy recording of observations
- ⇒ Need for process control
 - Influence of action or choice on output of:
 - Task
 - Sub-task
 - Whole process
 - Correct reaction to observations
- ⇒ Interface to process control has to be available in the work situation and in mobile environments. Utilisation of intelligent assistance to improve systems usability.

From the Finnish case study, it can be concluded that some of the farmers interviewed had adopted 'precision agriculture thinking', *i.e.* they were interested in the phenomena of the farming process and actively sought, used and created information to understand and learn more about this process, even without any specific PA technology.

It was found that technical skills to handle computers and other ICT tools are already present at a high level among farmers. However, it was concluded that adoption of new working practices which utilise information technology requires the new system to provide clear benefits. The use of new tools has to be meaningful and fluent. In additionally, these new tools have to support the matters and tasks where farmers genuinely need support.

5 Practice-based modelling of the core task of field work

5.1 Present needs regarding information management in precision agriculture

5.1.1 Interview study

In order to analyse the information flow on high-tech farms, farmers and advisors *practising PA* in Sweden were interviewed regarding their requirements for facilitated decision-making (2007). The interviews focused on the increasing problem of handling data and information in agriculture. There were two aims of this study: 1) to determine whether Swedish precision farmers had similar user requirements to Finnish farmers (section 4.2), thus supporting the assumption that the results from section 4.2 are generally valid in the Nordic Countries; and 2) to map the problems in data and information management in precision agriculture.

Ten interviews were conducted, with five farmers and their six advisors (one farmer had two advisors, both interviewed on the same occasion). The participating farmers represented the group of farmers in Sweden that have adapted most PA techniques. The farmers had been practising PA for at least 7 years. All of the advisors taking part in the study had a long experience of PA and had been working as advisors for between 3 and 34 years.

The interviews were performed using a qualitative interview method (Kvale, 1997). Separate questions were prepared for the farmers and advisors. The farmers were asked questions about their farms, precision agriculture and the handling of information in crop production. As part of the interviews with the farmers, a case study on the information flow for producing milling wheat was conducted. The advisors were asked questions about crop production programmes, the handling of information and their own personal opinions and career.

The interviews lasted two hours for each farmer and one hour for each advisor and all the interviews were recorded, transcribed and analysed. General information about the farmers and advisors is available in the work package report on the project website (<http://www.mtt.fi/infoxt>, Publications, WP2 report, Annexes 1-3) and in a Swedish report (Rydberg *et al.*, 2008). Two methods were used when analysing the interviews: a systematic analysis (Table 1) and the construction of an information flow chart. The *ad hoc* methods introduced in Table 1 were used throughout the systematic analysis.

Table 1: Different phases in the systematic analysis of farmers (Kvale, 1997)

Phase	Content
0	Four different ad hoc methods: 1. Look at the credibility 2. Form contrasts 3. Subordinate particularities under the general context 4. Create a conceptual/theoretical context
1	Select different themes
2	Formulate questions and answers to the questions

In the construction of the information flow chart, the farmers were asked to draw their own conceptual models according to section 4.2, based on their experiences of a general preceding farming period. In this case the core task was the production process for milling wheat instead of malting barley, due to practical reasons. The work was facilitated by paper tags prepared with

relevant information according to the core task (Figure 3) and additional comments from the farmers on information content and type of information were noted.

For each farming operation portrayed by the farmers, the activities unique to each farm were summarised and incorporated into a general information flow chart for the farmers participating in the study (Rydberg *et al.*, 2008). The flow chart created was only valid for the farmers participating in the study, but a more general information flow chart is presented in section 9 and Appendix VI. Both the flow chart in this study and the more general one presented in Appendix VI were divided into five parts: strategic, tactic planning, operational planning, execution and evaluation, see further section 6.1.

5.1.2 Analysis of interview responses

In order to understand the farmers' background and set of values in information management technology, general questions were asked about their motives for using PA techniques in crop production. Many of the farmers declared a great interest in technology as a possible reason why they adopted PA. Examples of added value with PA mentioned by the farmers were intended to be part of the technological development process and increased environmental values. However, the major motive for adopting PA techniques was that it offered the possibility to be more efficient and improve farm finances, although to date using PA had not improved their finances.

Information exchange is not entirely about technology. The human contact between the farmer and the advisor will continue to be an important factor that cannot be replaced by technology in the future. All farmers interviewed agreed that the information from field inspections, advisory services and PA considerably affected their decision-making and that the advisors had a major influence on decision-making on farms. However, the involvement of advisors in the farmers' handling of information varied to a great extent, which had an effect on the amount of problems experienced by the farmers regarding information handling.

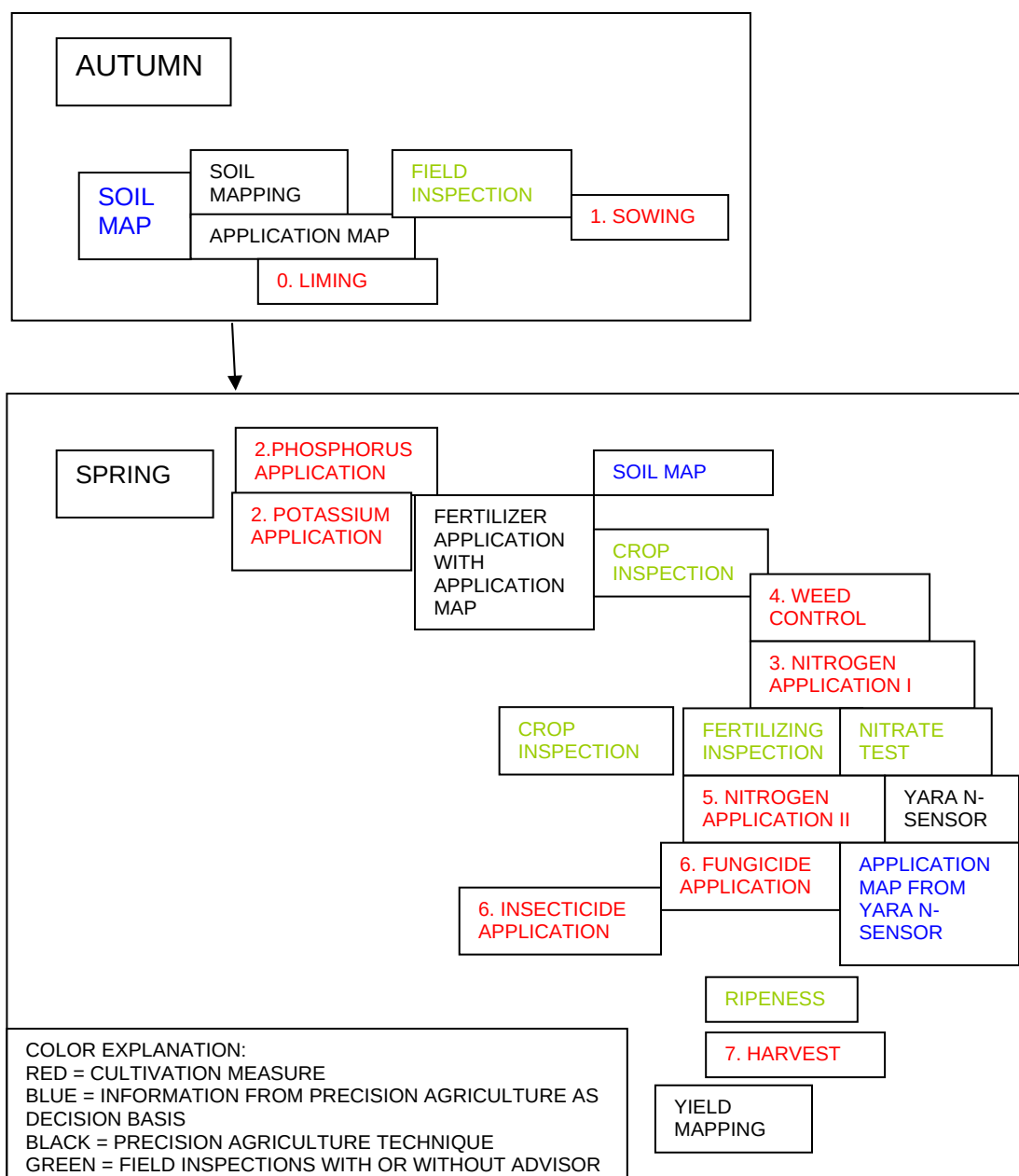


Figure 3: Diagram of farmers' view on the information flow in precision agriculture (PA) for milling wheat.

The farmer's interest and time spent on calibration and data collection very much affect the farmer's possibilities to move forward in the development of PA. If the technique breaks down when every other condition for fieldwork is perfect, it can be very difficult for the farmer to convince himself to spend hours refining his PA technique. Many of the farmers considered this a problem with PA, except for one farmer who said that he never continues with the fieldwork until everything in the PA technique is working perfectly. Looking at the previous study (Nurkka *et al.*, 2007), this farmer would belong to the ideal kind of farmer who is the most helpful collaborator in the design of concept development tools.

5.1.3 Flow chart analysis

The aim of this phase was to understand where in the information chain the most variations in information flows take place, *e.g.* where one farming operation will most likely result in several information pathways, and to understand what the obstacles and actual needs are for the farmers regarding information systems for PA.

When analysing the information from the individual flow charts, some contradictory results from the interview responses were revealed. For instance, a statement that no evaluation takes place during the growing season could be rejected since evaluation does take place in association with new decisions or problems arising in the growing season.

Aim 1: *To reveal whether farmers have similar ideas about process control in the Nordic countries*

Comparing the results from the interviews with Swedish farmers practising PA with the conclusions drawn from the study in section 4.2, the following demands were particularly highlighted by both studies:

- Analysis of existing farm data
- Understanding of growth factors and their influence in the process
- Influence of decisions in different phases to the final output
- Support for mobile work
- Facilitate fast and tight timetables instead of causing extra stress

Some of the parameters in the previous study was not regarded as equally important when translated into a Nordic PA concept. *Understanding realistic yield potential* was one such parameter. The reason for this was obvious problems with information analysis, as well as limited possibilities to act upon the information gained. Most farmers had been introduced to PA through yield mapping, but both farmers and advisors expressed the opinion that this is an expensive technique rarely used to any advantage. This resulted in the farmers only visually inspecting the yield maps, since too much time was required to monitor and process the data involved.

Aim 2: *To map the problems in data and information management of special interest in precision agriculture*

Problems and apprehensions relating to information handling in PA included:

- Limitations in communication between different modules
- Data exchange limitations due to various file formats
- Lack of time, knowledge or motivation to evaluate data from PA
- Great demand for automated and time-effective expert systems for data handling
- The information generated from one particular PA technique can result in numerous ways of data transfer and processing
- Farmers exchange information with many different actors and pieces of equipment.

Both advisors and farmers agreed that the technique used in PA today is too difficult. The main reason for this is that there are many different brands of PA techniques that cannot communicate with each other. Users also want to have programmes that are able to create export and import files.

The majority of the advisors would like to communicate with the farmer over a server. That is a good way to avoid problems that can appear when the farmer and the advisor are working on the same file at the same time. The farmers had many requests about what they wanted to get out of

the PA technique (Table 2), *e.g.* possibilities to process data into a format easy to understand and short processing time, and they are increasingly investing in mobile systems based on internet solutions in their crop production.

Table 2: Farmers' requests in information handling

Farmers requests in information handling

- <i>Reliable, comprehensive and flexible solutions for information handling</i> - o Friction free communication between different modules - o Software applications should be able to create export and import files - o Fast or instant data processing requested and systems based on online sensing and automatic data processing - o Information exchange using Internet based software - o A central database with automated updates of programmes or files - o High accessibility of data for both farmers and their advisors (broadband, reliable wireless connections) - o The possibility to compare maps from different PA techniques in one software.
- Flexibility to evaluate performance of production in association with new decisions or problems arising.
- Human contact between the farmer and the advisor will continue to be very important in the future
- Further integration of plant production programmes with the information from PA (an increasing part of the information flow chain is handled directly by the crop management software)

Possible future investments in information related technique for PA concerns:

- auto guidance
- the Yara-N-sensor
- Personal Digital Assistant (PDA)

Concluding remarks from this section is that the statements made in section 4.2 on the user demands in information handling in agriculture in general, is still valid from a precision agriculture point of view. As the results are valid for both Sweden and Finland it is reasonable to assume that they are also valid for precision farmers in all the Nordic countries. Additional claims regarding the spatial nature of precision data has been presented as well as requests for better communication between different machinery and software. There is a need for harmonization of standards for data transfer.

6 Integrated information modelling for new system design

In this phase, scientific information and practical information and experience are gathered together, and new ideas and technologies are brought in as material for a creative designing process. The work starts by defining a functional description of the needed system. Then, inventory of available technologies is made. Finally, specifications for a new concept for information management system in automated plant production are defined.

6.1 Introduction

6.1.1 Information and management activity structures

The planning and control architecture for mobile work units in the field includes different layers of abstraction for handling both deliberation and reactivity (Chatila, 1995). In a hybrid architecture, deliberation or mission planning focuses on the predictable or goal-directing behaviour of the work units (*e.g.* route plan), while local reactive behaviour deals with the uncertainty of the environment and adaptation to local conditions during execution. A number of approaches to operation planning for agricultural machinery, ranging from manual planning systems to various degrees of automated planning involving parameterisation of the planned operation, have been attempted (Stoll, 2003). Figure 4 outlines the basic management processes that have been identified within the agricultural plant production cycle for both manned and unmanned machinery items. The management activities concentrate on planning and controlling the execution of *operations* on some *soil* or *crops* (Sørensen, 1999). These operations include soil treatment, seedbed preparation, sowing, fertilising, plant care, harvesting and irrigation. Operations describe the agronomic purpose of an activity, while tasks describe the realisation of the operation involving relevant resources in terms of implements. The deconstruction of information processes is based on the management functions ranging from strategic to tactical and operational planning, execution control and evaluation, and a number of underlying processes and sub-processes. The operational plans are deconstructed for formulation and control of the planned operations and tasks.

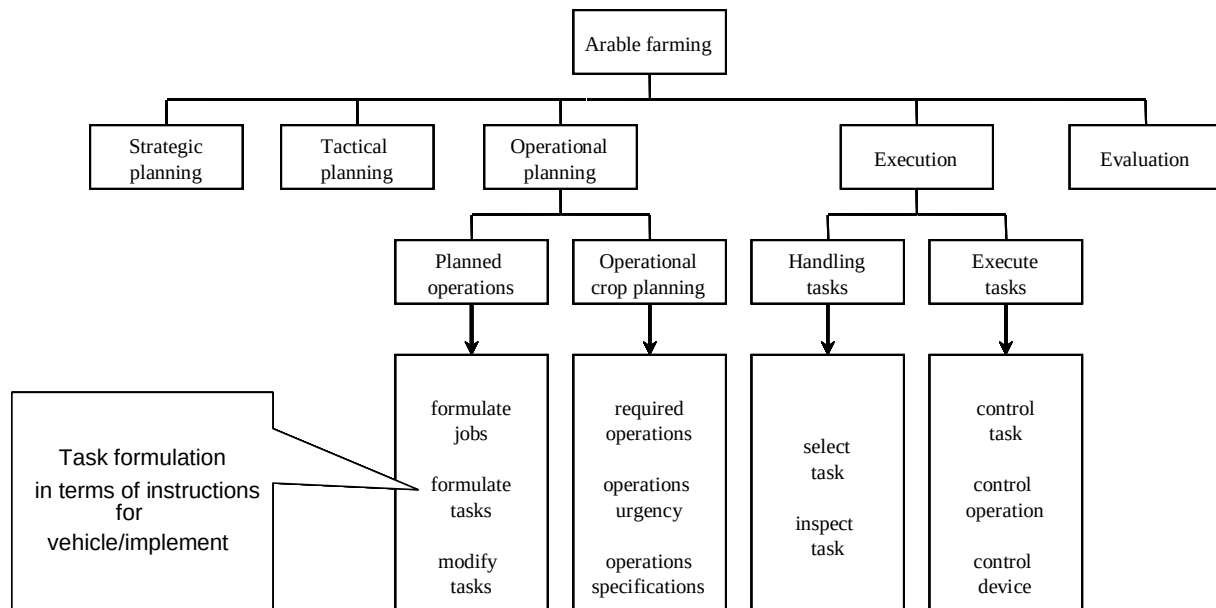


Figure 4: Information and planning activities in agricultural operations management with the identification of the revised task formulation to be invoked in the case of autonomous vehicles (adapted from Goense & Hofstee, 1994).

In relation to Figure 4, it should be noted that the activity of observing and monitoring is also to be regarded as an operation, which can be planned, executed and controlled in the same way as

conventional machine operations (Sørensen *et al.*, 2002). In this way, the task of observing/monitoring can be formulated according to the actual needs of observing or monitoring of the system states, the costs-benefits of acquiring a specific information, *etc.*

The functional environment of a mobile work unit within an automated plant production context consists of its internal and external interaction with an overall information management system on the farm. The focal point of the information management system is to sustain the planning and execution of farm operations.

When focusing on the management of field operations, the task of optimised field data management becomes one of carrying out the following steps or procedures:

- creating planned field operations
- transferring or delivering the plans to the field with specified tasks
- setting up the mobile work units for executing the planned operation
- managing, controlling and recording the field operation
- documenting the executed field operation for recordkeeping and managerial purposes

By specifying in detail the information provided and the information required for the information handling processes in Figure 4, the design and functionalities of the individual information system elements can be derived. That is the case both for on-board machinery information systems as well as for support service information systems.

6.1.2 Farm data openness

A question of sharing information sets a challenge for the data management. Open systems are usually considered to be systems that interoperate through open interface, a means to make a connection between two software components. An interface on the client presents an ordered set of parameters and instructions to an interface on the server that is structured to read and respond to just such a set of parameters and instructions. Thus, an interface enables one processing component to exchange data and instructions with another processing component. An open solution would empower technology developers to make complex information and services accessible and useful with all kinds of applications.

There are several needs that guide towards an open system solution. As presented by OGC (1999) commonly for geospatial information openness, the needs are valid also for agricultural information. Firstly, there is the need to share and reuse data, in order to decrease costs, get more or better information, and increase the value of data holdings. Secondly, there is the need to choose the best tool for the job, and to reduce technology and procurement risk. And as a third point, there is the need for more people with less training to benefit from using specific data in more applications: That is, the need to leverage investments in software and data.

Open specification also eases several activities. Adapting the OGC's (1999) highlighted facts to farm information, demands supporting open specification can be defined: Farm information should be easy to find, access and acquire. Farming related information from different sources should be easy to integrate, combine and use in different analyses. Information should also be easy to register, superimpose and render for display *e.g.* as a map. Displays and visualisations should be able to be specialised for specific purposes. Finally, the incorporation between many software and content providers should be easy.

6.2 Data flow analysis and technical requirements for the information management system in automated plant production

A detailed structuring and formalisation of physical entities and the information surrounding the planning and control of efficient mobile working units in automated agricultural plant production systems is a decisive prerequisite for the development of a comprehensive and effective ICT system for task management on the farm. In this context, it is essential that information requirements, communication protocols and common definitions of the exchanged information are set up. Scheepens (1991) presented the concept of information modelling as the basis for this important task. The basic idea is to model all the activities and decisions that take place in a targeted production section and combine this modelling with all the relevant data. The formal description includes *entity definition (in this case mobile work units)*, a *process model (activities and decision processes)* and a *data model (data relating to the processes)*. The defined processes in the process model and the entities and attributes in the data model provide the basis for developing compatible information systems.

A corresponding information modelling approach was developed in a Finnish research project focusing on analysis of user requirements for farm information management systems (Nurkka *et al.*, 2007; Pesonen *et al.*, 2007). This project focused on malting barley production and used this process as a case to implement a user-centred approach to farm system development. The project team exploited experience of cognitive systems engineering methods and especially that applying to functional modelling of the work domain. The methodology was originally developed at Risø National Laboratory in Denmark by Jens Rasmussen (1986) and was later refined by Vicente (1999). The model has typically been used to analyse generic work domain control demands for the design of automation systems for complex industrial processes. At VTT Technical Research Centre in Finland, the method has been further refined in two respects: first, a method has been developed for deriving generic user work demands, labelled core-task demands, on the basis of the functional analysis. Second, a tool for describing situational decision-making models has been constructed which includes analyses of available information and operating possibilities (Norros 2004). These tools were applied in the malting barley production process. The modelling exercise involved agricultural experts, malting process experts and farmers involved with farming methods. The models produced were tested and developed further in interaction with actual malt barley growers on four farms. In the next phase, the information models produced based on experience of the present conventional farming process were completed by research results concerning new information needs and possibilities of ICT-based precision agriculture. The results of these several modelling phases were used to conceptualise the information structure and user interface for farm information management.

The use of information modelling provides a sound approach for specific applications. As part of the applicability of such information modelling approaches, the formulation of international standards is important. On-going work in this area includes ISO TC 23/SC 19/WG1, which has the aim of setting up an open interconnected on-board system, permitting electronic units to communicate, and defining the data exchange with the Farm Management Information System (FMIS: includes software, decision support system, *etc.* for farm management).

6.2.1 Entity definition: identification of work units

In primary agricultural production, the high degree of mechanisation has increased productivity considerably in recent decades. This development is in the process of being coupled with automation and extensive use of embedded ICT systems. Control of field machinery (conventional, such as tractor with implement, or autonomous vehicles, such as robots) enables collection of detailed site-specific information during operation through the use of advanced ICT. This contributes to minimised resource input and to environmentally sound and quality optimised production via decision support systems or directly via on-line control (Sørensen, 1999; Martin-Clouaire & Rellier, 2000; Sørensen *et al.*, 2002; Suomi *et al.*, 2006). Planning and formulation of jobs includes indication of an expected time schedule on the basis of the immediate crop development, weather forecasts, *etc.* The job descriptions are transmitted to the tractor/implement for control and manual/automatic site-specific adjustment of implements. In cases of actual work results deviating from the plans, on-line corrective measures will be invoked. The final work result is recorded and documented, and the data obtained are stored for learning and use in connection with new loops of planning or control (see Figure 5).

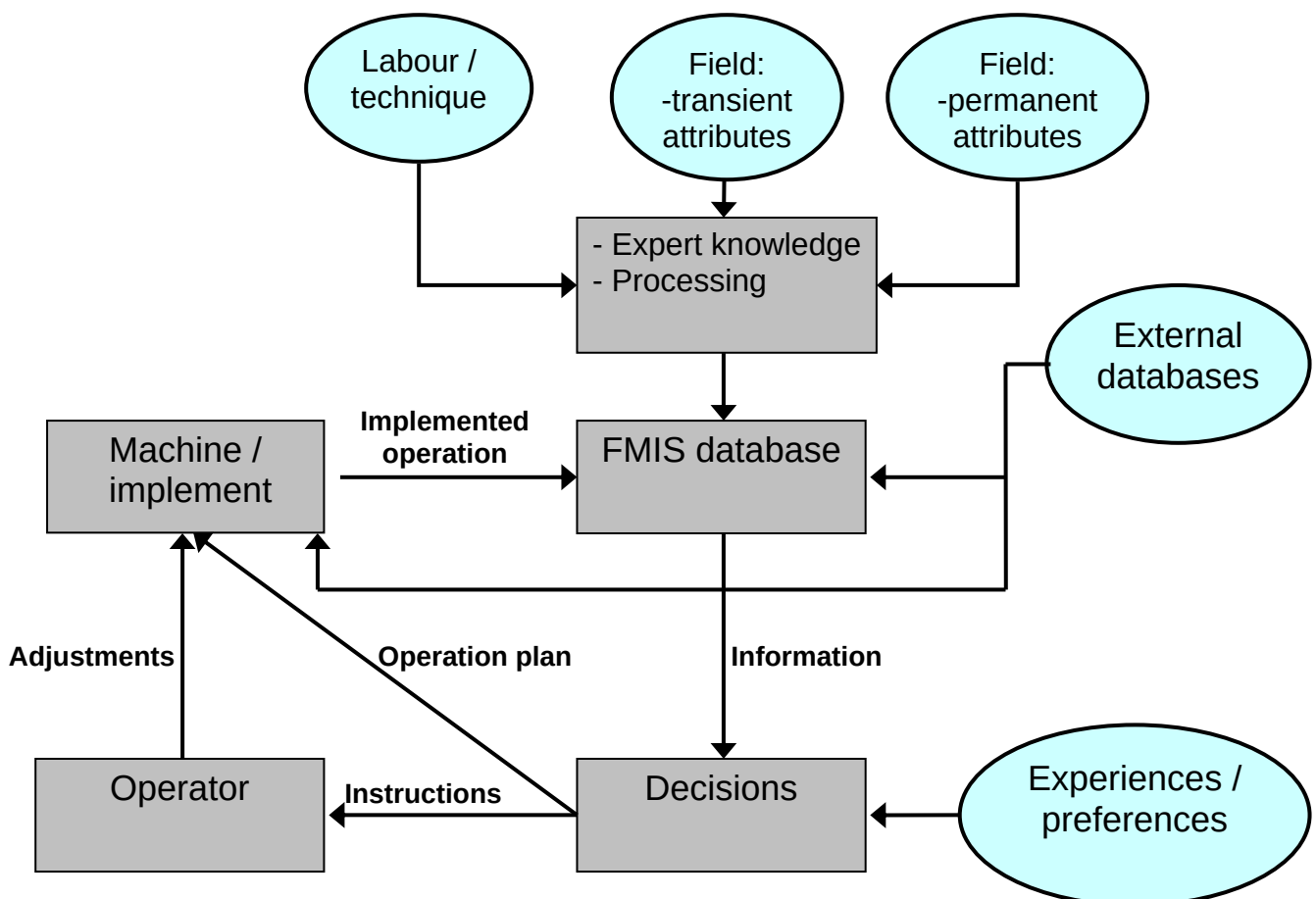


Figure 5: Information handling in the field and on the farm.

Figure 5 gives an overview of the information management necessary to implement effective task management on mobile work units in plant production. Within this concept, the task management function will provide the farmer with a scheduling tool for planning and controlling the tasks

relevant to the field operations. The principal output from the deliberation processes is the formulated operation and task plan, which will be downloaded to the machine/implement unit. Field operations maps are the instructions that both guide vehicle-based movements in the field and control concurrent agronomic operations. This task plan will be dynamic, indicating that time will be dealt with explicitly and if knowledge on the environment increases or improves, it will be possible to reformulate the plan in order to continually uphold a timely and cost-efficient operation. The planning and control system must be able to predict the evolution of system states (field and crop development, machine performance, *etc.*) and plan the actions of work units accordingly. The system must also be reactive and capable of reformulating plans based on observations and feedback from the actual implementation of the tasks. Figure 6 shows the planning and control loops of the general prescriptive task management functions together with its integration with the operator at various levels of the information system.

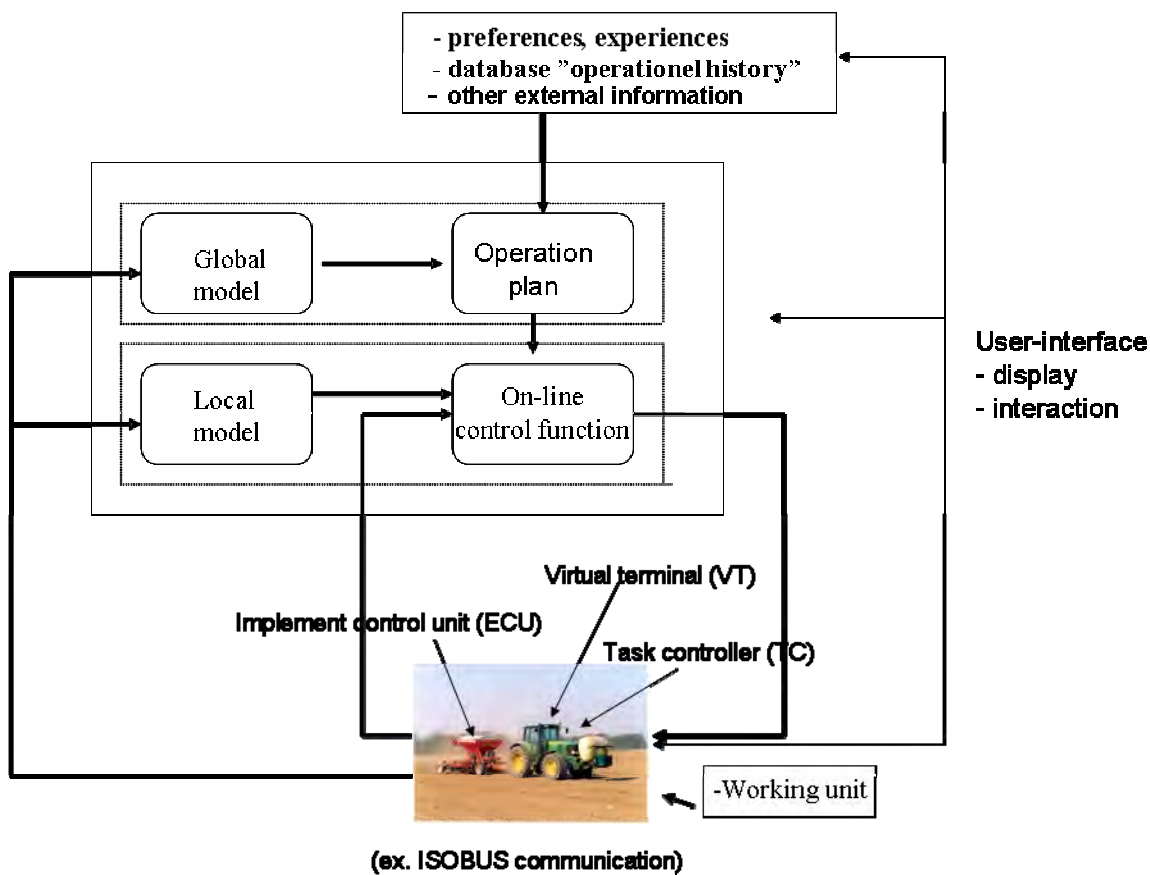


Figure 6: Planning and executive control loops for field machinery.

The global model indicates the overall off-line planned operation specifications outlining the agronomic requirements, such as dosage, working depth, prescriptive driving patterns, *etc.* The local model handles the reformulation of prescribed plans as a consequence of unexpected events during execution, user-induced alterations, *etc.* The local model together with the on-line control function keeps the machine and implement settings continuously on target.

The assessment of requirements and development and implementation of an information management system for mobile work units require a number of competences and approaches to be employed. In terms of management efforts and technological assessment, the following competences are required:

- Usability and applicability studies of the proposed technologies
- Analysis and deconstruction of machine operations
- Resource optimisation and decision support

As regards technology components, these include a mixture of sensor and communication elements:

- On-machinery monitoring/display units
- On-machinery control units
- Tractor-implement communication systems
- Wireless communication system between machines and support services (*e.g.* internal/external databases)
- Sensor systems for continuous updating of system status information

The implementation of field operations requires working units comprising field machinery. Field machinery is traditionally based on tractor-implement combinations or on large, self-propelled units. A working unit is, in this context, defined as an individual unit working on its own with a prescribed job.

A fully integrated ICT for mobile work units in arable farming is seen as comprising three main communicating elements:

- The *central unit* responsible for supervising the general *job* execution by sending specific *tasks* to the mobile *main work unit*, handling unexpected events, managing results of the performed *job*, and updating a *farm database* with work results.
- The *main work unit*, an independent vehicle that is able to traverse a field and reach specific and planned locations. Coordinates of the locations are sent from the *central unit* as part of the *task* description.
- The *implement*, a device along with its software connected to the *main work unit*. It is responsible for performing the planned agronomic operation according to the pre-set settings.

The embedded task management has the following workflow:

- Planning field tasks and/or operations using software on the FMIS in the farmer's or contractor's office.
- The task data produced by the planning software are converted to the data format required for the implement control units.
- The task data are transferred wirelessly to the task controller of the mobile work unit.
- The task controller uses the task data to transmit process data to the ECU on the implement.
- The task controller collects task data.
- The collected data are transferred wirelessly to the FMIS.
- The collected data are evaluated by the FMIS.

Using the derived definition of a work unit following two types of communication, configurations were selected for the project cases:

- Tractor-implement work unit:
 - equipped with an ISOBUS communication system.
 - equipped with a machine-specific communication system.

Work units also require rugged on-board computers (laptop, PDA ...), user-adapted interfaces in terms of interactions and displays, and type of supportive wireless network infrastructure (GPRS, Wlan, *etc.*).

Wireless communication enables online information exchange between off-road automated machines and external operators such as support services, databases or clients. This brings great possibilities to improve the quality and profitability of businesses such as machinery contracting (Pesonen *et al.*, 2007)

6.2.2 Information model

On the arable farm, field operations are carried out in relation to a number of different objects such as field, crop, operators, machinery, *etc.* Figure 7 shows the objects involved in field operation management together with the main attributes describing the information needed, as well as the interrelations between objects.

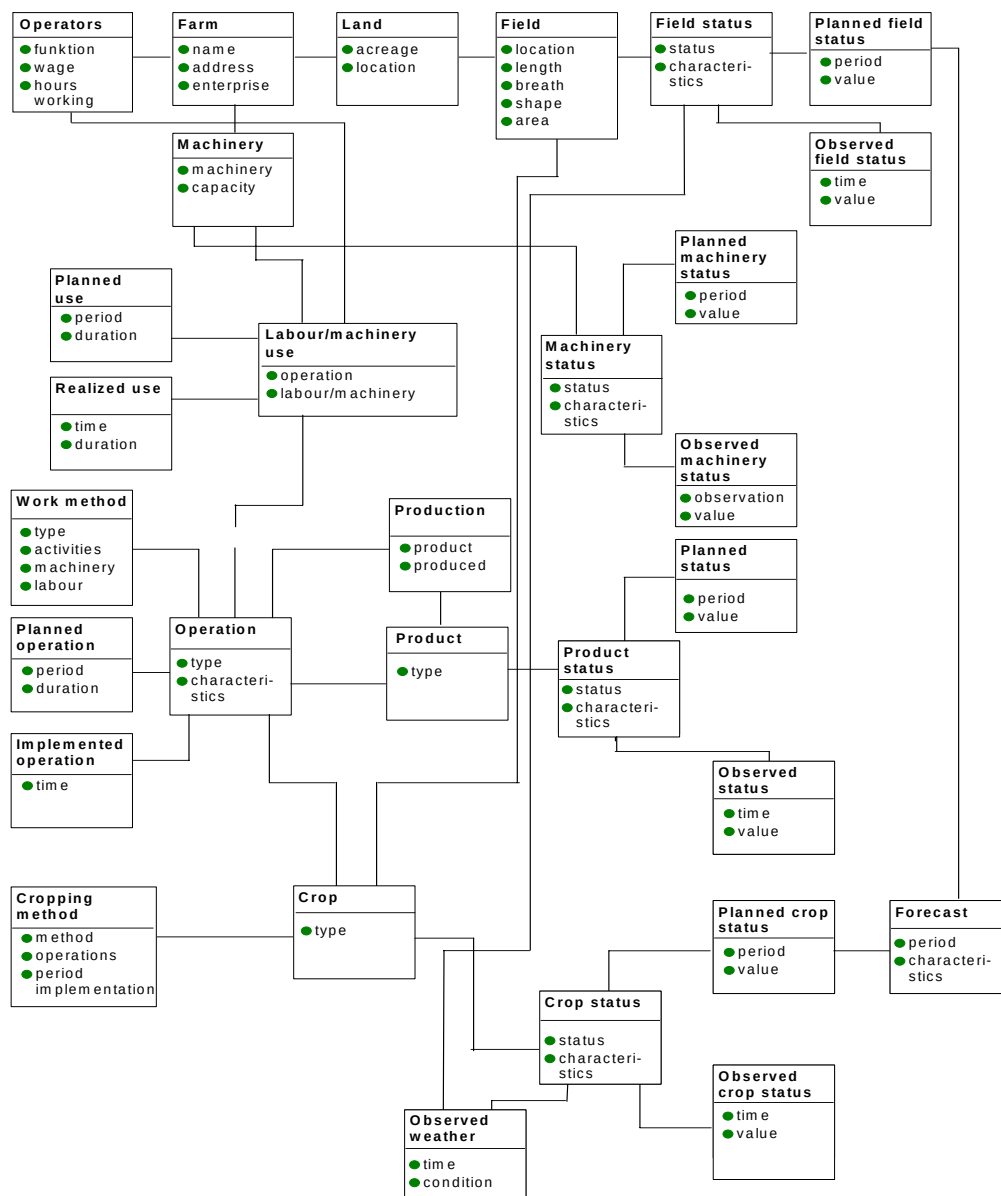


Figure 7: Objects involved in the planning and implementation of field operations (Sørensen, 1999).

The main components involve the farm and a number of fields hosting different types of crops. Production resources include operators and other types of work crews together with their use of machinery and equipment. Another component is the product or product mix identifying the output from the production process or operation (*e.g.* harvested yield). The focal element is the operation as depicting the operational activity performed by the resources on the fields and crops. The operations are carried out according to some specified work method describing, for example, the type of machinery items involved.

The information associated with the operational activities of the farm is described in the attributes of the elements listed in Figure 7. The attributes specify the kind of knowledge and data relevant to the decision-making processes connected with the planning and implementation of the operations. These attributes include *planned* and *observed status* of the entities, where the observation can be made directly by human observation or by the use of some monitoring device.

It is important to understand the concept of an operation and, for example, a task as part of the operational activities on the farm (Sørensen, 1999). A formal definition is given by van Elderen (1977), who states that an operation is ‘a technical coherent combination of treatments by which at a certain time a characteristic change of condition of an object (a field, a building, an equipment, a crop) is observed, realised or prevented’. This definition extends operations beyond those for crop production to supporting enterprise functions such as maintenance, repairs, observation, *etc.* An operation is generally seen as the link between some resources (*e.g.* labour and machinery), some materials processed, and some material produced (*e.g.* harvested crops, repaired machine, *etc.*). Table 3 gives the various definitions applying to farm operations.

Table 3: Structure of arable farm operations

Cultural practice	Cultural practices are seen as the human intervention in the agricultural crop production system. Examples include soil tillage, sowing, fertilising, plant care and harvesting.	Attributes: - type - ...
Operation	To realise the cultural practices the farm manager chooses one or more operations, <i>i.e.</i> operation deals with what should be done to meet the objectives set by the cultural practices. Specifications such as working speed, working depth, <i>etc.</i> must be given for each operation.	Attributes: - operation type - work method type - specification for execution - ...
Working method	The method by which the individual activities within an operation or chain of operations are carried out and co-ordinated with each other.	Attributes: - type of work method - sequence of activities - number and type of equipment - ...
Task	A task defines one or more operations carried out by a group of workers and machinery items, a <i>work-set</i> , working physically together (<i>e.g.</i> operator1 + tractor + sprayer). Each <i>work-set</i> carries out one or more operations simultaneously or sequentially following defined specifications, a certain working method, and on a specified object.	Attributes: - task type - operation type - ...

When field operations and tasks are planned and implemented, the central aspects of Figure 7 evolve around farmers acquiring information on the current or future states of the objects involved.

The farmers then make their planning efforts and subsequently revise their plans according to the observations made. This mechanism is shown in detail in Figure 8.

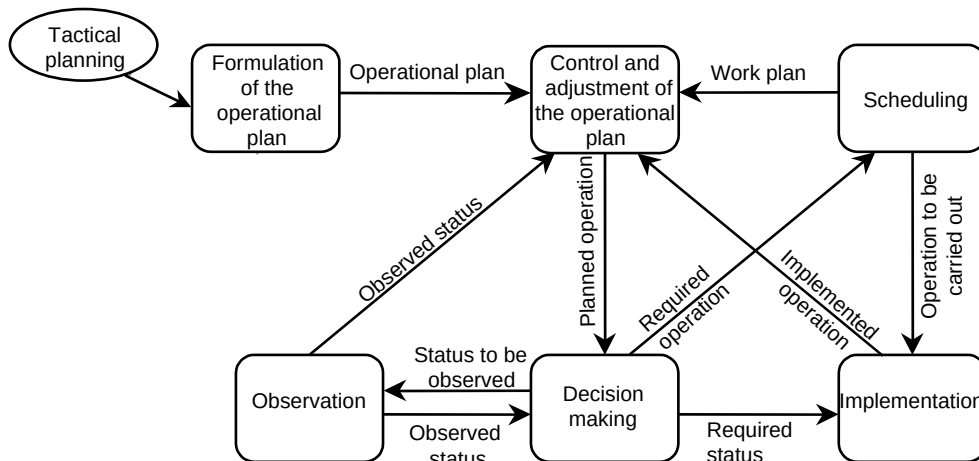


Figure 8: Task management for field work (Sørensen, 1999).

The task management is the tool to plan and evaluate work in the field. The decision-making processes are centred on specifying **what, where, how, by whom, and when** the field work should be carried out. On the basis of a tactical plan, the formulation of an operational plan can be carried out. In the course of time, this plan can be adjusted while following observations of the crop and forecasts of *e.g.* weather, as well as the results of already executed operations. The implementation of the operational planning follows the scheme below:

- A planned operation is reported to the *decision-making process*. Based on some *observed status* the decision-maker decides whether or not an operation is required
- A required operation is reported to the *scheduling process*. This process co-ordinates the required operation with the other operational activities on the farm. On the basis of the capacity, availability and priorities, the labour and machinery process determines which operation to implement and at what time
- The implemented operation is reported to the *control/adjustment process* for further planning and evaluation.

As noted, the operational planning process in agriculture is highly dynamic and interactive. That places heavy demands on any proposed planning system, which has to cover the creation of a schedule of work processes over a longer period (predictive scheduling) and the adaptation of an existing schedule due to actual events in the scheduling environment (reactive scheduling).

When a task is formulated and transferred to the mobile unit for implementation, the modification and revision of the task may be carried out as part of the operational planning or directly by the operator through a task controller interface (*e.g.* virtual terminal).

As a technological tool aspect for performing the core task, the present precision agriculture task was modelled and presented as an information flow diagram. To specify the information content for the further work in the project, a related data model was also built. Precision spraying was chosen

as an example for information flow modelling. The model includes phases from strategic planning via execution to evaluation, but only the execution part is presented here (Appendix III). The whole model can be seen in the work package report on the project website (<http://www.mtt.fi/infoxt>) in publications, WP1 report.

6.3 Functional description of the system

In a study by Sørensen and Thomsen (2006), different stakeholders (advisory service, software companies, machine contractors, *etc.*) were interviewed in order to identify requirements for future automatic data acquisition, on-line management, *etc.* Specific requirements included:

- A proven positive cost-benefit analysis
- A clear flexibility in relation to specific applications of the system
- A simple user interface requiring no intensive learning efforts
- Automatic data logging and data storage requiring a minimum of human interaction
- Integration options with other internal management tools

As a starting point for functional description of the system, the results of the previous Finnish project ‘Human interaction focused development of a concept for information management system of a plant production process’ were utilised. The design in the InfoXT project, however, focuses more on the special needs of precision agriculture and the use of mobile automation. It was clearly shown in information flow analysis that access to the system must be independent of the location. To fulfil this demand, the system was designed to be based on internet servers (Figure 9).

In the description, the farm data are relocated outside the farm into a database managed via internet servers. The task planning takes place either in the farm office or as a specialist service. When planning the task, farm-specific data are retrieved from the database via an internet connection. The finished plans are inserted back into the Farm Database, where they are available to the farmer (or contractor) who executes the task in the field. The plans are available for the farmer to view anytime independent of the location, and can be modified as necessary. When it is time for the task execution, the farmer (or contractor) retrieves the task to the Task Controller (TC) via a wireless internet connection, preferably via mobile broadband connection. The TC commands the automated work unit to perform the task according to instructions determined in the task file. The work performed is recorded into the TC according to additional instructions defined in the task file. The recorded information may include collected spatial field data, summarising data and driver’s notes. After the task is completed, the work document created is sent to the Farm Database straight from the field via a wireless internet connection. There, it is available for viewing and further processing by the farmer or specific service providers. The farmer or service provider may have access to different data sources located in separate databases (weather data, research data, soil analysis service, *etc.*) via an automated authentication system. This automated data retrieval requires agreement between the two parties to allow data transfer. Similarly, the processing industry for example can be given permission to retrieve data from the Farm Database in order to check that all contract requirements between the farmer and processing industry have been fulfilled. The system infrastructure can be used also to manage machinery-specific data such as system updates or fault diagnostic data between working unit/machine and remote service.

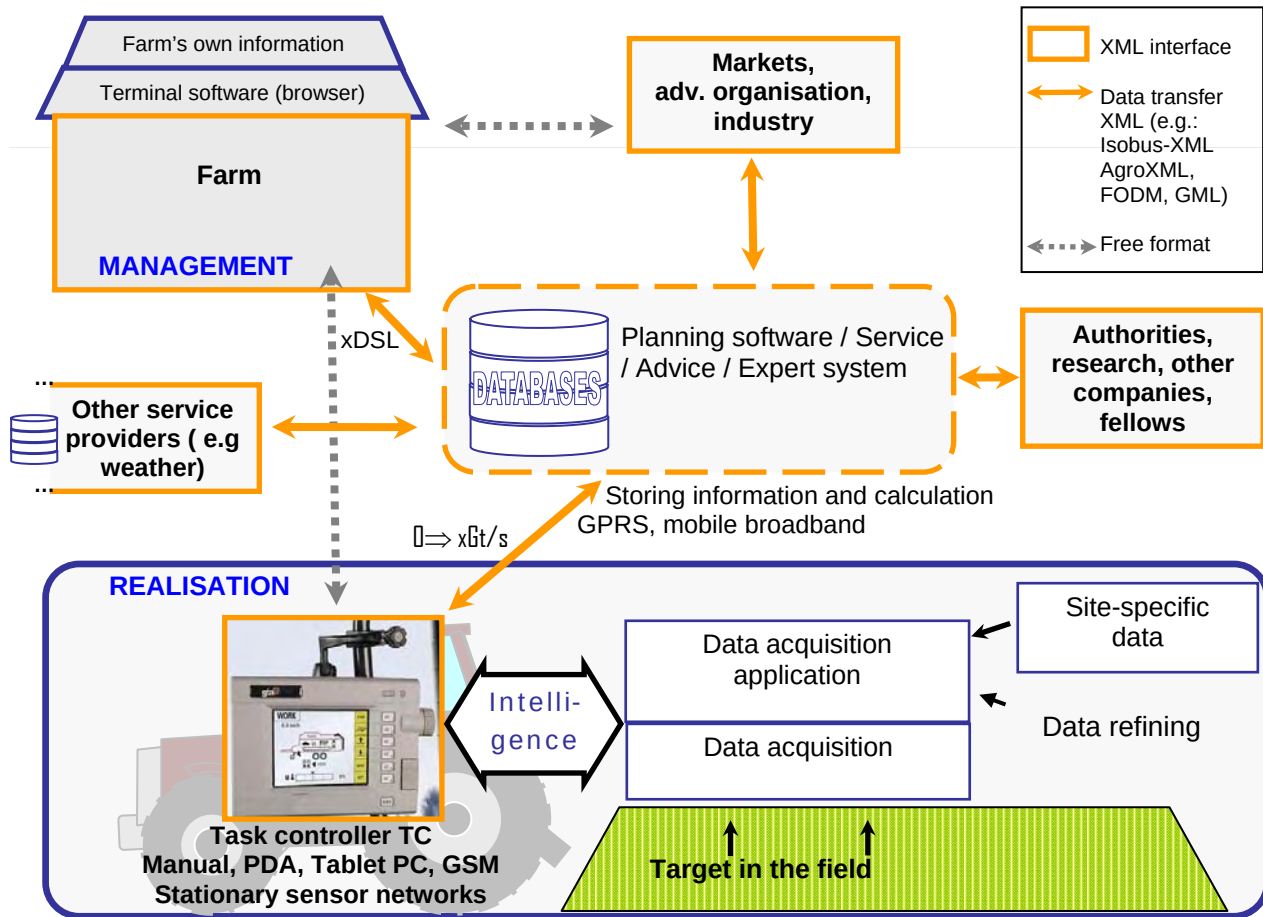


Figure 9: Functional model of the InfoXT information management system, modified further from the model presented by Pesonen *et al.* (2007).

6.4 Identification of technologies for data storage, transfer and management

6.4.1 Introduction

An inventory of technologies suitable for the implementation of a farm management information system (FMIS) is presented here. Farm management systems designed in particular for precision agriculture are also known as precision farming information systems (PFIS). A list of various technologies is provided, with a short description of each.

The technologies covered here are those for the overall architecture, data storage, data transfer, application development and data presentation. The emphasis is on practical solutions that are known to work and which are stable technologies able to provide a working basis for the FMIS specification developed. The technologies that are not so mature are covered very briefly, if at all.

There are two essentially distinct architectures for the FMIS; an *on-site* solution where the FMIS is a computer programme operating locally on what is usually a Microsoft Windows-based operating system; and an *off-site* solution where the FMIS is an internet server and the user interface is, in most cases, an internet browser operating on any general purpose operating system. In this project,

the decision was made to assume that the future FMIS will be an internet server and thus the first option is ignored and the inventory of technologies below concentrates on those used for the development of internet servers.

A combination of on-site and off-site solutions resembles the thin-client user interface solution. However, having data storage and application logic divided between several systems generates added complexity to the overall system.

The list of technologies suitable for an internet server-based FMIS focuses here on the cultivation of grain. The purpose of the specific FMIS is to aid farmers in farm management and to provide a means of communication between various services and field implements. One such group of implements is ISOBUS (ISO 11783)-compatible devices with the need for on-line communication with the FMIS or other external servers.

6.4.2 Technologies for the overall architecture

The overall architecture in this context means the base on which the internet server is developed. Multiple choices exist but in practice the selection can be narrowed down to just a few options. This choice affects the subsequent technological choices greatly as certain technologies are not easily interoperable, while other technologies have very highly advanced interoperability features.

One major decision to be made concerns the use of an application server, *i.e.* whether the existing application server architecture should be used for the internet server-based FMIS or whether a proper implementation of the FMIS requires features which are not either available or easily implemented in existing application servers. Application servers exist for at least all listed overall architectures.

(L)AMP

The *de facto* combination of the Apache internet server, MySQL relational database and the PHP programming language is a common basis for internet servers. The letter L in the abbreviation refers to the Linux operating system which usually accompanies the other three. However, Linux is optional, as any POSIX conforming operating system would be sufficient and most likely even Microsoft Windows could be used. The (L)AMP combination has the benefit of being free, open-source software under the relatively non-restricting GPL licence. Compared to most application servers, the (L)AMP combination is of a relatively low level but because of the expressive power of the PHP language, development is usually fast and prototypes are quick to create.

Java

The Java programming language offers high portability and as a general solution, Java or J2EE provides a platform for service development. The J2EE implementation is available free from Sun Microsystems and several free, open-source tools exist to further extend this architecture. There are also several application servers based on J2EE. Java can be operated in most operating systems, including those that are POSIX conforming, and on all versions of Microsoft Windows. While Java is a good general solution, software development or prototyping in Java is not as rapid as with other, higher-level programming languages such as PHP. Although Java does have a clear advantage in performance when compared with these higher-level languages, it cannot compete with C/C++/C# in computational performance. Java can be considered a middle-level language which positions itself between the high-performance languages such as C or C++ and high-level languages such as PHP or python.

Microsoft .NET

Microsoft.NET is a solution provided by Microsoft. It consists of several components and a wide variety of programming languages. Microsoft.NET is a popular choice for many commercial applications. In practice this solution is strongly tied to the Microsoft Windows operating system. Development also requires the use of specialised tools, most of which are commercially available from Microsoft.

6.4.3 Technologies for data storage

The FMIS will have to store data and for an individual farm this amount is relatively low (from a view of computing), apart from the GIS data produced and required by precision agriculture. However, the number of farmers using the system creates great demands for the data storage solution. Storing Geographic Information System (GIS) data is interesting as most field operations produce data with location information included. Managing GIS data in a relational database is somewhat difficult but for that, extensions such as PostGIS (GIS-related functions for the PostgreSQL server) exist. Most other data are relatively simple to manage in a relational database. For precision agriculture the availability and processing of GIS data are essential.

There is some batch processing of the data, most likely requiring several interactions with the data storage but most operations should be manageable with just one or two queries. Unfortunately the stress on the data storage system is divided very unevenly, as it can be expected that most users will want to use the system at practically the same time, creating a considerably peak in usage. The data should also be available for a convenient transfer to authorities and external services.

Relational database (RDBMS) with an SQL interface

The *de facto* data storage solution of the day is a relational database (RDBMS) with an SQL interface. Relational databases are a very mature and thoroughly studied technology; they are known to provide a highly efficient and reliable form of data storage. Most data involved in an FMIS can easily be represented as relations and are thus well suited for a relational database. One open question concerns the storage of GIS data, *i.e.* whether it should be stored as raw data or in some more manageable format through some database extension such as PostGIS. Relational databases are available as open-source, such as MySQL or PostgreSQL, and also as commercial software, such as the database systems provided by Microsoft or Oracle.

Other data storage technologies

Other storage technologies exist, such as object databases (OODBMS) with an OQL interface or native XML databases (NXD), but these are too young as technologies to actually compete with relational databases. Thus these options are not considered further and it is assumed that the relational database will be used as the data storage solution. The state of these technologies is such that *e.g.* for OQL (Object Query Language) there exists no complete implementation and for native XML databases there exists no standard at the time of writing.

6.4.4 Technologies for data transfer

The amounts of data transferred are relatively low and for most purposes a connection capable of transferring just a few kilobytes per second is sufficient. Connections between the FMIS and external services are not a problem, since it can be assumed that the server housing the FMIS has a high-bandwidth connection available.

The largest data transfers can be expected to be the transfer of task files and reports, both of which can be managed with a low-bandwidth connection. The latency of the connection is not an issue

apart from the user interface. Farmers can be expected to have a mobile GPRS connection and an xDSL connection available, the latter being more than adequate for any transfer of data required. Widespread xDSL coverage is underway in several countries and can be expected to cover even rural areas in a matter of years. The lack of an xDSL connection can always be compensated for by a 3G mobile data transfer system, which has better coverage than xDSL.

Physical transfer versus the data format

All data transfer can be expected to occur as TCP/IP or UDP/IP traffic over some physical medium. The medium used has some effect on the data format in the case of highly redundant formats on a low-bandwidth connection. A single data format cannot be chosen, as interoperability between various systems has to be achieved. The easily transformable XML format should be favoured over other formats, but the other formats will have to be supported as well.

XML Files

XML provides a good format for most data. XML files are easy to read and they can be transformed using XSLT transformations. Having XML as the general format somewhat simplifies systems as all data then share at least some common structure. The XML data format is designed so that it is easy for computers to read and manage. For transformations there exists a special language XSLT (XSL Transformations) to transform one XML file to another XML file. Such transformations are of particular interest when managing the interoperability of systems using different XML schemas. Raw XML as such is unusable so there has to be some structure to the XML file. For this, standards or propositions such as AgroXML exist. There are also several formats used with SOA which could be considered for use in this project.

HTTP(S)

For the user interface in particular and for some external services, HTTP(S) has to be used. The secure version of the protocol should be used whenever supported by the browser and it should be considered that the output of the FMIS is always in the W3C recommended format of application/xhtml+xml as described by RFC 3236 to assure strict adherence to standards and to facilitate interoperability with various browsers.

Application level data transfer

For the application level data transfer there has to be some format, as raw XML is unusable as such. SOA provides some basis for application level data transfer but the other option is to implement some application-specific format (XML schema).

Other and proprietary data formats

The world is currently filled with various proprietary data formats and interaction with systems using these formats is likely to be unavoidable. These formats should be managed by the FMIS with application logic to handle conversions to more manageable formats. In practice, the worst case scenario here is that of text files which are still relatively easy to parse and handle but each such format requires a separate parser designed to read the format.

6.4.5 Technologies for data management and application development

Data management and application logic cover the application logic of the FMIS. There is a high dependency on every other technical solution used in the system. For the proper choice of the development environment, common operations for the data have to be identified. The choice of the development environment should reflect the ease of use and how easy it is to add individual parts in a modular fashion. Computational efficiency is most likely a secondary requirement, as critical

parts can always be further optimised if required. One major decision to be made is whether the application logic should be bound to some existing integrated development environment (IDE).

Java

Using J2EE as the basis of the architecture would make Java the language of practically all application logic. However software development and prototyping is slightly slower in Java than for example in PHP.

PHP

PHP is a relatively new language and goes together with the (L)AMP architecture. PHP provides a very good interaction to the relational database and networks and application development in PHP is quite fast. It is also possible to create fast prototypes using the PHP language. PHP is also rapidly evolving with new features emerging and old bugs and problems being fixed.

ASP

Active server pages are used in Microsoft Windows-based internet servers. The language is similar to PHP in operation.

C/C++/C#

These languages are highly efficient but slow to develop. None should be chosen as the primary development language for the application logic, but some time-critical components might have to be developed with these languages for performance reasons.

Perl, Ruby, Python and others

Many other languages exist but they are not really suitable candidates for the implementation of the FMIS. Some of the very highest order of application logic might be written in one of these languages but extensive use should be avoided as they are either highly inefficient or essentially write-only-languages (Perl in particular).

6.4.6 Technologies for data presentation (HMI)

Data presentation in this context means the user interface. There is a slight dependency on data management but for the most part the user interface is relatively independent. There is no single user interface to the system, but for the human user there has to be a primary user interface (browser on a desktop PC) and a mobile version for use with smaller devices. In addition, there are interfaces for the external services, the TC on the tractor-implement combination and the interface for system administration. It should be noted that the importance of the farmer side user interface cannot be understated. For a system of this type in particular, great emphasis is on the user interface and much work should be done to make the user interface as good as possible.

A separate user interface based on the operating system graphical user interface (GUI) is undoubtedly the best in terms of usability and features. With internet servers this interface would be a thin-client type terminal with application logic and some data storage within it, making this a very complex solution that is also platform-dependent.

A traditional HTML-based interface is a very simple solution and sufficient for most websites. For an FMIS, however, this interface is too simple as basic HTML lacks several interaction elements providing features more suitable for an interactive form than a user interface comparable to that of a separate user interface. For the mobile interface, traditional HTML might be a suitable solution as the mobile interface has limited functionality and HTML is supported by practically every device. Interaction in HTML always requires a complete page reload.

Dynamic HTML was once thought to be standard for the interactive browser interface. Unfortunately, while interesting, this technology has turned out to be a commercial failure with very low adoption rates.

Asynchronous JavaScript and XML (AJAX) is currently a popular method of producing interactive websites. AJAX provides a relatively easy-to-use interface with existing technologies and is therefore a worthy candidate for the user interface. Combined with Java applets, it is possible to create rich browser-based interfaces with AJAX.

Terminal-based interfaces provide the benefits of a separate user interface without the trouble of actually having the user interface as separate. Unfortunately terminal-based interfaces pose great demands on network capacity and are completely unusable on even a low-end DSL connection. Examples of terminal interfaces are the X-terminals used in POSIX conforming operating systems and the Windows remote desktop.

6.5 Designing an open system architecture - Specification of a farm management information system for precision agriculture

6.5.1 Introduction

This section describes the software architecture specification of a farm management information system (FMIS) for precision agriculture. Since a complete specification of a general FMIS is beyond the scope of our work, the emphasis is on features specific to mobile work in precision agriculture. Features common to a traditional FMIS and an FMIS for precision agriculture are considered only when required for completeness and both the specification and implementation of the general FMIS features are assumed to be known. These include features such as record keeping, financial planning and the output of printable documents. When the presence of precision agriculture causes a significant change in the implementation of any of these features, the reasons for the change and possible implications are covered. The purpose is to describe the architecture of the FMIS on a relatively general level, intentionally omitting the finer details of the technical implementation except in situations where advanced or special techniques are required because of considerable computational complexity.

The key differences between the traditional FMIS and FMIS for precision agriculture are those related to the storage, transfer and management of GIS data. This justifies a four-fold description of the architecture, with data storage, data transfer, data management and data presentation covered separately. Here, the data presentation is considered in forms of various interfaces to the system. The architecture is presented in accordance with IEEE standard 1471-2000 (IEEE 2000), which is the IEEE recommended practice for describing software-intensive systems.

This section is organised so that it loosely conforms to IEEE Standard 1471-2000, Architectural Description of Software-Intensive Systems. Thus section 6.5.2 contains background information and an overview of the architecture, while section 6.5.3 identifies the stakeholders of a modern FMIS for precision agriculture. Section 6.5.4 specifies the viewpoints selected to organise the representation of the architecture and section 6.5.5 contains the architectural views and a definition

of the architecture. Section 6.5.6 contains a record of known inconsistencies and a rationale for the entire architecture is provided in section 6.5.7.

6.5.2 Identification of the architecture definition

The specification of architecture is for an FMIS for precision agriculture implemented as an internet application with elements of an internet server. This specification is in the context of precision in practical farming and thus the scope of this specification is focused on the features specific to precision agriculture instead of the features available in general, existing FMIS. Since many parts of an FMIS are such that they can be implemented as a routine software development project, this specification does not specify or cover these features. The specification also intentionally leaves many of the finer technical details open, as they are of low concern to the general architecture and thus there is little need to bind them to any specific implementations or technologies. Due to complexity, the full or even a partial implementation of this specification cannot be accomplished feasibly outside of a large software development project.

6.5.3 Identification of stakeholders and concerns

Below is a list of stakeholders identified for the FMIS¹. The list is in relative order of precedence, so that the two stakeholders considered the most important are the farmer and the combined provider, developer and maintainer of the FMIS. The consumer of the agricultural produce could be considered a remote stakeholder in the form of increased awareness as to the origin and production methods of the products. However, since the consumer will not have any direct access or effect on the FMIS, here the concerns of consumers are considered, perhaps naively, to be covered by the wholesalers who provide the agricultural products for consumers.

The farmer is the foremost stakeholder of the FMIS, as the system is intended for his daily use and much of his business is dependent on the correct and efficient operation of the FMIS. The concerns of the farmer lie in the availability, reliability and usability of the FMIS. For most other stakeholders, their concern is mainly that of convenience; increased availability and ease in data transfer are convenient, save human effort and thus reduce expenses. For the farmer, the system should ‘simply work’ and be available from any internet-connected terminal device that the farmer may have available and the system should appear to the farmer with a user interface suitable for that device. In addition, the farmer needs to have a well-designed and localised user interface to manage the availability and transfer of the farm data to external services and to other stakeholders listed here.

The provider of the FMIS is the stakeholder visible to all other stakeholders. It is up to the provider to manage the development and maintenance of the FMIS and handle matters such as customer interaction and agreements with other stakeholders. Unless operated by the government, the provider of the FMIS is operating a commercial system with normal business interests and concerns.

The developer of the FMIS is a large software project launched to decide the final technical details and to fully implement the FMIS. Since an FMIS is not a static software system, due to changes in *e.g.* legislation, the FMIS requires routine updates to keep up with these changes. Some of these changes can be handled by the maintainer of the system but for more complicated updates, the involvement of the developer of the system is essential.

¹ The list was composed in cooperation with the experts associated with the InfoXT project. Included amongst their fields of expertise were agronomy and various technical fields.

The maintainer of the FMIS is the system administration necessary for the operation of the FMIS. Regardless of the design of the system, some level of human administration is required, though this amount is highly dependent on the level of automation within the FMIS. The maintainer of the FMIS can be expected to be highly familiar with the system and all of its technical details. As such, the maintainer requires an efficient interface to the system with the least number of restrictions. This interface may even contain a direct SQL access to the databases of the FMIS.

Contractors are employed by farms for some of their field work and the reasons for using contractors are several. Some farms employ contractors for the convenience of scheduling and in the case of precision agriculture, a sound reason could be that the contractor has available a precise application device better than that of the farm. The contractors need to have access to the farm data to obtain the operational plan required to carry out their contracted work. In addition, the documentation of the contractors' work should be sent to the FMIS, as this is in the best interests of both the farmer and the contractor; the farmer can confirm that the work has been done and the contractor has documentation to prove both the quality and the timetabled execution of his work.

Customers of the farm are in this context considered to consist of companies and other entities greater than an individual consumer, and have concerns related to the product they are purchasing. The farm documentation can be used to prove that the product was produced with the agreed farming practices.

Suppliers of the farm are not stakeholders *per se*, but information on the chemicals and seeds that they provide need to be known to the FMIS. Hence, the convenient transfer of this information is important as most calculations require detailed information on the composition and availability of chemicals to properly create the operational plans.

Authorities set the legislative restrictions for farms, such as those for chemicals and their application, and also require the farm to report on its activities. It is convenient and therefore a concern of both the farmer and the authorities that this information can be transferred automatically, reliably and with little human effort.

Service providers provide the external services that farms rely on, such as those for calculating field characteristics, *e.g.* soil pH value. It is in the interest of the service providers to have these data conveniently and reliably transferred to the farmer. Services that require farm data and further process it also need convenient access to the data.

Manufacturers of equipment need to provide certain technical details for their products that are important for the calculation of the operational plans. For reliability and convenience, these characteristics should be provided by the manufacturer of equipment and stored in the FMIS. Depending on the form of this transfer, the same information channel could be used to transfer software updates and other information relevant for the users of the equipment.

The purpose of the system is to provide an FMIS supporting precision agriculture as an internet application. The novelty of the system lies both in the support for precision agriculture and the internet application architecture, compared with the traditional on-site architecture of most existing

FMIS. For some parts, the proposed architecture also acts as an internet service as defined by W3C2. As is explained in section 6.5.7, the choice of internet application architecture is considered the optimal combination of features, usability and reliability. The internet application architecture simplifies the construction of the system as internet standards are used for the client communication. Hardware-related problems can occur, but are restricted to the server of which there is just one or a few instances, all of which are operated by professionals. For the deployment of the system, the end-user needs an internet connection and a terminal device supporting the standards used by the user interface. A major risk in the operation of the FMIS is the availability of a network connection. In the event of a network failure on the client end, an individual farmer or a small group of farmers will be unable to access the system and risks being unable to perform the work. This risk can be amended by enabling the farmer to load critical data, such as operational plans, to some local storage medium and to buffer operational documentation so that a network failure will not cause unnecessary stoppages in the work of the farm. However, in the event of a network failure at the service end, all farmers will be unable to access the system. Allowing local storage of critical data can remedy this problem, although any network failures at the service end are likely to be repaired faster than those affecting an individual farm, because the server can be expected to have professional maintainers available to repair most problems at short notice.

Maintenance of the system is greatly simplified by having no computation or permanent data storage on the client system. This effectively limits all technical maintenance to the server or server cluster housing the FMIS, since client-based problems with hardware and software are unrelated to the FMIS. Routine maintenance that includes operations such as adding and removing users, recovering lost passwords or system backups is no different from that of a similar existing system and can be similarly automated and managed. Deploying the FMIS itself is a considerable task as the server or the server cluster needs to be set up, configured and the information on the system (mainly the uniform resource locator (URL) for the FMIS) needs to be communicated to the users of the system. For new clients, deploying the system requires a standards-conforming internet browser and an internet connection. One design goal is to pose minimal restrictions on the type of internet connection, type of computer or operating system running the internet browser. The system should be usable from any system for which the necessary platform-independent technologies are available. Parts of an FMIS need to change over time. Implementing these changes into the specified FMIS requires little effort as the change needs to be handled only once and is immediately visible to all users of the system without the need to change any client-end software or hardware unless the change introduces a new feature utilising technology previously unused by the FMIS. In comparison, for a traditional on-site FMIS any update requires all end-users to update their software accordingly. At the end of its life cycle, all users and their data can be transferred to a new system by transforming and transferring relevant parts of the FMIS database to the new system or systems.

6.5.4 Specification of viewpoints

The proposed architecture is presented from two distinct viewpoints. The first viewpoint is that of the farmer as the primary end-user and acts as the general view of the architecture. The second viewpoint is that of the combined provider, developer and maintainer of the FMIS and offers a more detailed view to the internal structure of the FMIS. Other stakeholders are not covered explicitly by any viewpoints but are considered in both of the viewpoints as being connected to the system. The existence of these omitted stakeholders is assumed not to create any inherent incompatibilities to the system or its proposed architecture.

² <http://www.w3.org/2002/ws/>

The *user viewpoint* addresses the primary stakeholder, the farmer, and provides a general overview of the FMIS and its relations to other systems and stakeholders. This viewpoint also partially considers the contractor a stakeholder, since the farmer could be considered a contractor operating on his own fields for himself. The viewpoint of the user is presented as the general overview of the entire system, since the user of the system should have a basic understanding of what the system consists. Furthermore, the user should know of the services and other stakeholders connected to the system and how they relate to the business and activities of the individual user. The primary method of presentation is graphical, showing the connections between the system and the stakeholders with emphasis on the connections relating directly to the farmer. The rationale for selecting the viewpoint of the farmer is self-evident, as the viewpoint of the primary stakeholder cannot be disregarded.

The other *viewpoint* is shared by the *provider, developer and maintainer of the system*. While these stakeholders have distinct interests and concerns, each of them has to have an understanding of the technical details of the system. This understanding must also extend further than the simple viewpoint of the farmer, where the other stakeholders are not grouped and their method of connection to the system is not known. This viewpoint is presented as a graphical description of the architecture and a detailed description of the essential elements of the system. These essential elements consist of data storage, transfer, management and presentation for the operations of precision agriculture. The maintainer of the system could be considered a separate viewpoint, covering the architecture from a physical view. However, since the mapping of the logical parts of the architecture to the physical servers is direct, there is no real need to have a separate view for this. The rationale for choosing this viewpoint is that the architectural description is useless without a technical description and a detailed structure of the FMIS.

6.5.5 Architectural views

The following describes the two architectural views chosen, representing the viewpoint of the farmer and the combined viewpoint of the developer, maintainer and provider of the system. The former viewpoint is intended to provide a quick overview of the system without any technical details, while the latter viewpoint contains the actual technical description of the architecture.

View of the user

Figure 10 shows the entire system architecture as it should be understood by the user of the system. The essential structure that should be understood is the centrality of the FMIS as the system to which all other parties are connected. The arrows, representing communication, are purposely left vague in the sense that they do not specify the protocol or content of the communication. This is because the end-user need not know or even care how the communication between the various systems is handled, only that it occurs and that it is possible. The entire system appears to the farmer through a browser interface or the interface provided by ISO-11783 TC. The TC interface is a special case to the other available interfaces as it acts as the gateway between the FMIS and the ISOBUS-enabled tractor-implement combination.

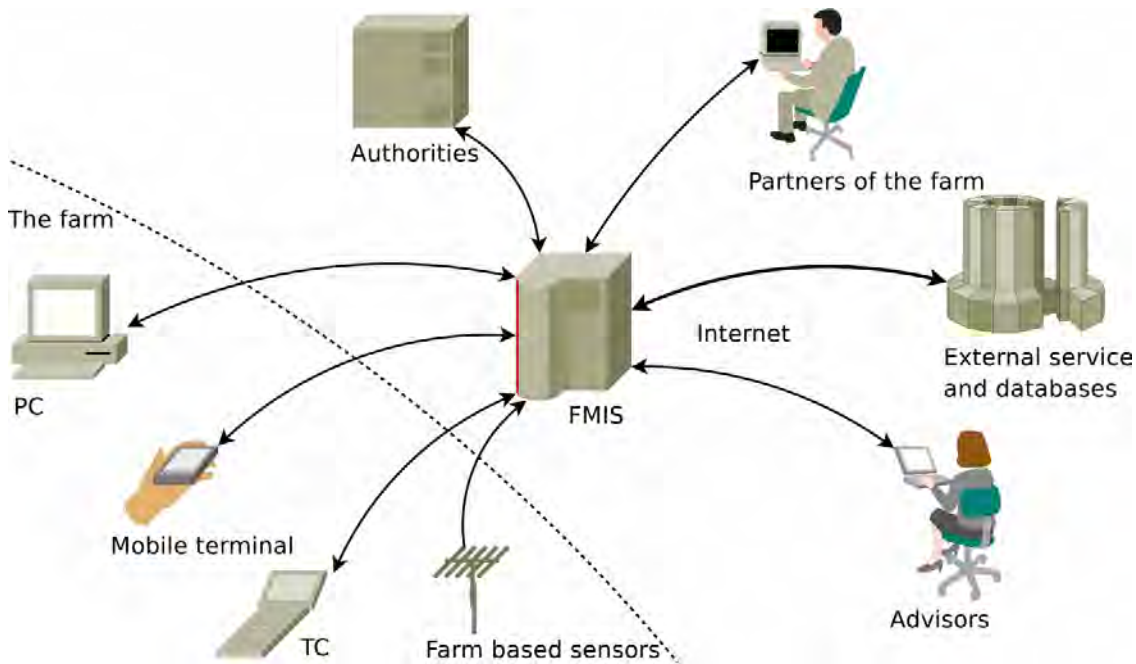


Figure 10: FMIS architecture from the viewpoint of the user.

The contractor shares this view of the system since the viewpoints of the farmer and the contractor are close to identical. The only difference for the contractor in this context is that the data of another user are visible to him through the system.

View of the provider, developer and maintainer of the system

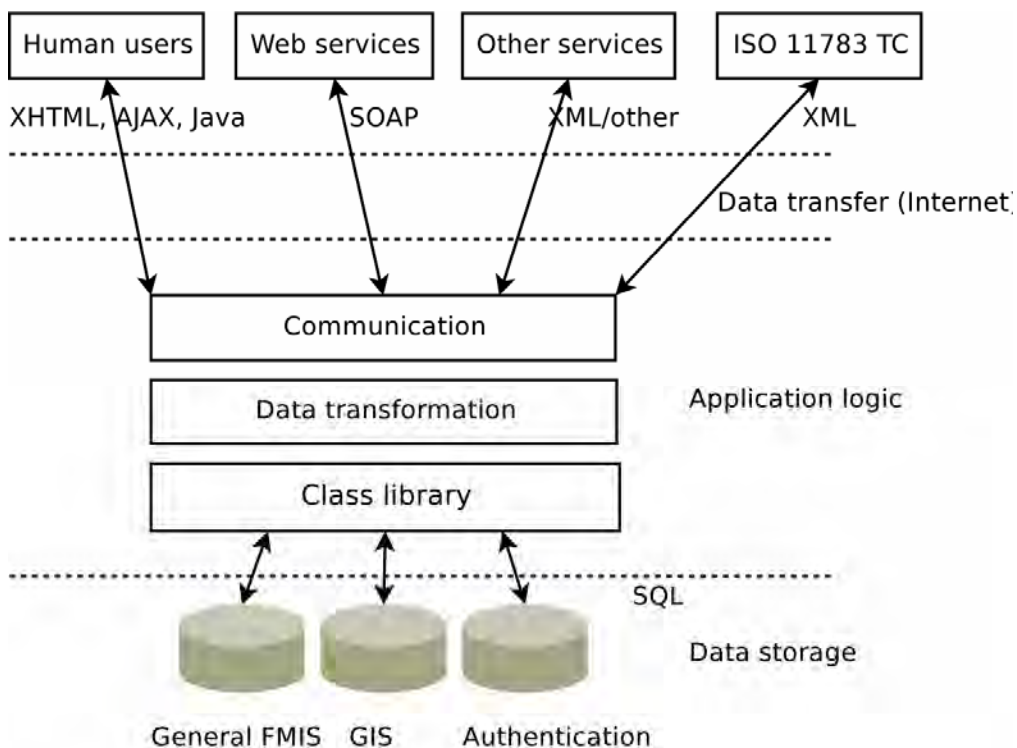


Figure 11: FMIS architecture from the viewpoint of the developer.

Figure 11 shows the technical view of the FMIS with the connected systems grouped into four categories. The architecture is discussed below bottom-to-top, starting with the data storage and then moving on to the application logic. The application logic is further divided into class library, data transformation and communication layers. Finally the data transfer and formats to the different systems are considered.

All data within the FMIS are stored to several RDBMS (relational database management systems) using the SQL (structured query language) query language for interaction. The three databases of Figure 11 are:

- **Authentication database** containing the identification and authentication information for all users of the system. Also contained within the authentication database are the access permissions to data that are used when dealing with for example authorities and contractors. In addition, the authentication database contains the authentication information to other services; if mutual trust and agreement exist between the maintainers of the FMIS and some external service, the FMIS can automatically authenticate users for the external service.
- **General FMIS database** containing the same heterogeneous collection of information about the farm that is stored by any commercial FMIS. One difference is that the general FMIS database must also contain information on farm equipment required for precision agriculture. The schedule of the general FMIS database is complicated by the amount and diversity of the stored information. However, this complexity requires no novel techniques as the design and implementation of similar databases can be considered routine work in software development.
- **GIS database** containing exclusive data relating to precision agriculture. The data need not be stored in a native GIS format, although several relational databases have GIS extensions available to provide efficient searches for the stored GIS data. The GIS database is also the first database expected to exhibit performance problems under an increasing load.

RDBMS and SQL are admittedly the traditional choice for data storage but no mature technology exists to compete with them. Alternative solutions such as ODBMS (object database management system) or NXD (Native XML) have yet to reach a state where they could be considered for the sole data storage solution of a production system. The three separate databases exist for functionality and scalability. Considering that the system could face a load as high as 20,000³ or more users, sub-division into several databases cannot be avoided. Designing the system so that the architecture supports several databases allows the system to be extended by adding new database servers for load balancing. Database duplication can be avoided as the load balancing can be achieved by dividing the data into separate databases based on the owner of the data and having the application logic select the appropriate database for each user. Due to locality, very few operations require the data of several users and in situations such as the calculation of statistics, where the data of multiple users are required, it is up to the application logic to collect the data from separate databases. Furthermore, having several databases with a standard SQL interface allows the entire system to be composed of different database servers so that the server solution most suitable for any given task can be used. The authentication database can be expected to handle any reasonable load due to the nature of operations required of it. The general FMIS database can also be expected to handle high loads as very few queries or operations require extensive computation or data transfer. However, the database containing the GIS information is unlikely to survive under a severe load, as the GIS operations involve queries requiring considerable computation as well as the transfer of non-trivial amounts of data. Initially all three

³ A rough estimate agreed upon by the experts of the InfoXT project.

databases can occupy the same physical system but as the system scales upwards, the GIS database in particular needs to have several instances to which the access is arbitrated by the application logic.

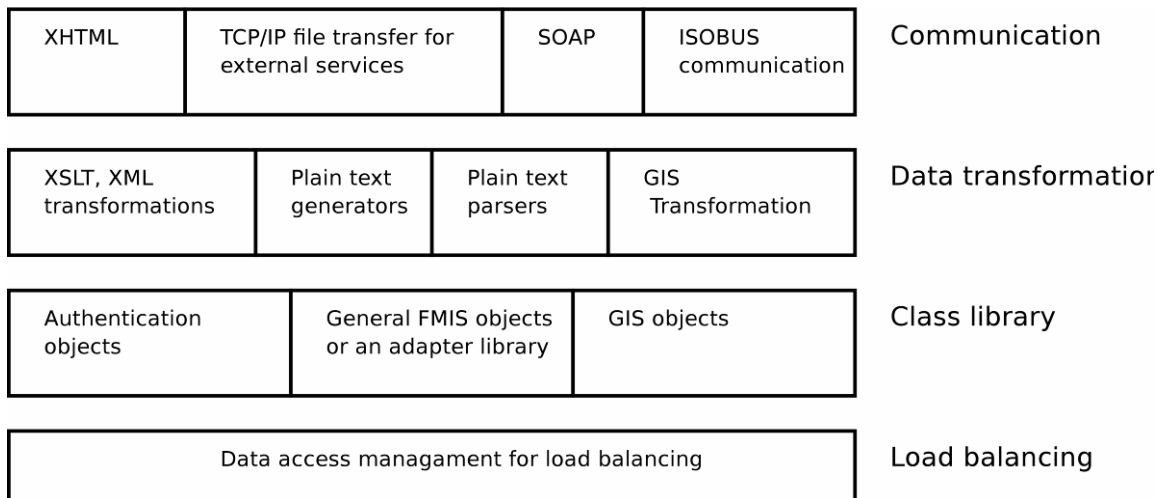


Figure 12: Detailed view of the application logic of the FMIS.

Figure 12 shows the modules of the application logic of the FMIS. The complexity of the modules varies greatly, the XHTML user interfaces and the SOAP interface being the most complicated, whereas the plain text generators and parsers are relatively straight-forward to implement. Also shown in Figure 12 is the data access layer, which is responsible for using the correct database for queries. The selection of the database is based on the ownership of the data.

The application logic is at the core of the FMIS. The lowest layer of the application logic is the class library, which provides an object-orientated abstraction for the data stored to the relational databases. The class library can be provided in more than one programming language to allow parts of the FMIS to be developed in different languages or to allow the connection of existing components to the FMIS. The second layer of application logic is data transformation, which is used to transform data from the internal representation of the FMIS to a format more suitable for external services or modules connected to the application logic. For some operations there is no need for data transformation, in which case the data can be passed through this layer unaltered. The top layer of the application logic is communication, which is the most complicated layer as it creates the XHTML user interfaces, transfers data between the FMIS and external services and contains the SOA elements for communication with internet servers. The application logic can be divided over several different servers using simple load balancing methods such as DNS Round Robin. The load balancing is somewhat complicated by having the data further divided to several database servers, because all of the application logic servers need to have access to every database server. The most trivial form of load balancing, having entirely separate servers with their own application logic and databases, cannot be applied due to *e.g.* contractors requiring to access data other than their own, which can reside on a different server. The application logic can be implemented with any suitable programming language and ultimately the choice of this programming language lies with the software development project of the FMIS. No single programming language or environment is superior for the implementation, as the familiarity of the developers with a particular language is an important criterion in choosing the development environment. Noteworthy options for the application logic are languages such as Java or PHP due to their relatively high level of abstraction and the rapidity of software development. Some parts of

the application logic could be implemented using an application server but there are elements to the system which are unlikely to be available from any existing application server. An application server is an option particularly for internet server-related communication, for which there exist several good application servers.

Data transfer is a complicated element of the FMIS as there are several mutually incompatible systems connected to the FMIS. All data transfer occurs through the communication layer of application logic and over the internet using the TCP or UDP protocols over IP. Some of the data transfer formats are well known, such as the XHTML for the user interfaces, but others are more problematic. There is no single agreed data format for communicating agricultural information. Although some such as AgroXML and FODM have been proposed, none has risen to the position of a standard or even a *de facto* standard. External services related to agriculture can be expected to communicate in some XML-based or other plain text format, which is then managed by the data transformation layer of the application logic. The most complicated form of data transfer is that between the FMIS and the ISO 11783 TC, for which there is no existing protocol. However, this communication is critical for the operation of the FMIS as it is used to transfer the operational plans and receive documentation on work. Therefore, this communication must occur over the internet instead of some physical medium transferred between a computer and the TC. This specification does not pose restrictions on the protocol of this communication, but expects it to be in some computer manageable format similar to the XML used internally by the ISO 11783 system.

One important aspect of the FMIS is the number of different interfaces to the system, as each stakeholder has different requirements for their interface. The most challenging of these interfaces are those shown to the farmer, as they have considerable usability and localisation requirements. Most interfaces are simple data transfer between the FMIS and other stakeholders or services, although the format of this transfer is greatly dependent on the stakeholder or service. The communication with the customers and suppliers of the farm is essentially business-to-business, which justifies the use of SOA and related protocols.

Standard browser interface is the interface that offers the full selection of the FMIS capabilities to the user. To assure compliance to standards and prevent dependencies on browser vendor or version, this interface is in XHTML and as per W3C recommendation⁴ it is served with the 'application/xhtml+xml' MIME document type with the appropriate header information. Since an XHTML interface as such is somewhat limited in its features, technologies such as AJAX (Asynchronous JavaScript and XML) and Java should be used to provide greater usability for this interface. Great care should be applied in designing this user interface as the usability of an FMIS is critical.

Mobile browser interface is similar to the normal browser interface in that it is also in XHTML, with the difference that the interface is designed for small terminals and that only features relevant to mobile use are present. This interface can be implemented as a subset of the standard browser interface.

Administrative interface is for the system administration of the FMIS. Like the interfaces for users, this interface is in XHTML but additional interfaces such as a direct SQL command

⁴ <http://www.w3.org/TR/xhtml-media-types/#application-xhtml+xml>

interface to the databases can be provided. Unlike the user interfaces, however, the administrative interface is meant for professionals familiar with the technical details of the system and as such, the usability of this interface is of lower concern than that of the other user interfaces.

Partner interface is for the partners of the farm, which include both the customers and suppliers of the farm. The partner interface bears a close resemblance to business-to-business communications and hence this interface can be implemented with the FMIS acting as an internet server using the techniques and protocols of SOA (Service Orientated Architecture).

Service interface is used by external services that are required for the operation of the FMIS. These services can be expected to communicate in some format appropriate for the individual service. This means that the FMIS will have to handle the data conversions for any communications related to external services. In practice these formats can be expected to be either XML following some schedule or other plain text file formats.

Authority interface exists to provide information to authorities that farmers would otherwise have to file themselves. The interface should provide the information in a form best suited to the needs of the authorities. Even though this is a privileged interface, the farmer should still see which data were sent to authorities and when.

ISOBUS interface is the means of transferring data between the FMIS and the TC of the ISO 11783 tractor-implement combination. This interface appears to the user through the virtual terminal (VT) of the tractor-implement combination and is therefore distinctly different from the browser interfaces. There is no existing standard for the connection between the TC and the FMIS but the transfer can be expected to consist of an XML-based format similar to that used by ISOBUS.

6.5.6 Known inconsistencies

There are no known inherent inconsistencies in this proposed architecture. However, there are a number of concerns that affect the internet application architecture in general. These concerns lie with the user interface and the availability of the system. The user interface offered through an internet browser has evolved considerably in recent years, but is still lacking in features when compared with a normal programme using the graphical user interface (GUI) library of any modern operating system. The browser interface can be further enhanced with technologies such as AJAX and Java, which make it possible to create user interfaces of sufficient interaction for an internet browser. As with any internet application, the availability of a network connection is critical for any operation of the system. Farms risk stalling in their work because of unavailable internet access and therefore the system must allow the operational plans to be stored to a local medium and the documentation of work to be buffered locally.

6.5.7 Rationale

The internet application architecture can be justified by its many benefits for all stakeholders. For an internet application the user need not concern itself with maintaining software other than an internet browser and some additional elements on a local computer. With no FMIS-related data storage or computation on the local computer, the user of the system need not worry about data integrity as all of the data are stored on the FMIS server. The maintainer of the system has the

benefit that all updates only have to be implemented once to a single system and all software-related problems are limited to the single system without the concern of problems related to differences in operating system versions or hardware. Most other stakeholders have the benefit of communicating with a single system instead of having to communicate directly with local computers where there might be obstacles such as firewalls to cause problems. The chosen architecture is also beneficial for the life cycle of the system as the eventual migration to other system or systems can be handled by transferring and transforming the databases to the new system.

The only real alternative, the traditional on-site solution, was considered but rejected due to the above benefits that the internet application architecture has over the on-site architecture, regardless of the problems listed in section 6.5.6.

The FMIS could be further enhanced with features based on the structure of the system where the FMIS is in the centre of everything. These enhancements could be something as simple such as an internet forum for local farmers to communicate, news services or other gateway features.

7 Scenario-based concept construction, implementation and technical validation

7.1 Farmer and technology company interviews using precision spraying scenario

Throughout the project, farmers and technology companies were interviewed and consulted in order to form a total view over their role in the value chain of information management technology of plant production, the problems and the good points they see, and whether they have suggestions for better technologies and management structures in the area. The subsequent scenario with pictures and texts was made on the basis of an *integrated information modelling phase*, where scientific modelling and early farmer and company interviews carried out in the beginning of the project were utilised. The scenario was used as a tool to introduce the problem field to other farmers and technology companies in further interviews and it was modified and improved according to the cumulative understanding and knowledge. The scenario introduces the way to execute a precision spraying task utilising the novel InfoXT system concept. The scenario with pictures and attached narrative is presented in Appendix I.

7.2 Implementation and technical validation

Implementation and technical evaluation were carried out to validate the technical functioning of the InfoXT concept. The implementation and validation involved the parts of the concept which represent technically new solutions in the application area and that thus needed to be validated as functioning in an appropriate way. Figure 13 shows the parts of the InfoXT system architecture which were implemented and included to technical validation. The technical validation was carried out in Finland and Denmark by building and testing system prototypes. The test in Finland was based on the implementation of the specified non-commercial open system prototype. The test in Denmark demonstrated implementation of the system based on commercially available techniques at the moment, and evaluation of its functionalities.

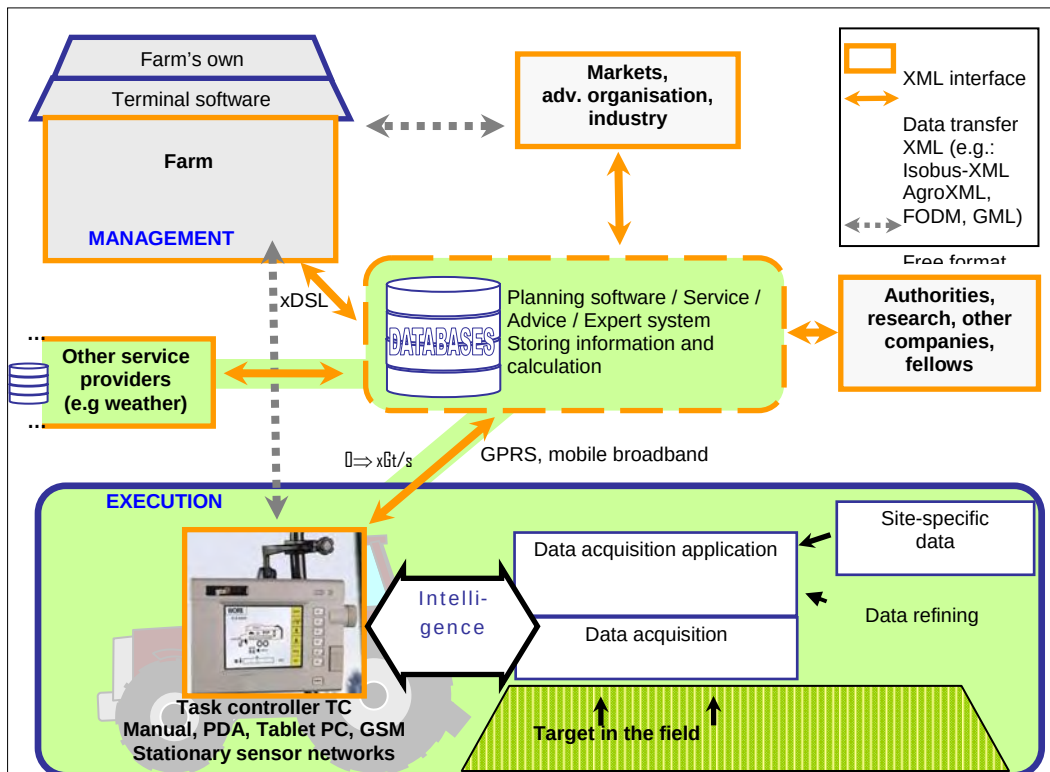


Figure 13: Evaluated parts of the system architecture as shown in light green background colour.

7.2.1 Implementation of the specified non-commercial open system prototype

The purpose of the implementation was to present an FMIS for precision agriculture operating as an internet application with the ability to communicate directly with the ISO 11783 (ISOBUS) tractor-implement combination. This communication consists of transferring both the operational plans and the documentation of the field work, as well as the transfer of real-time weather information from the FMIS to the ISO 11783 TC (Task Controller). In the test set-up, an Agrix ISOBUS sprayer prototype system developed in an earlier Agrix project (<http://automation.tkk.fi/Agrix-en>) was utilised as a mobile working unit test platform.

Requirements of the implementation

The technical details of the implementation are not bound by the project; the requirements only relate to the functionality and features of the system, not to the manner of their implementation. The requirements for the InfoXT project demonstration can be summarised to a list of four criteria (see below). In addition to the requirements, the context of the demonstration was that of precise spraying of a field and thus the implementation need not necessarily support other field operations.

1. The operational plan must be generated within the FMIS given the necessary input information.
2. The operational plan must be transferred wirelessly from the FMIS to the ISO 11783 TC.
3. The documentation of the work done by the tractor must be transferred wirelessly back to the FMIS.
4. Real-time weather information must be made available to the ISO 11783 tractor-implement combination during its operation.

Criterion 1 states that given the necessary input information, the FMIS must be able to generate an operational plan that, when transferred to the ISO 11783 TC, is usable without any additional transformations. In practice, this means having the user transfer the input files via the browser interface to the FMIS. The necessary input information consists of N files: A, B and C; and none of these files needs to be stored by the FMIS and hence the input files can be discarded after the operational plan has been generated and stored to the FMIS. The generation of the operational plan is done by tools based on the work done in the AGRIX project 1. These tools, although intended for human use, can be called by using an appropriate scripting language, thus allowing automatic generation of the operational plan.

Criteria 2 and 3 are closely related, with the direction of the communication as the distinguishing factor. The wireless connection is achieved by having the ISO 11783 TC connected to the internet through some suitable wireless medium. For both these criteria, the connection needs to reliably transfer a file from one system to another. Both of these files, the operational plan and the documentation of the field work are essentially GIS data; the operational plan is the location-specific amount of chemical to apply to the field and the documentation of the field work is the location-specific amount applied to the field. For a minimal implementation, these files and their locations could be hard-coded on both ends but for flexibility and at least some degree of generality, it is better to have some dynamic selection mechanism for the files. The TCP/IP protocol provides a suitable transfer method for the required file transfer and a TCP/IP connection can be used to reliably transfer the files in binary format.

Criterion 4 is related to the previous criteria 2 and 3 in the sense that it requires a network connection between the FMIS and the ISO 11783 TC; but unlike the previous criteria, the network connection is used to transfer information in real-time at regular intervals instead of just at the beginning or end of the field operation. However, the transfer of weather information does not require file transfer as the weather information intended to be used in the demonstration consists of only three values and is a subset of more complete weather information provided by an external service in an XML-format. For more complete weather information, the amount of values rapidly increases and thus would require the weather to be transferred as a file. For simplicity, the weather information is transferred as values over the same protocol used to provide the control for the establishment of the connections required by criteria 2 and 3. Should the network connection be unavailable, the tractor-implement combination can use the last known weather information until such times as the network connection can be re-established.

Description of the implementation

The internet application, in its entirety, was written to fulfil the requirements stated above. The generation of operational plans within the internet application was done using tools developed for the AGRIX project. The implementation and the modifications to the ISO 11783 TC were done by the Crop Science and Technology research group at MTT in co-operation with the laboratory of Automation Technology of TKK. The requirements for weather information and its effects on the spraying operation were formulated by the Crop Science and Technology research group at MTT.

Most of the implementation is based on the popular open-source solution stack LAMP (Linux, Apache, MySQL and PHP). Even though it is used in this implementation and demonstration, the LAMP solution is not considered superior to the other alternatives, but rather was chosen because it is fast to install, free of licensing issues and sufficient to fulfil the requirements of the demonstration. Several other platforms could also have been used, such as those based on Java or Microsoft.NET. The versions of software used for the implementation are shown in Table 4.

Table 4: List of software used in the implementation.

Linux	Debian Linux with a 2.6.21.2 kernel
Apache	2.2.4
MySQL	5.0.45-Debian_1-log
PHP	5.2.3-1+b1

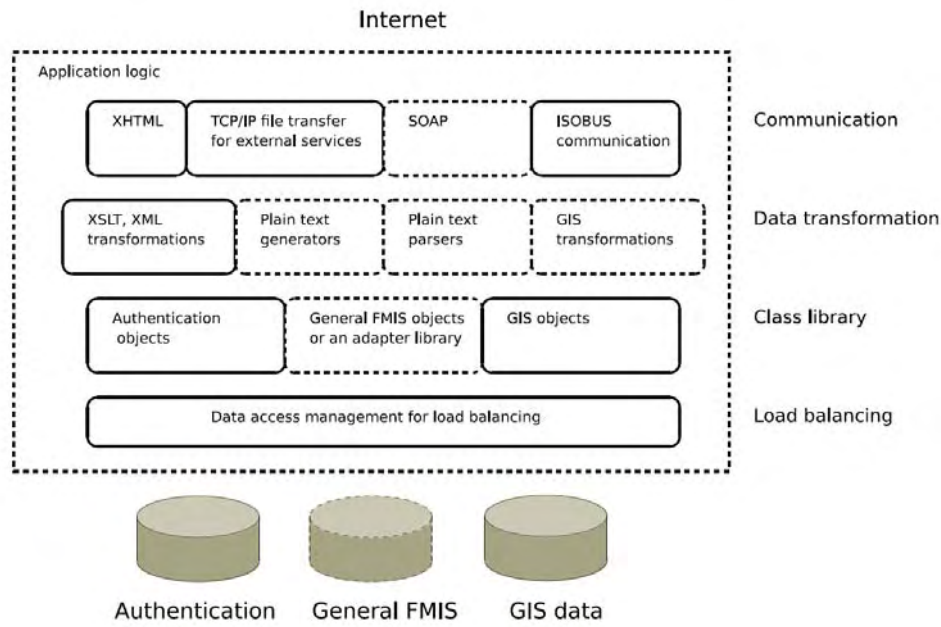


Figure 14: Overview of the internet-based system implemented.

Figure 14 shows an overview of the implementation in comparison to the specification of the application logic presented previously in section 6. Elements of the architecture not required in fulfilling the requirements of the demonstration, and therefore not implemented, are drawn in dashed lines.

More detailed information, *e.g.* flowcharts for the operations presented in the demonstration, are given in Appendix 3 of the WP3.1 report on the project website (www.mtt.fi/infoxt, Publications). The flowcharts describe all essential operations with consideration to possible and likely error conditions. The error conditions covered are those deemed likely to occur during the demonstration, *i.e.* error situations that stem from the instability of a wireless connection or from other likely causes. Error recovery is considered only for situations where it is possible to recover from the error without considerable additional work. The point of view for the flowcharts is that of the FMIS and hence the consideration is limited to the communication between the FMIS and the ISO 11783 tractor-implement combination.

Internet application

The primary task of the internet application is to allow the transfer of input data to the system in order to allow generation of the operational plan required for the demonstration. The internet application communicates directly with the underlying databases and user interaction is achieved through a minimal implementation of the standard browser interface described in section 6. The

standard browser interface is a website that provides the functionality to transfer input data to the internet application for the generation of the operational plan. Once the field operation has been concluded, the documentation of work is made available through the same standard browser interface.

Figure 15 shows all of the technical elements used in the implementation. The entire system operates on a Linux 2.6 based operating system and all data are stored to the MySQL-based databases. The visible internet application itself operates on the Apache 2 internet server and all of the application logic is written in PHP, which in turn communicates with the MySQL databases. The communication between the internet application and the ISO 11783 TC occurs at the database level. The internet application stores the plan to the database, which is then read and transmitted on request to the ISO 11783 TC by the server described in section 6.5.5. Similarly, once the field operation is concluded the server stores the documentation of the work to the database, which can then be retrieved through the internet application.

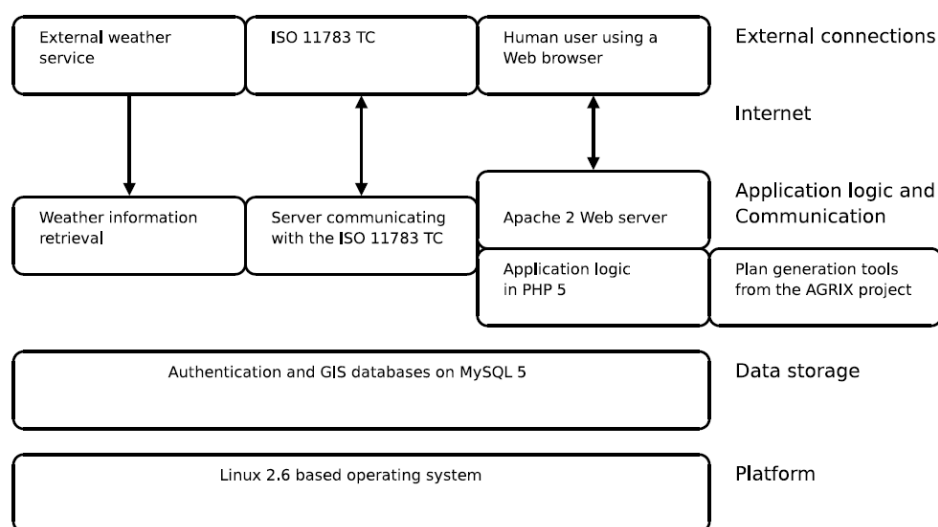


Figure 15: Technical elements of the implementation.

Databases

Of the three databases described in section 6, the authentication and GIS databases have been partially implemented for the system. The general FMIS database was not implemented as the functionality found therein can be found in existing commercial FMIS and since general FMIS features are not required for the demonstration. The implementations for the authentication and GIS databases are far from that required by a production system as they only contain the set of relations required for the spraying operation shown in the demonstration.

The databases for the demonstration operate on the popular MySQL RDBMS. The authentication database consists of five tables and the GIS database consists of two tables. SQL foreign key constraints are used to assure the consistency of both of the databases, although there are no constraints between the two databases. Integrity between the two databases is managed outside of SQL in the application logic.

User interfaces

The system developed for the demonstration partially implements three of the interfaces specified in section 6. These interfaces are the standard browser interface, the administrative interface and the ISOBUS interface. The standard browser interface implemented utilises XHTML 1.1

(<http://www.w3.org/TR/xhtml11/>) with strict adherence to the standard. The interface is not meant for end-users but rather for the researchers involved in the InfoXT project and its demonstration. Therefore, the interface is spartan in design, lacking graphical features most appropriate for user guidance but providing the required functionality without restrictions.

The administrative interface, in the context of the demonstration, is a direct SQL access to the databases of the system. While a similar interface could be provided even for a production system, a direct SQL access is powerful and simple to provide. However, a direct SQL access requires strong working knowledge of the system as well as general familiarity with SQL. For the purposes of the demonstration, there is little or no need to provide any other administrative interface to the system.

Communication with the external weather service

For criterion 4, real-time weather information is transferred from the FMIS to the ISO 11783 TC. The weather information deemed sufficient for the demonstration by researchers at MTT consists of three values of air temperature, wind speed and rainfall. The weather information is obtained from an online service provided by a-lab (<http://www.a-lab.fi>), which is connected to external sensors located in the vicinity of the location planned for the InfoXT project demonstration. The service provides the weather information in well-formed XML format, thus allowing convenient automatic management of the information. The weather information is fetched periodically by the internet application server and stored to the GIS database (while not GIS data *per se*, the weather information is still location-specific) of the system. The entire operation is achieved with a POSIX shell script using XSLT (<http://www.w3.org/TR/xslt>) for the extraction of weather information from the XML file. The weather information is made available to the ISO 11783 tractor-implement combination by the QUERY command of the protocol used in the demonstration.

Communication with the ISO 11783 TC

As specified in the requirements of the implementation in section 6, the FMIS and the ISO 11783 TC require bilateral communication and file transfer. The internet is used as the network medium with both the FMIS and the ISO 11783 TC having internet connectivity. The file transfer occurs over the TCP/IP protocol but the initiation of file transfer and the transfer of weather information require additional control to be present. In the prototype implementation, this control is provided by an implementation of a protocol specified in (www.mtt.fi/infoxt, Publications, WP3.1 report). The server implementation of the protocol is located on the FMIS internet application and the client implementation is located on the ISO 11783 TC.

The protocol is designed to be sufficient for the purposes of the demonstration, though with minimal work it could be extended for more general use. The implementation of the server end of the protocol is done in ISO C99 (ISO/IEC 9899:1999) for a POSIX conforming (IEEE 1003 family of standards) operating system. The server implementation is an asynchronous TCP/IP server with file transfers occurring in separate processes. The server communicates directly with the GIS database, retrieving and storing the files for operational plans and the documentation of work, and handling the values for the QUERY and REPORT commands of the protocol.

For a production system, the protocol would have to be extended and the implementation of the server would require considerable additional work. However, as a concept, the protocol is sufficient and effective for all forms of communication required between the FMIS and the ISO 11783 TC. The protocol has limited support for interrupted file transfers and for a production version of the protocol this support would have to be extended to support interrupted file transfers. The current implementation requires the operational plan and documentation to be sent as

complete files, when in practice it might be useful to transfer only parts of the plan or to transfer the documentation during the operation in parts.

Implementation of the Task Controller (TC)

The Task Controller (TC) was re-built for InfoXT test by MTT in co-operation with Agrix system developers at TKK Automation laboratory. TC is programmed using MS Visual Studio software, C# language and its library functions on PDA environment, Panasonic PocketPC CF-P1, serving as TC device.

The TC used in InfoXT test has the following features:

- Sending commands to/getting error messages from FMIS server
- Requesting and downloading files from FMIS server
- Saving files to TC file store
- Choosing files (TASKs) from the list obtained from FMIS server
- Opening, reading and writing files in TC
- XML interpretation
- Identifying the treatment zone according to the given GPS coordinates
- Making and saving notes by pushing the button(s) in TC/ (VT) (stones, weeds, etc.)
- Sending reports to FMIS in XML format
- Controlling IECU using Agrix drivers
- Description of the implement by Agrix drivers

The functioning of each of these features was tested separately in the building phase of TC.

Implementation of Agrix ISOBUS sprayer prototype system

The software of the basic system is implemented with the RTI's Constellation software development system, which uses UML standard. The machine control system is 'wired' together from various software components using the graphical tool. The logic of the control system is modelled as state machines. From these models, the tool automatically generates runnable code. The basic system was tested with three different agricultural implements during summer 2004 (<http://automation.tkk.fi/Agrix-en>) (Figure 16).

Junkkari Sprayer

- Tractor's manual hydraulic valves are used to control hydraulic functions
- Pressure and application rate controllers implemented in software
- Calibration functions
- Position-based control

Virtual Terminal (VT)

- The virtual terminal is a 'browser' to which different implements can download their user interfaces
- Agrocom and Kverneland VTs were used for testing but in principle any VT should work

Task Controller (TC)

- The information needed to complete different tasks is stored to the task controller (*e.g.* application rate maps)
- The task controller can also be used to collect data during different tasks (*e.g.* yield maps)
- PDAs are good TC platforms since they can be used to move information from the farm management information system (FMIS) to field and back easily

Implement-PC

- A PC running RedHat Linux operating system is used as an implement electronic control unit (IECU)
- PCs are good research platforms but they are overkill for commercial applications
- The implement PC has CAN interface card for connection to the ISOBUS network and WLAN adapter for testing wireless communication

GPS-Adapter

- A GPS-adapter is used to relay messages from a GPS-receiver to the ISOBUS network
- The adapter is based on Dallas Semiconductor's TINI module and its software is written in Java programming language

ISOBUS compatible GPS-receivers are not yet commercially available

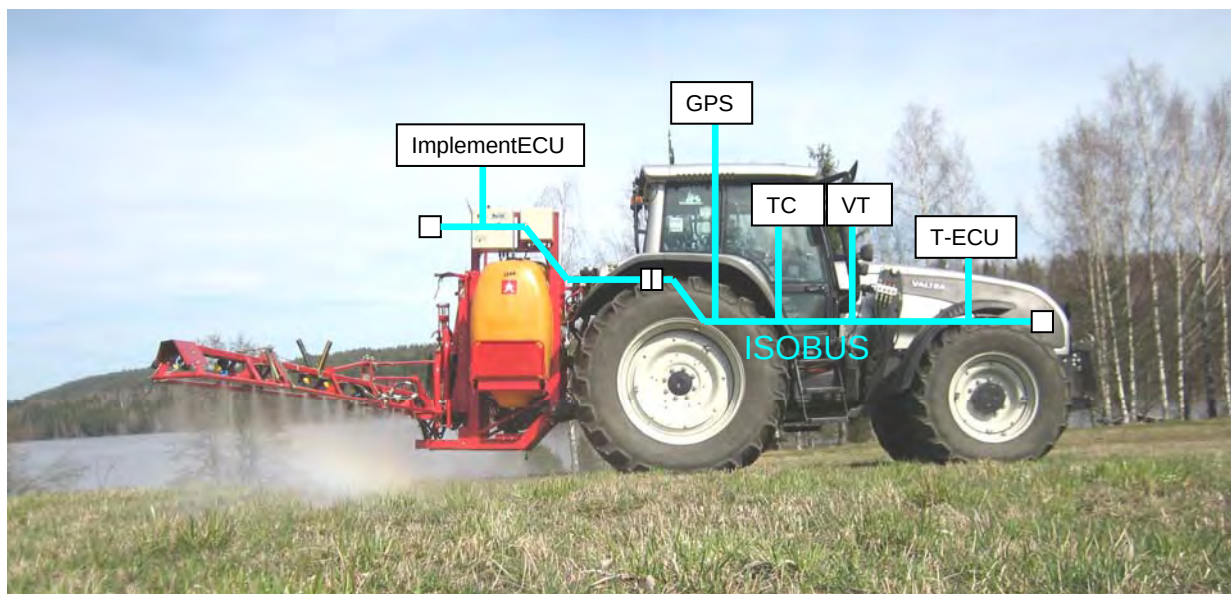


Figure 16: Parts of the ISOBUS system in the tractor-implement combination.

7.2.2 Evaluation of the implementation of non-commercial open system prototype

Based on the partial implementation, the system specified in section 6 would appear sufficient as an FMIS for precision agriculture. The system has components to provide all the features required of an information system for precision agriculture. Many of these components are independent of the rest of the system and can thus be implemented as separate entities and with technologies other than those used for the system framework or other components. For other components, the class library of the system could be provided in several different technologies to further ease the integration of components to the system. However, offering the foundational class library in too many different technologies would greatly increase the workload of maintaining the system and even slight differences in the parallel versions of the class library could make the system error-prone. While several parts of the specified architecture were not included in the partial implementation, such as SOAP or GIS transformations, they are in themselves existing technologies that could be integrated to the system.

Comparison between the system presented in this work and existing FMIS is somewhat difficult due to the nature of the implementation. The strict focus of the implementation in precision agriculture and its requirements leaves the general FMIS features entirely unimplemented. Implementations of general FMIS features exist, in a way, on all commercial FMIS and hence their

implementation is not meaningful in a research project. Features of precision agriculture, however, are currently not found in any commercially available FMIS. The system specified in section 6 could be implemented as an extension to an existing FMIS so that the general FMIS features are all provided by the existing system and the new implementation would only introduce the features necessary for precision agriculture. This form of implementation would not work with an FMIS based on the on-site software architecture but would be relatively easy to implement to an internet application FMIS. Compared with the system presented in Linseisen (2001), the system presented in this work is more general. However, both systems feature similar storage and management of GIS data. The system of Linseisen (2001) focuses more on the processing and analysis of information used and generated by the field operation.

Both the implementation and the specified architecture are highly extensible, as new features can be added easily and with very little effect on the existing components of the system. In the most simple case, a new functionality can be introduced to the system by programming it as an independent PHP source file and adding a link to that file to the user interfaces. Similarly, more complex functionality can be added with the appropriate changes to the databases and possible consideration to the interaction with existing features of the system. However, extensibility in the context of this implementation does not consist of extending the system to a production system, but rather the introduction of new features relevant to research.

The internet application architecture would appear to provide an optimal combination of features, availability and ease-of-use for the end-user, *i.e.* the farmer. An internet browser interface can provide most of the functionality achievable with a local user interface; internet interfaces are still rapidly developing with new features and functionality added by various plug-ins to the browser software. The availability of the system is coupled with the availability of an internet connection. Essentially, the system is available from any terminal device equipped with an internet browser and connected to the internet. This makes it possible to use and add information to the system while, for example, walking on fields making visual observations. Since no critical information is stored to any system managed by the user, the farm data can be considered secure and the user need not be concerned about matters such as routine backups or system updates, which are managed by the internet service provider. Most of the population is also familiar with internet browsers and various internet interfaces, which lowers the learning curve of the system.

The user interfaces to the implemented system are minimal at best and hence the system is ill-suited for non-professional users. Studies involving actual end-users would require considerable enhancements to the standard browser interface, which is the primary user interface. The user interface of the ISO 11783 TC is that implemented in the AGRIX project with minor alterations for the demonstration due to the inclusion of the real-time weather information for the operation. However, the development of a user interface is beyond the scope for this work, as it is in itself a separate field of study.

Practical evaluation of the implementation

Practical evaluation and testing of the system was carried out in the InfoXT project demonstration. The demonstration featured three essential functionalities of an FMIS for precision agriculture; the communication between the FMIS and the tractor, the transfer and handling of the field operation plan and documentation and the internet application architecture for an FMIS. The communication between the FMIS and the tractor was achieved with a specialised protocol based on the requirements of the demonstration. The ISO standard 11787 (ISO 11787) specifies a data exchange format slightly similar to the protocol used in the demonstration, but since the data format is explicitly not intended for real-time data exchange, it was not sufficient for the demonstration as the weather information cannot be transferred using it. The operational plan (TASK file) was

created through the internet browser interface to the system and stored to the database of the system. The plan was then transferred using the previously described method of communication between the FMIS and TC in the tractor. After the completion of the field operation, the documentation of the work was transferred back to the FMIS, stored to the database and made available for viewing through the internet browser interface. The internet application architecture of the FMIS is also new compared with most FMIS available and provides the functionality of the FMIS through any internet-connected terminal device.

Partial validation of the system features

The practical evaluation of the implementation was carried out in two phases, a partial and total validation. In partial validation the essential new features of the InfoXT system were tested separately in practice.

In the test, *the operational plan (the TASK file)* was saved to the FMIS server as ISOBUS XML format and GML format. The TASK file was able to create in GML format using TNT Mips software (GIS software). ISOBUS XML files had to be created manually, since the commercially available GIS software is not able to create files in ISOBUS XML at the moment. Programmes for translating GML to XML are commercially available, but were not used in this exercise.

The procedure to start the field operation was executed using the previously introduced ISO 11783 compatible TC (Panasonic PocketPC CF-P1) and InfoXT FMIS server. The TC was installed to the tractor cab of the Agrix tractor-sprayer system and connected to ISOBUS CAN. The communication between TC and FMIS server took place via GPRS connection. TC requested and downloaded in ISOBUS XML format the saved TASK file from the FMIS server to TC. TC identified and interpreted the TASK file. The TASK file contained the following information:

- The task identification data: Farm, customer, worker, crop, cultural practice and operation technique.
- The 'real-time' operational data: Treatment zones and their areas in polygonal format and device description and datalog trigger data.

The TC established *the on-line GPRS connection* to FMIS for receiving the latest weather information (air temperature, wind speed and air humidity). In the test implementation, the FMIS server was connected to the internet server of the weather station network (A-Lab Ltd). The weather station, located in the test field, belongs to the network and sends its weather information to the server every 20 minutes. So, the weather information in TC is updated every 20 minutes.

Data logging from the implement to TC files according to the datalog triggers in task file was performed to *send the data to FMIS server* at predetermined times (delays). Storage of this kind of data locally in TC is necessary because the on-line connection to the FMIS server may have some breaks.

At the end of the working session the TC creates *a summary document (report) about work performed* from the data it has saved to its data storage during task execution. The summary document contains following information:

- The identification data in task file.
- Start and stop times of the operation.
- The treatment zone distribution for the whole working time (more exactly in map format if triggered during operation).

The execution of the individual procedure was successful. Establishment of connection between TC and FMIS and data downloads and uploads were fluent, taking only few seconds of time.

Total validation of the specified system

In the total validation, the whole spraying field work was performed as a successive flow of the above-mentioned 'sub-events'. The machinery and devices described above were used. The test drive was executed in an area which consisted of three treatment zones (Figure 17). The driving path was tortuous, crossing all the zones. The driving took place back and forth along the same path, with a couple of digressions. The system seemed to perform in an expected way. However, two kinds of problem arose during the test. Firstly, since the test equipment consisted of several prototypes connected together, there were often problems with one or other of them in the beginning, which caused delays in testing. Secondly, the wireless communication environment with the prototypes was found to be not as reliable as the wire-based option (in the laboratory). It seems that the dependability of wireless communication is an important issue to be examined in further development work. The results of the technical validation of spraying as documented by TC is presented in Figure 17. Execution of a spraying operation in the field is presented in Appendix IV. As a sum of the total validation, it can be stated that the system concept developed is technically valid.

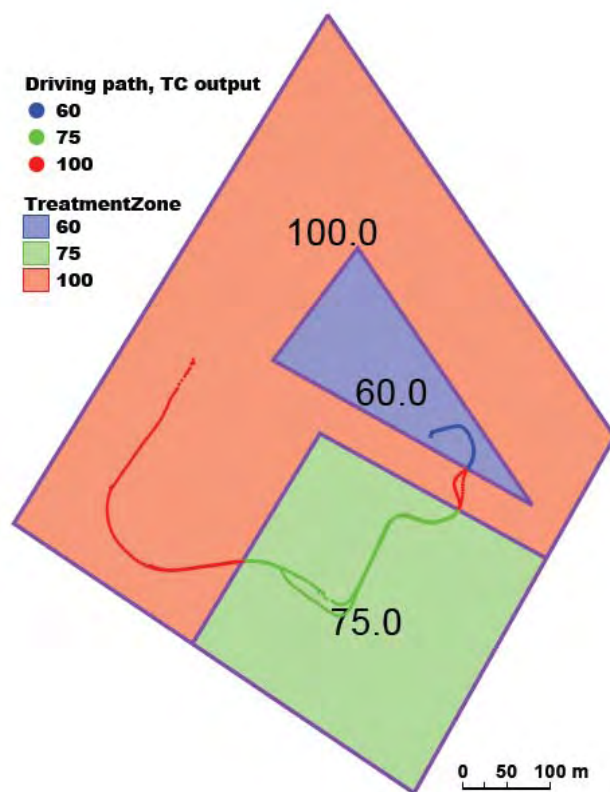


Figure 17: Result data from total technical validation of the non-commercial sprayer prototype.

7.2.3 Implementation and evaluation of system functionalities based on Commercially Available Techniques

In order to technically evaluate the automatic data acquisition part of the on-line information flow for mobile work units, various tests were carried out at the Bygholm Research Centre, Department of Agricultural Engineering, Aarhus University, as part of various research activities. The objective was to demonstrate the feasibility of an on-line information flow between a mobile unit such as a tractor and sprayer and a central database/FMIS environment. Figure 18 shows the principal information flow as regards the mentioned entities.

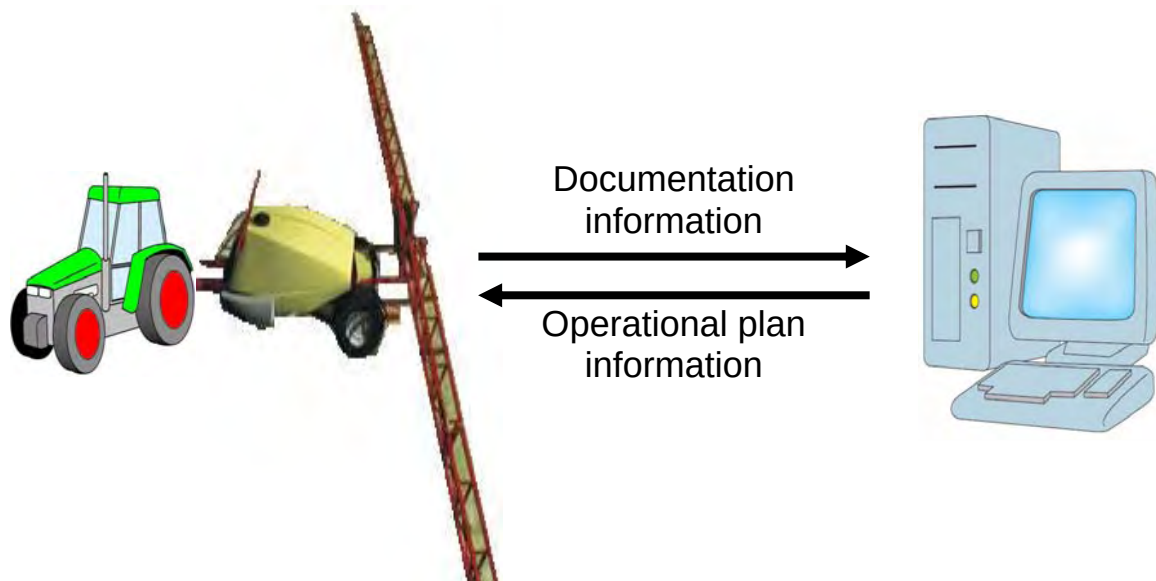


Figure 18: Information flow in connection with the spraying operation.

Technology components in the test setup

1. PDA platform.
2. Wireless communication.
3. Communication with internal/external databases.
4. Sensor information for continuous status information.

In this, the Task Controller environment was configured in a PDA environment, Psion Workabout Pro, serving as the TC device. In many aspects, PDA functions well as a transmitter of information from FMIS to the field and *vice versa*.

1. The PDA/TC configuration used in the test had the following features:

- Sending commands/error messages to FMIS server
- Requesting and downloading files from FMIS server
- Saving files to TC file store
- Opening, reading and writing files in TC
- XML interpretation
- Identifying the treatment zone according to the given GPS coordinates
- Sending reports to FMIS in XML format.

2. Data/information was transmitted through use of GSM/GPRS in real-time to an online database using GPRS (client/server solution). It is worth noting that the transmission of data is in compliance with ISO 11783/Part 10 (ISO/FDIS 11783-10:2006 (E)).

3. The approach to building the on-line communication was first to develop a local system using the same data structure as the Danish Field Database, and when this system was functioning, the next step was to establish a direct on-line connection with the Danish Field Database[®]. The Danish Field Database is an internet database where it is possible for the individual farmer to store data regarding fields, yields, soil, maps, GPS-data, slurry, fertiliser and plant protection. The database is fully integrated with a number of crop management programmes, which are available to both the farmer and his advisor. The interface developed to the database is based on open standards enabling the collection of data from different data providers.

4. The sensor configuration in the test included a HC5500 spraying computer functioning as both a terminal and an IECU for the sprayer and delivering performance and machine data to the TC configuration. The actual transmission of data from the IECU was performed via a serial interface (RS232) documented by the producer of the process computer employed (HC5500). The data communication involved the PDA asking for process data and these requested data then being immediately returned through a binary communication.

Implementation

The implementation of the tests included selected data being sent from the FMIS environment to the tractor/implement and selected signals being sent back from the tractor/implement. Data sent from the FMIS environment included:

- Software updates
- JobID
- Acknowledgement

Data sent from the tractor/implement included a number of operations data. Every 5 seconds, the PDA logged a text string containing the following information

- Sampling Date
- Longitude
- Latitude
- Altitude
- Speed
- True course
- Application Rate
- Programme Rate (planned application rate)
- Boom Size
- Number of Sections
- Nozzles
- Active Sections
- Status End Nozzle
- Nozzle Size

Example of logged text string:

031105 092351;01153.633157;5454.166976;25.27;3.4;175.2;0.01517;0.01500;
36.00;09;09,06,07,09,10,09,07,06,09,12,12,12,12;1,1,1,1,1,1,1,1,0,0,0,0;R;00;

A number of test configurations were carried out involving specifics such as turning the sprayer on and off, whether the spraying is performed with or without overlap, interruption of the GPS signal, *etc.*

Evaluation of the initial test

The logged data in the database proved correct when compared with both the security log of the PDA and the manual recordings throughout the duration of the test. In the case of failed connections, the data were not lost but were available in the security log. Not all data available in the HC5500 could be extracted, whereas in a genuine ISOBUS setting a more complete data set would be available.

The transmitted data set size amounted to 1.52 MB, equating to a cost of € 1.25 for 1.5 hours of effective operation. However, processing of the data acquired revealed the presence of redundant data which might prolong the on-line communication. When only position data and spraying dosage were transmitted, the costs of data transfer were reduced to € 0.65 for 8 hours of effective operation.

Further development of the system

The initial test showed that in the case of automated operations documentation, there is no significant need for a user interface. Hence, the TC environment was changed to only consist of a terminal, basically functioning in the same way as the Psion PDA. In this way, tests were performed to demonstrate the infrastructure involved in collecting data in an automated way on the tractor/implement. The collected data from the field machine comprised GPS data creating a time and geostamp for every set of data acquired. Data were then transmitted through the use of a GSM/GPRS terminal (Siemens, 2006) in real-time to an online database using GPRS. The transmission of these data is also in compliance with ISO 11783. The farmer will be able to monitor the machine work from a website on his PC (see Figure 19).

Based on the initial tests, the protocols for the system were also extended to support more job computers. New protocols were implemented so that the Java terminal (Siemens TC65) can recognise and communicate with the following job computers:

- Hardi HC5500
- LH 5000
- Bøgballe UNIQ

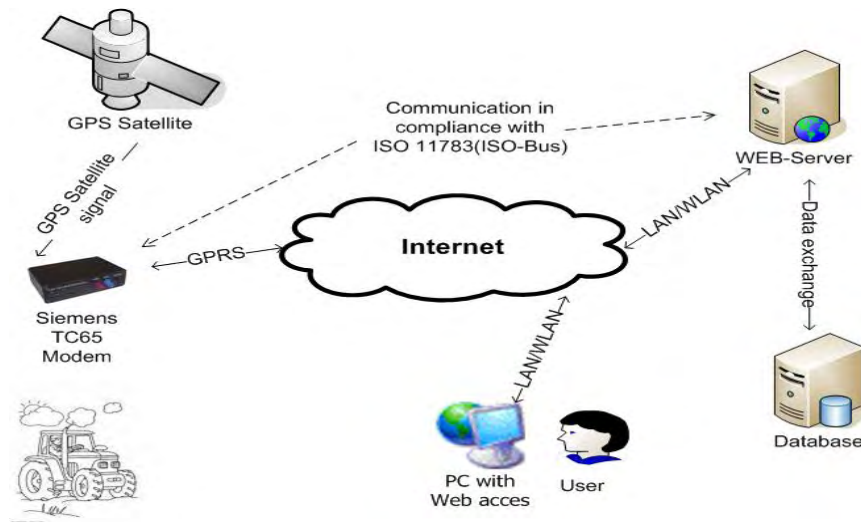


Figure 19: Automated dataflow.

The setup in Figure 19 has several advantages:

- All field operations documented
- Data security (security log implemented)
- Data accessible anywhere with an online computer
- Accessible to anyone with permission to use the data.

The software running on the Siemens module has a built-in safety log, which means that even though there is no GSM network connection, data are stored internally and sent when connection is once again restored. The mobile unit chosen for these experiments was the Siemens TC65 platform, which has the following main characteristics.

- Quad-Band
- GPRS Class 12
- JAVA IMP-NG
- Powerful processor (ARM© Core, Blackfin© DSP)
- Large memory profile (400 kb ram, 1.7 Mb flash)
- TCP/IP connectivity
- Interface-rich (USB, RS232, I²C, SPI and more).

The Siemens TC65 is a small powerful computer with a built-in modem. It contains a lot of I/O options which makes it very versatile, and being an off-the-shelf product, it is also quite inexpensive.

Concerning the GPS hardware, the Holux GR-213, again a very reasonably priced GPS unit, was used. The GPS hardware could actually be any type of GPS that can deliver a NMEA 0183 GGA string via a RS-232-compatible serial port. This means that it is possible to choose the precision of the logged data by changing GPS unit.

Data processing and decision support

The evaluation and prediction of agricultural machinery performance are important aspects of all machinery management efforts (Sørensen & Nielsen, 2005). By specifying and quantifying the operational performance of farm machinery, it is possible to select and plan the use of equipment in any given environment. The specific driving pattern that a farmer follows in order to cover a particular field has a significant influence on the efficiency with which, for example, time is consumed. By monitoring the driving paths using a precise GPS positioning system to record the coordinates of, for example, the sprayers as they cover the relevant field areas together with other performance data, it is possible to analyse and deconstruct the operations. This analysis is then used for subsequent planning and optimisation.

Testing of the proposed method of automatic data acquisition in field machinery has demonstrated that it is possible to acquire operational data from mobile working units and subsequently use these data to analyse and evaluate designated machine efficiencies. Targeted case analysis has also shown good compliance with theoretical models and estimations (Jensen *et al.*, 2007). A specific benefit of the system is the possibility to automatically document the activities of the machines at given times. This could be used as a documentation and traceability measure to comply with increasing legislative regulations in this area.

8 Analysis of interactions in use cases – evaluation of systems usability

8.1 Introduction

In evaluating the usability of the farm information management system (FMIS) concept, the boundaries of traditional usability evaluations are crossed in several respects listed below:

- FMIS is a comprehensive and complex system with several user interfaces.
- The system needs to be evaluated with regard to deeper functional features of the system, as evaluation of user interface features as such is too superficial.
- The system is a professional tool which cannot be evaluated adequately without considerable experience of the work for which it is aimed.

As a consequence, the concept of usability itself must be extended. In this connection the boundaries of the traditional process of usability testing also have to be crossed. The following changes become necessary:

- Due to the complexity of the system under development, the design process is not restricted to creating a singular product. In parallel with product development, a more forward-looking and generic concept is formulated that facilitates steering of system development. In concept development, practical experience and scientific knowledge of farming are used and the information needs of the future precision agriculture modelled. The usability evaluation process needs to trace the design process and offer design input. A straightforward singular test or repetitive series of acceptance tests are not sufficient.
- Due to the required depth and comprehensiveness of the usability evaluations, different kinds of data must be integrated into an overall view of the usability of the system. New methods must be developed to enable such a synthesis.

- The systems designed are unique cases that cannot be compared with any other system. Hence, it is evident that normative references are necessary in usability evaluations, the fulfilment of which may be monitored during the maturation of the design process. The concrete methods and focus of evaluation change over the process with regard to the development of the product, but a coherent evaluation of usability should still emerge.

Sometimes, especially in safety-critical solutions, usability evaluation is used mainly to support official acceptance. In this case usability evaluations serve a normative function. In the present case, however, usability evaluation supports an innovative function, as it is meant to support design.

8.2 The concept of systems usability

To meet the needs of a more comprehensive and integrated evaluation of usability, a new approach to usability evaluation has been developed at VTT Technical Research Centre, Finland. This approach is going to be used in the evaluation of the system concept. In doing so, it is foreseen that the method should be adapted and developed further to meet the specific requirements of the present evaluation.

The central concept of the evaluation approach is the concept of *systems usability* (Norros and Savioja, 2006; Savioja and Norros, 2008). This is the comprehensive ability of a tool to promote fulfilment of the aims of the particular work. An evaluation method called ‘Contextual Assessment of Systems Usability’ has been developed to define and evaluate the systems usability of complex information technology-based tools. This approach is described in more detail in the references cited above. In the following we highlight the main characteristics of systems usability.

8.2.1 Core-task related demands on the system

Systems usability of a complex human-system interface means, first, that the technology should be evaluated in a *holistic* and *context-dependent* way. This we achieve by claiming that the technology must *facilitate fulfilment of the core task* of the particular work.

In this system concept aspect, it is necessary to identify the core task of farming and specifically how the core task will change when precision agriculture (PA) technology becomes available. This question was tackled in the Finnish project that preceded this (Nurkka *et al.*, 2007; Pesonen *et al.*, 2007). There is much more relevant material on the changes in the core task of arable farming than these authors were able to exploit. Hence, in the present technology-orientated development project, the development pressures in the farming business and the changes in core task must be given sufficient attention.

When defining the precision agriculture core task, the Finnish studies made use of a model developed by Norros (2004) to guide the articulation of the different functional constraints and demands of farming. As indicated also in section 3.2, there are three logical phases in the core-task modelling process (see also recent work by Norros and Salo (submitted)):

- Modelling of the work domain and core-task (definition of constraints)
- Modelling of situations (definition of goals and resources, *e.g.* means and critical information)
- Analysis of work activity (operative, communicative and collaborative actions and their reasons)

With regard to the first modelling phase, which focuses on identifying the generic domain and work-related constraints, and drawing on studies in human factor engineering, for example Vicente (1999) or Woods (1988), Norros proposed that the intrinsic qualitatively different dimensions of constraints that characterise these environments are dynamicity, complexity and uncertainty (DCU). The DCU features must be specified for each concrete work domain separately. Certain skills, knowledge and collaborative demands are related to these domain-related dimensions. The idea is further that work domain demands must be fulfilled for maintaining the overall objectives, or purposes, of the activity. Via analysing the DCU features of farming by considering the skill, knowledge and collaborative aspects of enacting the generic core task, the demands of farming were inferred. The procedure of deriving the core-task demands is demonstrated in Figure 20.

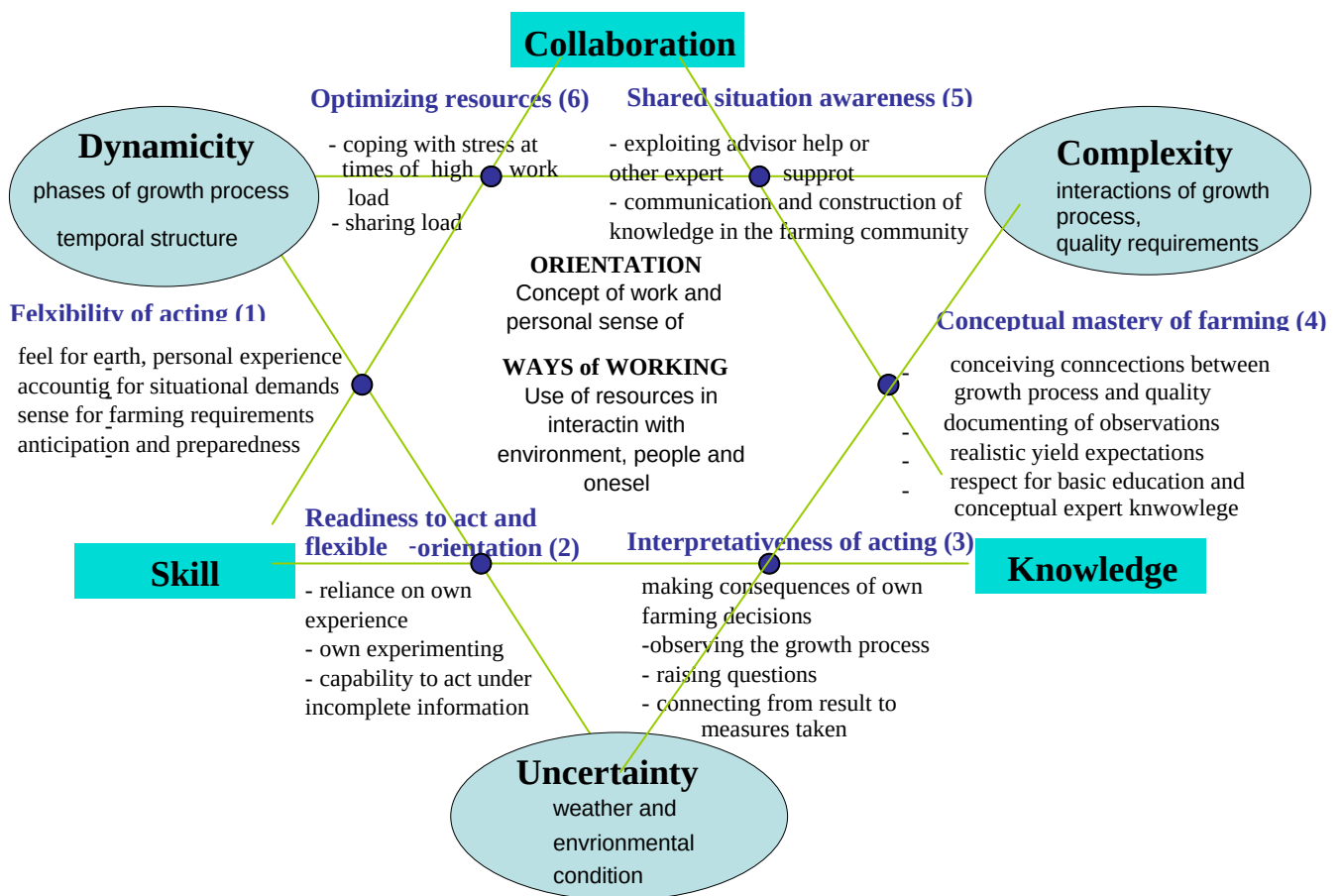


Figure 20: Deriving the core-task demands for knowledge-intensive farming (after Nurkka and Norros *cit.* Pesonen *et al.*, 2007).

Fulfilling the work domain and core task introduced constraints on farming, but also constituted the meaning of certain situation-specific goals and tasks. In the second phase of the analysis, the work is modelled according to how it is accomplished in certain situations. These situations may of course be more generic types of situations or even very particular problem situations. On a

generic level the farming tasks portray a rather clear temporal structure. Farming work is structured by the seasons and the growth processes of plants. The different goals of farming, which often compete with each other and must hence be balanced by the farmer, have to be analysed in this second phase of analysis. The sequential structure comprises fulfilling different tasks, for example sowing.

As a result of this second level modelling, situation-related tasks are defined. Their connection to the higher level purposes, functions and constraints allow them to be labelled as *primary tasks*, a term typically used in task analysis that does not articulate clearly the need for a functional level of task analysis (e.g. O'Hara *et al.*, 2003). Strategic business planning, evaluating the yield prospects, choosing the seed, sowing, *etc.* are examples of general primary tasks. Primary task sequences may be defined according to different types of farming and to specific situations. It should be noted that on this level of modelling, the core task is presented as a process or also in scenario form.

It is obvious that information and control technology is an inseparable element and resource in the control of DCU environments. It provides an interface between the process environment and the human users/operators and should provide support in all above-mentioned primary tasks and still not overwhelm operators with too much information. Depending on the type of farming equipment and the specific monitoring and control devices of information systems, the so-called *secondary tasks* of farmers vary. Secondary tasks are those needed to handle the information system itself and to navigate within it. It may be possible that the modernisation of farming technology will affect the secondary tasks even more strongly than the primary farming tasks. The technology or medium we use shapes our lives and activities.

The third logical phase of the Core-Task Analysis (CTA) framework is the analysis of work activities as they are performed in real work situations. It is clear that any modelling of the work domain and core task must be complemented by analysis of people's real behaviour. According to the CTA methodology proposed (Norros 2004; Norros and Savioja, 2006), it is necessary to analyse both the conceptions of work (work orientation) and work operations (habits of action) in order to understand the content and sense of daily work in particular situations. In work focused on malt barley production, Nurkka *et al.* (2007) presented an analysis of farmers' orientation to malt barley production and also a scenario-based analysis of habits of action.

8.2.2 Tool functions that the system supports

In order to meet the demands for systems usability, work tools must fulfil *three generic functions of tools, the instrumental, psychological and communicative*. These functions are drawn from the cultural-historical theory of activity and integrated with ideas of media theory as proposed by Rückriem (2003). Thus, systems usability of tools means that tools are such good instruments to induce a desired effect, they are good cognitive tools that fit and shape the human dispositions to act appropriately, and they communicate the relevant content to the users in a meaningful visual or multimodal representation. Hence, we use *efficiency and effectiveness, fitness for human use and meaningfulness in use* as evaluation dimensions. Table 5 shows a proposal for evaluation of dimensions for intelligent systems and environments prepared on the basis of the three tool functions. As can be seen, many of the criteria are included in traditional usability lists. The possibility to link single criteria to theoretical foundations is beneficial in performing assessments.

Good systems usability is visible in the users' work performance, as systems usability promotes the construction and development of work practices. Good work practices are such that they produce *good directly measurable results*, and they have internal quality features such as *interpretativeness, communicativeness and orientedness to the core task*, and the users experience the technology to be *promising* for the future development of the work and its core task.

Table 5: Evaluation criteria for assessing intelligent environments and systems (Kaasinen and Norros 2007, p. 267)

NATURAL IMPACTS (Instrument function)
Efficiency- intended result is achieved
Effectiveness – aim is achieved with reasonable resources
Absence of being hindered – aims achieved even when physical capabilities are limited
Availability – system/environment always available when required
Easy to understand – users understand what the system/environment is doing
Affordance available – possibilities of the system/environment are perceivable
Easy to implement – system/environment is readily exploitable
SEAMLESS INTERPLAY IN THE JOINT HUMAN-TECHNOLOGY SYSTEM (Psychological function)
Appropriate allocation of tasks – division of labour between human and technology is appropriate
Stress – system/environment puts an optimal mental and physical load on human
Safety – physical or mental health is not endangered
Privacy – system/environment provides shelter from invasion of personal privacy
Security – personal data are not delivered to unwanted outsiders
Controllability – people have a sense of control and real control over the system/environment
Trust - people can rely on the system/environment as a partner
Initiative – system/environment takes initiative in an appropriate way and level
Adaptability – system/environment adapts to the user and situation
MEANINGFUL WORK AND USE (Communicative function)
Meaningful – environment/system is important and makes sense due to its useful, joyful or other contribution
Adjusted to identity and values - system supports people's identity and values
Collaborative - system/environment supports people's role in communities
Attractiveness – system/environment is pleasant for people to use
Emotionality – system/environment evokes desired feelings
Aesthetic – system/environment has appeal to beauty and intelligence
Imperceptible – system merges into the environment
Tactful – system/environment behaves courteously
Challenging – system/environment requires active participation in appropriate amounts

8.3 Implementing systems usability evaluation in the design process

In the system concept development process, usability evaluations should serve design. Hence, we are interested in the practical effectiveness of usability evaluations on the system designed. The problem is to structure and exploit usability information so that the designers and developers are able to take the results into account in the design process. The VTT human factors group is

currently developing a new type of approach to usability evaluation and design which is called Usability Case. This is a methodology aimed at tackling the diverse challenges imposed by a longitudinal design-orientated usability evaluation process. In the following, the background to the Usability Case approach is presented (Liinasuo and Norros, 2007).

8.3.1 Background to Usability Case

The development of the Usability Case approach drew on the established tradition of Safety Case. Safety Case is a requirement in many safety standards; explicit Safety Cases are required for military systems, the offshore oil industry, real transport and the nuclear industry. Furthermore, equivalent requirements can be found in other industry standards (Bishop and Bloomfield, 1998). The latter define a Safety Case as ‘a documented body of evidence that provides a convincing and valid argument that a system is adequately safe for a given application in a given environment’. The idea of a Safety Case is to gather safety-related information into one document that is also usable later to demonstrate the safety of the system. Information is structured in an orderly manner that takes into account the abstraction level of the information as well as interconnections between the pieces of information.

Liinasuo and Norros (2007) claim that this way of organising information is also fruitful in the context of usability evaluation. Given the specific demands that are set for usability by the design of a complex and unique system, the existence of a clear methodology taking into account the versatile nature of usability evaluations is urgently needed.

The concept of Safety Case is widened in the proposed usability case approach by two perspectives. Firstly, while Bishop and Bloomfield (1998) focus on positive support for claims, it seems reasonable to also indicate whether evidence provides negative support for a certain claim. Hence, problems of usability are reported in the case description. Secondly, Bishop and Bloomfield (1998) aim at producing a documented final description of the good performance of the system to be used during its operation. In addition to this, we see the need for usability information during the design process to guide and give feedback to design.

Following these refinements, Liinasuo and Norros (2007) describe a Usability Case as ‘creating an accumulated documented body of evidence throughout the design that provides a convincing and valid argument of the degree of usability of a system for a given application in a given environment’ (p. 12).

8.3.2 The conceptual structure of a Usability Case

As in Safety Cases (Bishop and Bloomfield, 1998), three concepts are used to structure usability information in the Usability Case. *Claims* are entities that express the quality of the system in terms of usability. The abstraction level of a claim is high but various viewpoints and levels of detail are possible. Each claim comprises one or more *arguments* that are instrumental descriptions supporting the claim in question. Finally, each argument is based on *evidence*, i.e. various data.

A case can be demonstrated in several ways. Kelly (1998) lists many different options to articulate evidence in arguments: describing the [safety] level through free text; tabular presentation structuring claims, claim structures that are built up from claims joined together in a hierarchical manner; traceability matrices that represent how one statement (claim, requirement, objective, etc.) is related to a series of other requirements; Bayesian belief networks that are graphical networks communicating the probabilistic causal relationship that exists between variables; and finally, goal

structuring notation that graphically presents the structure of a safety argument by using goals of several hierarchical levels with constraints and solutions (roughly parallel with evidence).

The representation of claims, arguments and evidence seems to be a clear and extensive way to describe the status of usability. Given the complexity of usability evaluations, free text seems to be a flexible means of describing the variety of usability attributes in a given system. Beyond this, tabular or hierarchical structures are also possible means to represent the Usability Case logics.

8.3.3 Characteristics of Usability Case

Usability Case (UC) describes *how well the system in question fulfils the usability demands specific to that system*. In understanding these demands, both theory and practice are needed here through applying the theory of systems usability described above.

The concept of systems usability indicates the appropriateness of a tool for an intended use. Above, we described how systems usability can be defined context-dependently by analysing the core-task demands and task performance the tool should support. We also indicated that the systems usability approach maintains that systems usability is manifested in working practices, which are generic tool-using patterns of the users established in the specific communities of practice. To elaborate tool-using practices, we analysed how the three generic tool functions described above are represented in the users' practices. In addition, we also considered user experience as an important element of systems usability. In particular, we were interested in how promising the tool appears in future usage. Of course, traditional usability concepts, *e.g.* by Nielsen (1993), and corresponding breakdown of usability requirements are taken into account in our concept of systems usability. As a result of the above considerations, *systems usability claims* for the particular system can be produced.

When a Usability Case is produced throughout a long design process, the results of *usability evaluations are accumulated* in the Usability Case. This means that in accordance with new phases of design, the claim structure will be complemented and part of the claims must presumably be restructured to meet the new situation. In this way, the Usability Case is always up to date.

Each claim must be supported by arguments that describe how the claim is demonstrated in practice.

Each argument, in its turn, is justified by showing what data, *i.e.* evidence, that argument is drawn from. In usability evaluations, those data can be ergonomic standards, results from questionnaires delivered to the employees, heuristic evaluations and so forth.

The basic structure of the Usability Case is demonstrated in Figure 21. The concept and method of the Usability Case are currently being developed in three applications at VTT - nuclear power plant control room modernisation; civil emergency centre information system development; and the present case.

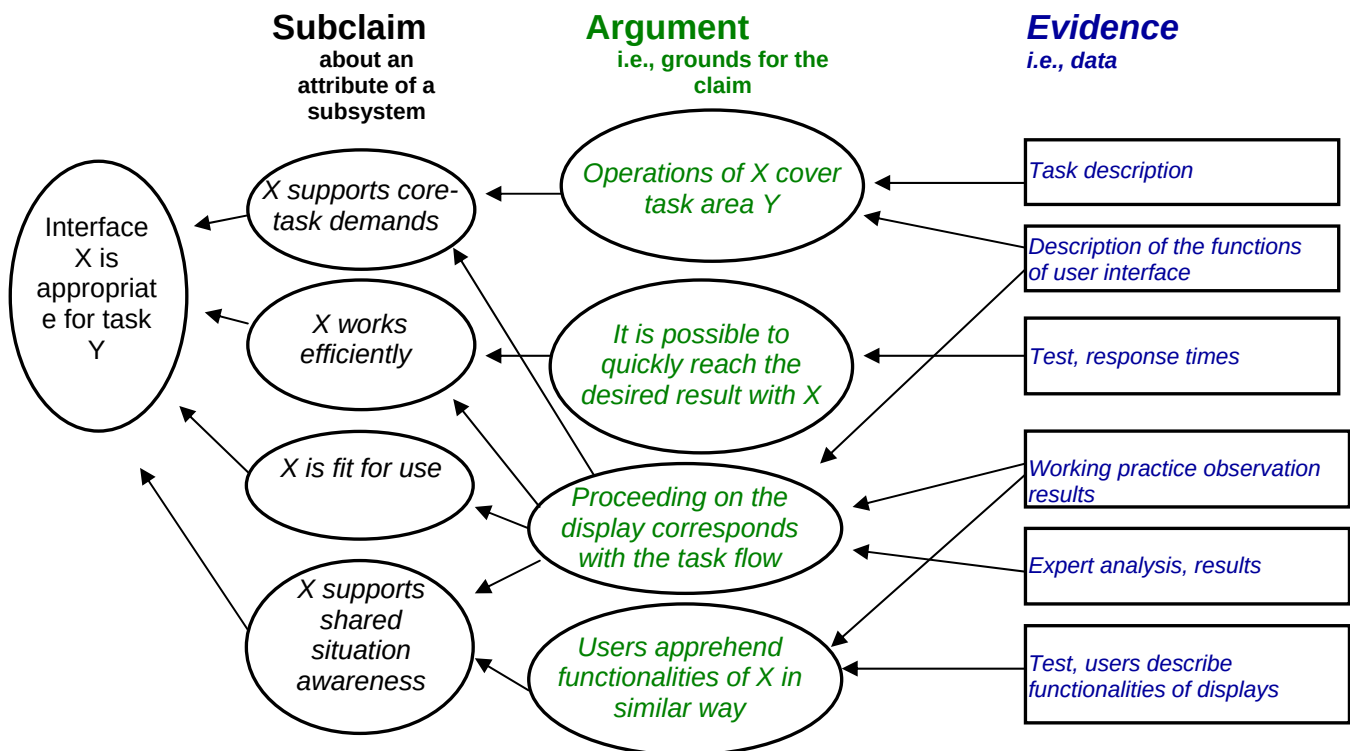


Figure 21: Demonstration of the basic structure of a Usability Case (Liinasuo and Norros, 2007).

8.4 The AFMIS Usability Case

When considering the Farm Management Information System (FMIS) from the perspective of systems usability presented here, the information management system is more than just data storage and functionalities supporting farm management. It has an important active role in providing on-line support and assistance in everyday farm activities. Thus we suggest that the newly designed information management system concept for automated plant production should be named Active Farm Management Information System, AFMIS.

The Usability Case is constructed by utilising the CmapTools Knowledge modelling kit. This programme enables complex conceptual maps to be created. In the following, the structure and concepts of the Usability Case are explained. The informative chart drawn with the aid of the CmapTools was also prepared from this case. Simplified version of the map is presented in Figure 22, and the map as a whole is available on the project website (www.mtt.fi/infoxt, Publications, WP3.2 report).

8.4.1 Structure and concepts of the Usability Case

The systems usability claims concerning the AFMIS are defined by a four-layer hierarchy of claims. A Usability Case is designed to have claims and sub-claims. In the AFMIS case, we do not

make use of the sub-level notion but rather use a name that characterises each hierarchical level. Hence, we propose the following layers of systems usability claims:

- Top claim
- Core-task claim
- System requirement claim/Interface claim

The top claims of systems usability constitutes the highest level. These claims are drawn from the systems usability theory and represent the three basic tool functions. They are named as the *natural impact* claim that represents the instrumental function, *seamless co-operation of the joint human-technology system* claim that represents the psychological function, and the *meaningful work* claim that represents the communicative function of the tool.

The second level of systems usability claims is called the core-task claims. Accordingly they are derived from our analysis of the core task demands of arable farming. The demands are articulated in a technology-independent way. The core-task claims are drawn from the analysis depicted in Figure 20 to which the numbering refers (1 is the skill-related demand on the upper left-hand side of Figure 20, from where the numbering continues counter-clockwise and finishes with the collaboration-related demands). Core task 5 is represented twice, on a more specific and on a more general level. The core task claims are considered to fulfil particular tool functions in the following way: *On-line observations and anticipation of changes*, and, *flexibility of farming tasks* fulfil natural impact top claim, *understanding cause-effect relations of the farming process*, *shared situation awareness within the joint system*, and *optimising of farming efforts* fulfil the top claim of seamless co-operating with the joint system, and finally *conceptual mastery and competence building* and *common farming culture* fulfil the meaningful work top claim.

In the two upper levels the claims have been defined as technology-independent. The third level of systems usability claims, the system requirement claims, concerns the *specific technology under development*. From this stage the reasoning follows two lines.

First, the claims describe how the system requirements for the precision sprayer system fulfil the core tasks claims. The particular *system requirement claims* are depicted in Figure 22. The solutions that support the specifications are considered as *design arguments*. Figure 22 indicates those design arguments that we consider definable at the present stage of development of the system. Evidence is collected via interviews and scenario techniques among different interest groups to test whether the system solution arguments will be found relevant to support the system requirement claim. Here the aim is to *test the precision sprayer system concept*.

Second, we interpret the system requirement claims from the point of view of interface requirements needed to fulfil the core-task claims. Then, it is necessary to find and formulate *interface arguments* that would support the system requirement claims. Interface arguments have so far not yet been defined for the sprayer. When they have been defined it will also become necessary to accomplish heuristic usability evaluations and usability tests with end-users to see whether there is evidence on which the interface arguments could draw and support system requirements. In this line of reasoning, the aim is to test the *precision sprayer system interface*. It is possible that the concept is acceptable and a product could be designed but, at the same time, the interface does not make the possibilities that the system requirement claims specify evident to the user. Hence, the possibilities would not be afforded.

As indicated above, we must collect different kinds of data for the Usability Case. The main types are:

- Data collected within the designer-driven design process. In this process the aim is to develop claims and solution arguments:
 - technical experience, tests and literature evidence on which the formulation of solution and interface arguments to support systems usability claims can be based
 - interview evidence on which the formulation of solution and interface arguments to support systems usability claims can be based.
- Data collected within the user-driven design process: In this process the aim is to collect data that could be used as evidence to support arguments for systems usability claims:
 - usability evaluations as evidence to support the solution arguments
 - usability tests as evidence to support interface arguments

The Usability Case is the means of demonstrating that the solutions proposed at present are such that systems usability is achievable. When the design process matures, more evidence can be collected and used as a basis for arguments that support the claims.

8.4.2 Usability evaluation

In the *usability validation* (<http://www.mtt.fi/infoxt>, Publications, WP3.2) phase we produced two sets of scenario-based interviews. The first were carried out in Denmark, Finland and Sweden with the aim of acquiring material to develop usability claims. The claims were utilised further in the concept design work. The scenario and interview questions can be found in Appendix I and II. The sub-questions of the main interview questions were differentiated to some extent depending on which part of the value chain the interviewee represented. Interview notes (from Denmark) or transcribed interview protocols (from Finland) were made available and used for claim development. The research team also met in two workshops to define and later comment on the claim structure. The claim structure was then developed further and the structure is currently that depicted in Figure 21.

The second scenario-based interviews served to collect evidence for arguments to support solutions that fulfil the systems usability claims. The scenario was presented as a video demonstrating functional features of the system concept in real task execution, precision spraying. The features and functions of the system were introduced to the watcher by narrative text. These interviews were carried out during January-April 2008. They were targeted mainly at professionals within spraying, such as farmers, contractors, advisors and technology companies in the value chain of this particular task, who are thus capable of judging what they see. After watching the video the interviewees were asked to answer questions concerning system features and functions. The answers provided evidence to either support or refute the suggested solutions. The video and questionnaire were available in English, Danish, Finnish, Icelandic, Norwegian and Swedish on the website <http://www.mtt.fi/infoxt>. The questionnaire was advertised in farmers' professional journals, lectures and meetings in connection with presentation of InfoXT topics, as well as by e-mail sent to relevant actors. The video and questions were also used when interviewing companies and farmers who had not yet participated, face to face or via telephone conversations.

8.4.3 Results from the internet questionnaire

By 23 May 2008, the video was watched through 74 different internet addresses, providing 37 answers to the usability evaluation internet questionnaire. The answers were divided into different countries; 15 from Sweden, 10 from Finland and 10 from Denmark, 1 from Norway and 1 outside of the Nordic countries. The data obtained gave an average support of 80-90% for the system features presented in the video. The support ranged from 50-100% among all answers. The strongest support came from Sweden and the weakest from Finland. Nineteen of those responding were farmers and 20 had a farm. Eleven of these farms had only one person working on the farm. The rest of those responding were agricultural students, agricultural workers, advisors, researchers and machine and device manufacturers. Thirteen of those responding had experience of precision farming technology, only one of whom came from Finland.

Eighteen of those responding saw this kind of spraying system becoming common in the future, and only four did not see this happening at all. Twenty-five responses believed that this kind of way of working creates new professional know-how. Sharing farm data among other farmers was considered beneficial for the farming business by 25 responses.

Overall, on the basis of the feedback data received the work being done is on the right path, and the system concept designed provides good possibilities to produce usable information systems for the mobile plant production environment. Some comments attached to the questionnaires also stressed the importance of the usability of user interfaces in order for this kind of system to be really satisfactory.

9 Science-based modelling of the core task of field work – the new situation

In the new situation where the novel information management system concept is utilised, the description of the core task will change. At the end of the project, the information flow model for the case of fertilisation was run according to the new system concept. Figure 23 shows the execution part of the model, while the whole information flow model is presented in Appendix VI. When comparing the differences between the information flow model using the old information management concept and this new model, the changes caused by the new system concept to the nature of farmers' work (Core-task 2) can be identified. The differences compared with core task 1 are:

- Recording and storing of implement status/work documentation into farm database. This also means increased usage of numerical / formative data.
- Farm database has a central role in both human and machine decision making.
- Active use of external services increases.
- Increased use of automation.
- Smart assisting system features to support work are common, used information management technology shifts towards knowledge management technology

These changes mean that farmers have to be ready to adopt new working habits and perhaps also undergo further training. Farmers can utilise different services more efficiently and they are able to outsource some of the tasks they had previously performed themselves. Farmers have better knowledge of their production processes and are able to evaluate the performance of the chosen technology. This should lead to better process control in farms. Farmers can also utilise the collected farm data to show the quality of farming *e.g.* traceability, to markets and administration.

The system concept also allows the farmers to access and utilise better scientific research and technological developments by providing fresh real process data and the ability to update the systems according to the latest knowledge. The results are in accordance with the policy recommendations to *implementation strategies* proposed by Ahlqvist *et.al* (2007) in the summary report “Nordic ICT Foresight: Futures of the ICT environments and applications on the Nordic level”.

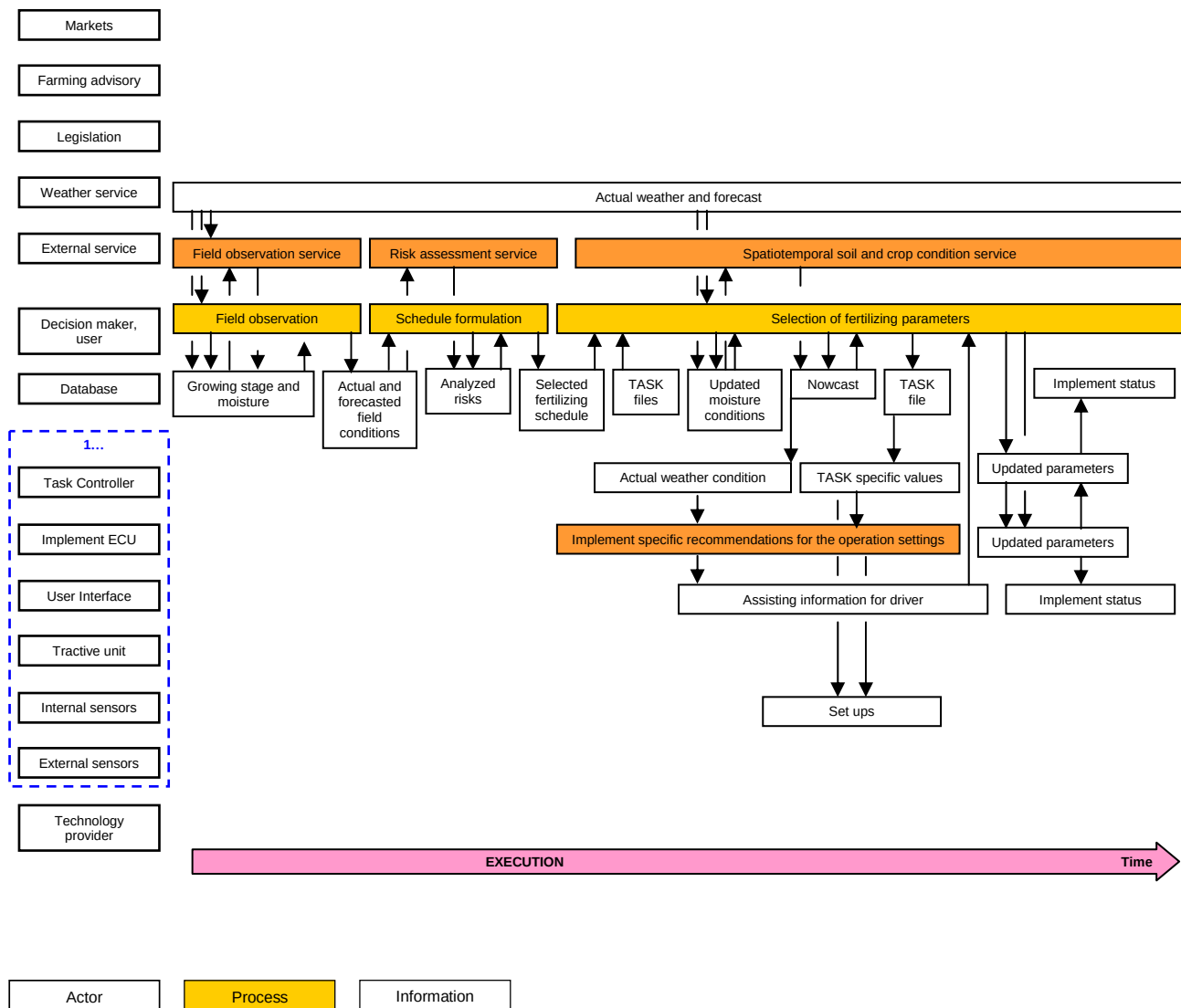


Figure 23: Information flow model for execution of field fertilisation operations. The elements include actors (physical entities), processes (information users and producers) and information (information flow).

10 Conclusions

11.1 Recommendations and guidelines

The following list of recommendations and guidelines should be recognised by all actors in the value chain:

- Efficient information management systems in mobile plant production environment should be internet-based with an open interface.
- Farm data saved in a central database should be accessible to the farmers via internet-servers.
- Difficulties are often related to manual transfer of data and incompatibility between links in the information chain. Therefore, there is need to harmonise or standardise data transfer formats, and to some extent also data models, for better economic efficiency. ISOBUS xml format is suitable and promising for efficient data transfer between mobile work unit and database.
- FMIS (Farm Management Information System) can be rather called AFMIS (Active Farming Management Information System), since the farm database has to have features that *actively* support farming activities and knowledge management. There is need to develop assisting interactive functions
 - o as automatic programmed features
 - o to give situation/context-aware advice
 - o to be utilised in work situations in the field, buildings or office
 - o which have additional personal/farm-specific services attached
- Wireless connections essential to the system concept have to be reliable and powerful enough in their data transfer capacity

11.2 Research requirements

It is necessary to further develop in research and cooperation at Nordic and European level:

- Standardised or harmonised open system interfaces, data formats and data models
- Interoperability of the agricultural domain with other domains such as traffic, forestry, *etc.*
- Dependable and efficient wireless communication networks, also in rural areas
- Smart system features leading to smart environments to fully utilise the concept
- Usable user interfaces to devices
- Larger scale pilots of the new system concept.

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Appendices:

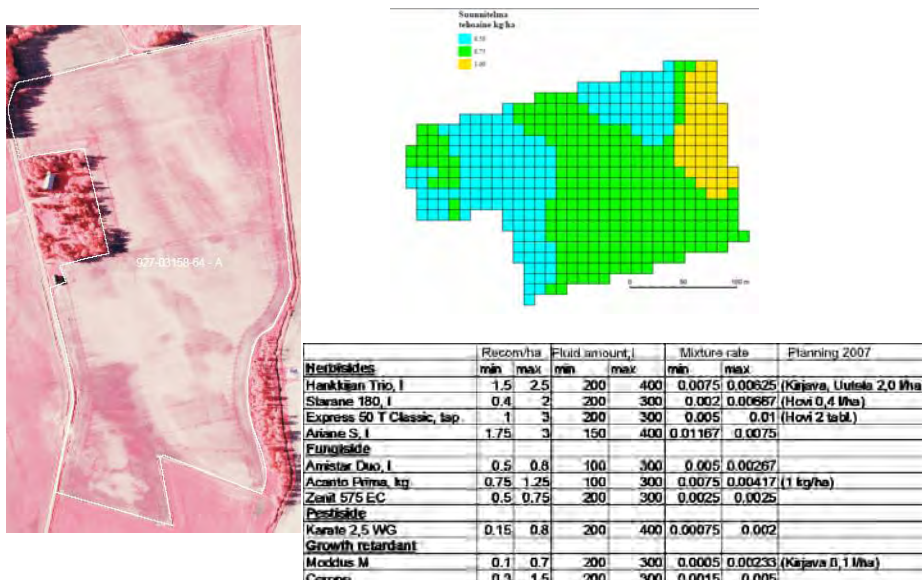
Appendix I

The scenario of precision spraying task utilising the novel InfoXT system concept.



Picture 1.

- The summer has begun and the growths in farmer's fields look good.
- However, according to the forecast and observations of advising service there is a need to protect growths against diseases.
- The advising service gives a disease alarm to the farmer.
- The alerted farmer is now aware of the risk and decides to carry out field inspections in his own fields.
- Farmer uses with GPS and digital camera equipped PDA-phone to make field notes.
- He sends the results and selected pictures to Farm database straight from the field by his PDA-phone.



Picture 2.

- After evaluating the situation in the fields he chooses – with advising services assistance - the most suitable chemical from his storage to be used in spraying.
- He asks the advising service to make a spraying plan to the fields.
- The advising service gets the biomass maps and other field specific information from the Farm database.
- The advising service produces a spraying task which contains following information: field ID, area, relative application map, chemicals, default application rate (mean rate, min and max rates), expected spraying date, expected wind, expected canopy humidity. It is also determined in the TASK file, which information and in which accuracy will be documented during the work.



Picture 3.

- When the plan is ready and the task is stored to the Farm database, the service informs the farmer by SMS to his phone. The service sends the content of the plan and the visualised application map to the farmer by e-mail, so that he can give feedback to the plan if necessary.
- Now, the farmer is ready for action.



Picture 4.

- The farmer decides that now is the best moment for spraying and climbs up to his tractor-sprayer combination.
- He retrieves the planned task and information about available nozzles from the Farm database to the Task Controller (TC).
- TC initializes the task, retrieves weather data from the weather service and sends the information to Sprayer ECU (Electronic Controller Unit).



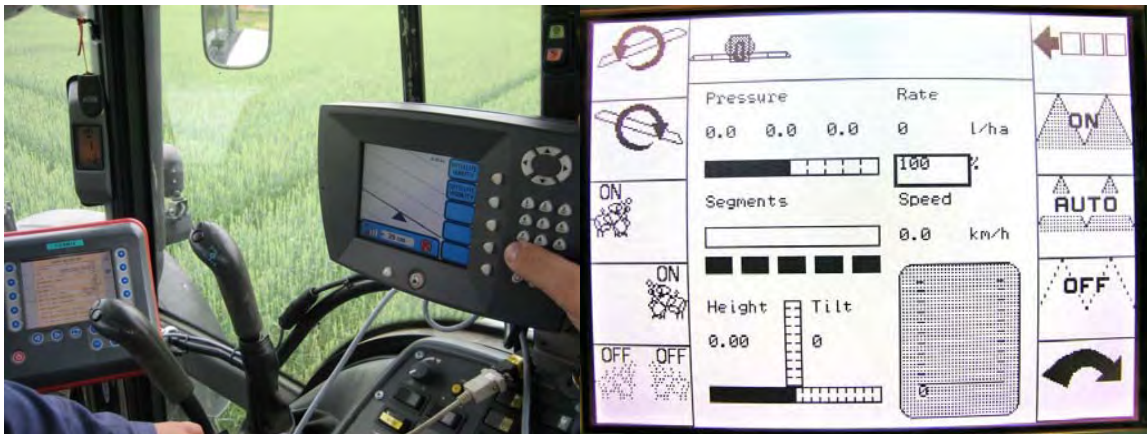
Picture 5.

- The Sprayer ECU uploads the sprayer specific view to Virtual Terminal (VT) of the system.
- VT acts as a user interface.
- Expert system of the Sprayer ECU determines, on the base of the latest information, the optimal combination of parameters for the spraying session.
- The system tells via VT to the driver which nozzle type to use, and the "recipe" for the tank filling.
- When the preparations are ready the execution of the task can begin.



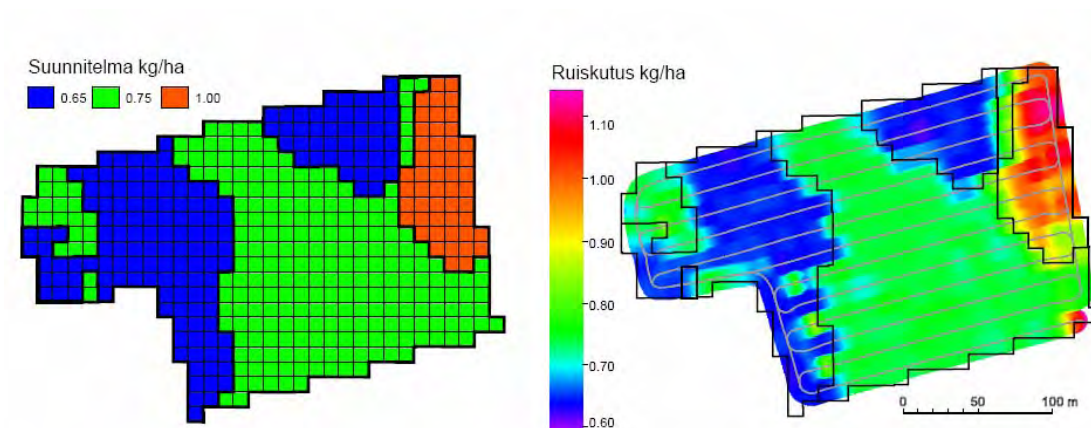
Picture 6.

- When the actual task realization starts the TC gives commands to Sprayer's controllers site specifically for Variable Rate Application (VRA).
- If ISOBUS version Class 3 is in use, the Sprayer ECU gives commands to TractorECU to control the driving speed automatically to adjust the application rate (with constant chemical mixture).



Picture 7.

- The TractorECU and its auto steering system take care of driving lines in the field and show them to the driver via VT.
- Sprayer has automated user assisting functions, like headland automation, remaining area that can be treated with present tank filling etc.
- The state of the system is shown and updated to the VT during the work, so that the driver is always aware of the situation. He has opportunity to take over the control when ever he wants to.
- The driver can make notes during the work session and save them to TC.



Picture 8.

- In the end of the work session TC prepares document file of the realized task as it is determined in the TASK file.
- The file is uploaded straight from the field to the Farm database, where it is available for later use.

The scenario ends

Appendix II

Interview questions to farmers

1. How does the farmer see his role in the value chain of information management technology of plant production?

(Value chain picture)

- What is the size of the farm and what are the main products of the farm?
- Which arrows he/she can identify his/her activities with in the value chain picture?
- Where he/she locates contractors or other services he/she uses at the moment in his farm?

2. What is good in his/her present farm information management technology or in the technology that will be available in the markets in near future?

- Does the farmer find the present technology easy to use?
- How much time does he/she uses for updating collected and stored data?
- Does the farmer find data quality, data acquisition devices and data transfer reliable?

3. What problems or bottle necks in the present technology?

- Are there any features in the information system he/she uses at the moment that are not in use because they are too difficult or complicated to use?
- Is the farmer satisfied with compatibility between different systems or applications in use?
- Does the data transfer between observation devices and cultivation planning system function well?

4. After general questions the scenario could be presented as introduction to deeper discussion. The farmer is asked to comment what is good or OK in the scenario and what is problematic.

(Scenario pictures and story)

- Does the farmer use data or information from the previous years in next years strategic, operative of tactical planning?
- Does the advisor use farm specific data when he is giving assistance to the farmer at the moment?
- Does the farmer feel comfortable with the idea of using external services (advisory services, farm database in internet server) as it is described in the scenario?
- Does the farmer find it reasonable and realistic if the automation system like intelligent sprayer changes spraying settings automatically according to the changed weather information retrieved from the local weather service?
- How many screen monitors the farmer can consider to have in his tractor cabin?

5. The architecture draft is shown to the farmer so that they can give comments on what is OK and what needs rethinking. They can also suggest new technologies or new structures to the architecture and share their experience in the subject.

(Architecture picture)

- Where the farm database should locate and who should maintain it?
- Where the calculation/data reduction should take place, on-board or in centralized services?
- How the farmer finds it if VT and TC are separate from Implement control unit and serve also other implements as common system parts (as in ISOBUS)?
- Is it OK if the same information system serves both cultivation practices and machinery (remote) service?
- If advisory service makes the cultivation plans for the farmer, should the planning software for the farmer be differentiated (simpler) from the one the advisor uses?
- In the scenario there is access to the FMIS from the office computer as well as from mobile devices. Does the mobile application need to have all the same features that the office application have?
- Can the farmer suggest other farm tasks where the introduced information management system could be useful?

Appendix III

Execution part of dataflow model and data model for precision spraying using present information management concept.

Function: Execution

Definition: The function execution comprises activities concerned with the initiating and controlling the execution of the planned task

Process: Field observation

Definition: The timely observation of the current crop condition

Information flow: Input information comprises field information identifying the relevant fields and external received information on possible occurrence of plant diseases, weeds, etc. The output comprises the immediate status of the crop in terms of actual disease and weed occurrence.

Process: Select formulated task for realization

Definition: Select formulated TASK-files for execution and derive an updated spraying schedule

Information flow: Input information comprises the observed actual crop condition and the actual weather together with the weather forecast for the coming days. The output comprises the final specified and selected TASK-file as well as the updated spraying schedule indicating the timetable for the pending spraying operation. The specifications of the TASK-file (specifications on the spraying operation, like dosage, expected pressure levels, etc.) are downloaded to the task controller as default values. Based on these default values and actual weather conditions, recommended parameter or set values are generated by the sprayer ECU and show on the user interface for consideration. Also, the initializing parameters are generated for sensors that can control the spraying process. (e.g. Yara N-sensor).

Process: Selection of spraying parameters

Definition: Selection of recommended parameter values

Information flow: Input information comprises the selected spraying schedule and the actual weather conditions as the basis for selecting the best adopted spraying parameters. The output comprises the selected spraying parameters at the time of initiating spraying execution as well as the continuously updated parameters and schedule due to changing weather conditions and forecasts.

Process: Inspecting and controlling the spraying task

Definition: Supervision and controlling of the operations specifications

Information flow: Input information comprises the updated spraying parameters and schedule, the spraying unit status information, and overall task and operation status. Internally within the sprayer ECU, a control process is running with inputs like process information (e.g. on-line Yara sensor), status information and set values for the spraying operation, etc. Based on the set values and the actual spraying performance controls are realised. The realised controls are input to the realised spraying work which again is input into the continuously overall operation status (this operation status might include multiple spraying units). Based on the operation status, the operator or some control systems might generate correcting information which are fed into the task controller and the realised controls affecting the overall task performance.

The spraying equipment may be equipped with external sensors providing information on various parts of the spraying performance. This monitoring and documentation information is inputted into the task controller for later usage.

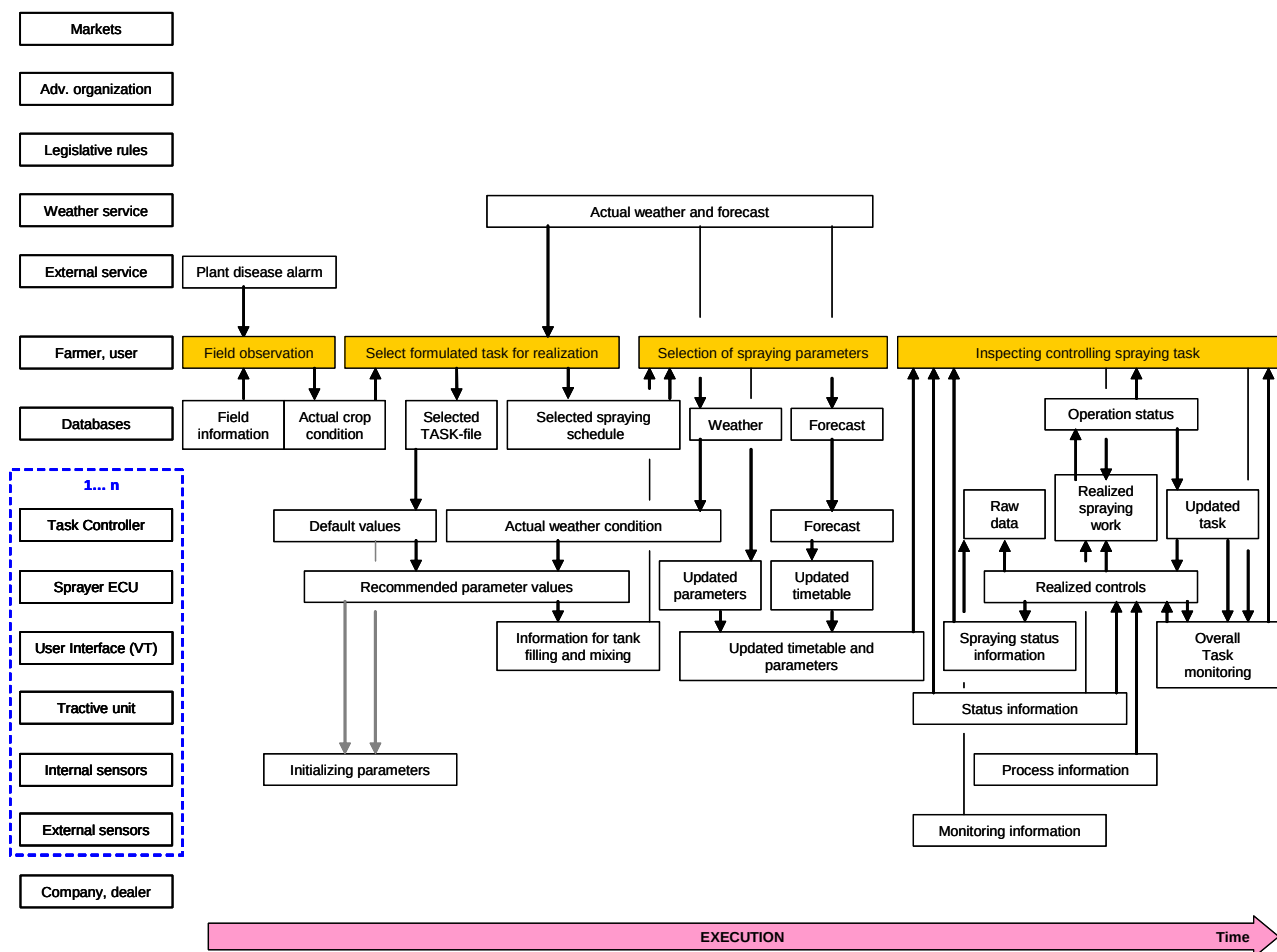


Figure 1: Information flow model / Execution.

Table 1: Data model / Execution

<i>Entity</i>	<i>Definition</i>	<i>Attributes/data</i>
Plant disease alarm	External plant disease alarms	- type of alarm (e.g. fungicide) - prognosis for occurrence
Field information	Description of needed field information	- field ID - crop type - crowing status - farming actions - known risks based on previous field observations on the farm
Actual crop condition	Current status of the growth	- field ID - current growth status - type of observation (e.g. weeds or fungicides) - level of occurrence
Selected TASK-file	The selected TASK-file for execution	- field ID - type of setting (chemical 1... n, nozzle type, nominal dosage, mixture rates, driving speed, boom height and width, documented parameters, variable rate application (VRA) map) - control settings value for the specified types of settings
Actual weather and forecasts	Current weather and short term forecasts	- type of weather parameter - parameter value (e.g. temperature,

		wind, humidity, precipitation) - forecast probabilities
Selected spraying schedule	The selected spraying schedule for implementation	- expected time of executing spraying operations - expected dosage to be applied - workable weather conditions
Default values	Downloaded default values in the TASK-file	- field ID - type of setting (chemical 1... n, nozzle type, nominal dosage, mixture rates, driving speed, boom height and width, documented parameters) - control settings value for the specified types of settings
Recommended parameter values	Selection of the best adopted spraying parameters	- type of setting (chemical 1... n, nozzle type, nominal dosage, mixture rates, driving speed, boom height and width, current weather) - control settings value for the specified types of settings
Initializing parameters	Default values for external sensors (e.g. Yara sensor)	- type of set parameters - setting values
Information for tank filling and mixing	Guidelines for filling and mixing chemicals in the sprayer	- type of chemicals - type of nozzles - ingredient rate - water dilution

		- mixing rates - driving speed - wind speed - humidity
Updated parameters	Adopted ECU parameters	- type of setting (chemical 1... n, nozzle type, nominal dosage, mixture rates) - control settings value for the specified types of settings
Updated timetable	Adopted spraying timetable	- type of spraying - time for individual spraying operations
Operation status	Current operation status	- specified spraying unit - current capacity - current operation progress - remaining spraying work - status of external system (e.g. dryer)
Realized spraying work	Executed spraying work and documented supporting information	- acreage sprayed - applied amount of chemicals - weather - process data (e.g. farmer notes, fuel consumption)
Updated task	Revised and updated task specification	- field ID - type of setting (chemical 1... n, nozzle type, nominal dosage,

		mixture rates, driving speed, boom height and width, documented parameters, variable rate application (VRA) map) - control settings value for the specified types of settings - capacity compliance (for example, the need for additional capacity) - status of external system (e.g. dryer)
Realized controls	Invoked control parameters	- type of realized control (e.g. spraying pressure, dose rate, driving speed, headland automation) - control values - diagnosed status information (e.g. faults) - undefined online operational parameter (raw data)
Raw data	Raw monitoring of operational data	- type of operational parameter - log of operational parameter
Process information	Control information from external sensors (e.g. Yara sensor)	- online measurements (e.g. spatially calculated biomass amount)
Monitoring information	Supervision information	- type of operational parameter - log of operational parameter
<u>Actual weather conditions</u>	Current weather	- type of weather parameter - parameter value (e.g. temperature, wind, humidity, precipitation)

<u>Weather</u>	Current weather	- type of weather parameter - parameter value (e.g. temperature, wind, humidity, precipitation)
<u>Forecast</u>	Short term weather forecasts	- weather forecast probabilities - parameter value (e.g. temperature, wind, humidity, precipitation)
<u>Updated timetable and parameters</u>	Adopted spraying timetable and ECU parameters	- type of spraying - type of setting (chemical 1... n, nozzle type, nominal dosage, mixture rates) - control settings value for the specified types of settings - time for individual spraying operations
<u>Spraying status information</u>	Description of spraying process status	- current control values (e.g. spraying pressure, dose rate, driving speed, headland automation, alarms) - control values
<u>Status information</u>	Description of tractive unit status	- type of tractive unit parameters - parameter value (e.g. fuel consumption, driving speed, pto)
<u>Overall task monitoring</u>	Real-time status information and adjustments	- overall spraying task status - capacity compliance - status of external system (e.g. dryer) - spraying process adjustments

Appendix IV

Total technical validation in task execution of spraying operation in field

This is a real task file used for spraying task in MTT Vihti, Vakola Farm, Uutela field. The notation is not real Isobus xml, but it resembles one. The parts needed to fulfil the operation can, however, be found in the task file below.

The taskfile of Uutela in graphic form

The Vakola farm, Uutela field, area is 5.36 hectares.

In the treatment map below the area is divided in four parts, with VRA percentage values of 65, 75, 65, and 100.

The task is formulated below in two formats

- the graphics, picture
- the task file , with treatment zone values and polygons

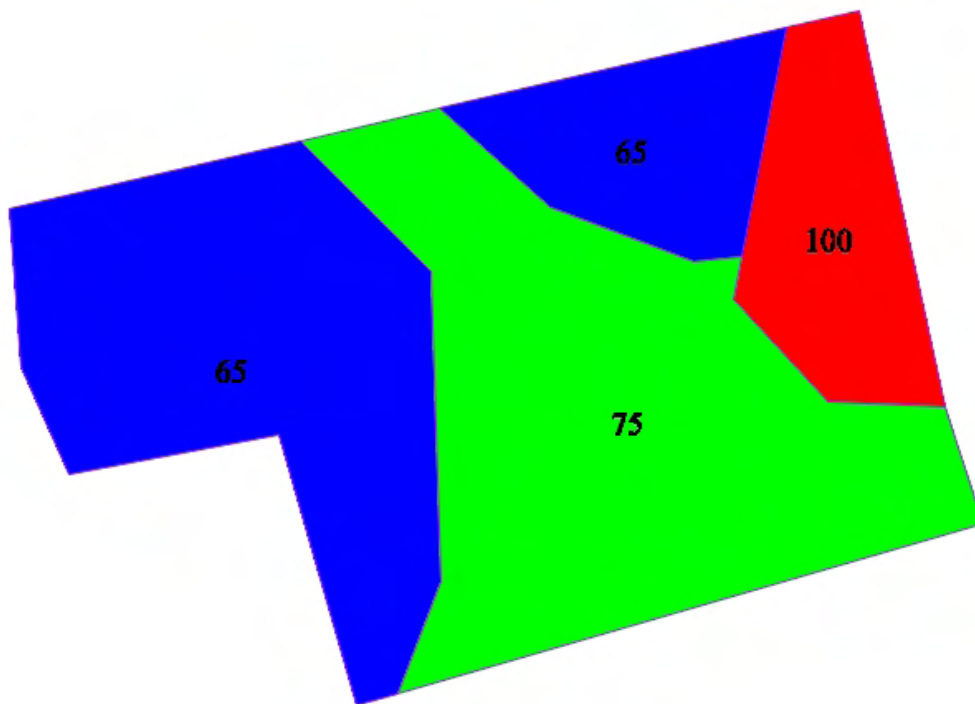


Figure 1: Graphical presentation of the planned task.

The taskfile downloaded to the TC via GPRS connection

Notes on XML nodes:

task=whole task

ccl=comment

frm=farm

zon=treatment zone declaration

tzn=treatment value percent

pln=polygon area on the field , treated with tzn amount of treatment

```
<TASK>
<CCL>Uutela Task 2008 6.5.08</CCL>
<CCL>4 areas:65,100,65,75 </CCL>
<FRM>MTT Vakola</FRM>
<ZON>
<TZN>65</TZN>
<PLN>24.335710092,60.4815246905 24.3354425173,60.4814864006
24.3349455081,60.4823369012 24.3336179977,60.4822143791 24.3333114946,60.4825484653
24.3332358897,60.4830499147 24.3350844244,60.4832628914 24.3359224578,60.4828529856
24.3359803181,60.4818770481 24.335710092,60.4815246905</PLN>
</ZON>
<ZON>
<TZN>100</TZN>
<PLN>24.3379001495,60.4828977976 24.338184168,60.4836200247
24.3386388805,60.4836724139 24.3391851371,60.4824254967 24.3384406452,60.4824427273
24.3378474974,60.4827639093 24.3379001495,60.4828977976</PLN>
</ZON>
<ZON>
<TZN>65</TZN>
<PLN>24.3379001495,60.4828977976 24.3375866247,60.4828840689
24.336674511,60.4830529365 24.335969901,60.4833649106 24.338184168,60.4836200247
24.3379001495,60.4828977976</PLN>
</ZON>
<ZON>
<TZN>75</TZN>
<PLN>24.335710092,60.4815246905 24.3359803181,60.4818770481
24.3359224578,60.4828529856 24.3350844244,60.4832628914 24.335969901,60.4833649106
24.336674511,60.4830529365 24.3375866247,60.4828840689 24.3379001495,60.4828977976
24.3378474974,60.4827639093 24.3384406452,60.4824427273 24.3391851371,60.4824254967
24.3394314399,60.4820570968 24.335710092,60.4815246905</PLN>
</ZON>
</TASK>
```

The IECU (Implement ECU) commanding

The commanding of the IECU can be made through task file, but it is also not yet fully implemented. In the present system the IECU commands concerning the devices' initial settings is made by calling the library functions of the iecu (Agrixbox , made by TKK). An example below:

Example of IECU commanding

Initial values for DDIs and ElementIDs

```
isobus.initSet(0, 0, 35, 3); // dev=0, index=0, DDI=35, ElementID=3
isobus.initSet(0, 1, 11, 2);
isobus.initSet(0, 2, 633, 6);
isobus.initSet(0, 3, 633, 7);
isobus.initSet(0, 4, 600, 5);
isobus.initSet(0, 5, 35, 4);
isobus.initSet(0, 6, 11, 14);
isobus.initSet(0, 7, 36, 18);
```

```
isobus.step();
```

```
isobus.writeSet(0, 0, 1000000); //rate
isobus.writeSet(0, 1, 0);      //area cleared
isobus.writeSet(0, 2, 100);    //agent 1 units/m2
isobus.writeSet(0, 3, 200);    //agent 2
isobus.writeSet(0, 4, 1);      //job type
isobus.writeSet(0, 5, 741126); //ppm
isobus.writeSet(0, 6, 53600);  //area , m2
isobus.writeSet(0, 7, 3000);   //envtemp
```

Triggers read from IECU during the test (0-7):

rate, totflow, speed, msrate1, msrate2, flow1, flow2, area.

Triggers read at the end of test (8-12):

l/ha, liter, speed, flow1, area.

These 8 triggers are read during the operation, on time basis 1 per second. Final 4 triggers are read at the finishing point of the work. The trigger values are recorded on TC memory and sent to the FMIS server via wireless internet.

Log file structure

The PCs log file contains the following data:

timestamp

longitude x

latitude y

treatment zone

triggers 0...7

some TC technical data

triggers 8...12 in the end.

The spraying task execution

The spraying operation took 28 minutes, and it was logged on TC memory on rate of 1 Hz.

Below there is an example of the log file that was sent back to FMIS server from the field via GPRS connection:

```
5/9/08 11:27:33 PM,24.3351716666667,60.482855, 65,0,3186,2452,0,0,1390,2781,0, 00001111
5/9/08 11:27:34 PM,24.3352166666667,60.4828616666667, 65,0,3186,2452,0,0,1390,2781,0, 10000000
5/9/08 11:27:35 PM,24.33526,60.4828683333333, 65,0,3186,2408,0,0,1390,2781,0, 00001111
5/9/08 11:27:36 PM,24.33526,60.4828683333333, 65,0,3186,2408,0,0,1390,2781,0, 10000000
5/9/08 11:27:37 PM,24.33535,60.48288, 65,0,3186,2469,0,0,1390,2781,0, 00001111
5/9/08 11:27:38 PM,24.3353933333333,60.4828866666667, 65,0,3186,2469,0,0,1390,2781,0, 10000000
5/9/08 11:27:39 PM,24.3354366666667,60.4828916666667, 65,0,3186,2430,0,0,1390,2781,0, 00000111
5/9/08 11:27:40 PM,24.3354816666667,60.4828983333333, 65,0,3186,2430,0,0,1390,2781,0, 10000000
5/9/08 11:27:41 PM,24.335525,60.4829033333333, 65,0,3186,2491,0,0,1390,2781,0, 00000111
5/9/08 11:27:42 PM,24.3355716666667,60.48291, 65,0,3186,2491,0,0,1390,2781,0, 10000000
5/9/08 11:27:43 PM,24.33562,60.48292, 65,0,3186,2633,0,0,1390,2781,0, 00000111
5/9/08 11:27:44 PM,24.33562,60.48292, 65,0,3186,2633,0,0,1390,2781,0, 10000000
5/9/08 11:27:45 PM,24.3357116666667,60.4829283333333, 65,0,3186,2619,0,0,1390,2781,0, 00000111
5/9/08 11:27:46 PM,24.3357566666667,60.4829333333333, 65,0,3186,2619,0,0,1390,2781,0, 11000000
5/9/08 11:27:47 PM,24.3358,60.4829383333333, 75,0,3186,2469,0,0,1390,2781,0, 00000011
5/9/08 11:27:48 PM,24.3358433333333,60.4829433333333, 75,0,3186,2469,0,0,1390,2781,0, 11000000
5/9/08 11:27:49 PM,24.3359333333333,60.482955, 75,0,3186,2422,0,0,1390,2781,0, 00000011
5/9/08 11:27:50 PM,24.3359816666667,60.4829616666667, 75,0,3186,2663,0,0,1390,2781,0, 11100000
5/9/08 11:27:51 PM,24.3360316666667,60.4829666666667, 75,0,3186,2663,0,0,1390,2781,0, 00000001
5/9/08 11:27:52 PM,24.3360833333333,60.4829733333333, 75,0,3186,2816,0,0,1390,2781,0, 11100000
5/9/08 11:27:53 PM,24.336135,60.4829816666667, 75,0,3186,2816,0,0,1390,2781,0, 00000001
5/9/08 11:27:54 PM,24.3361866666667,60.4829883333333, 75,0,3186,2861,0,0,1390,2781,0, 11100000
5/9/08 11:27:55 PM,24.3362383333333,60.482995, 75,0,3186,2861,0,0,1390,2781,0, 00000001
5/9/08 11:27:56 PM,24.3362916666667,60.4830016666667, 75,0,3186,2916,0,0,1390,2781,0, 11100000
5/9/08 11:27:57 PM,24.336345,60.4830083333333, 75,0,3186,2916,0,0,1390,2781,0, 00000001
5/9/08 11:27:58 PM,24.3364,60.4830166666667, 75,0,3186,3013,0,0,1390,2781,0, 11100000
```

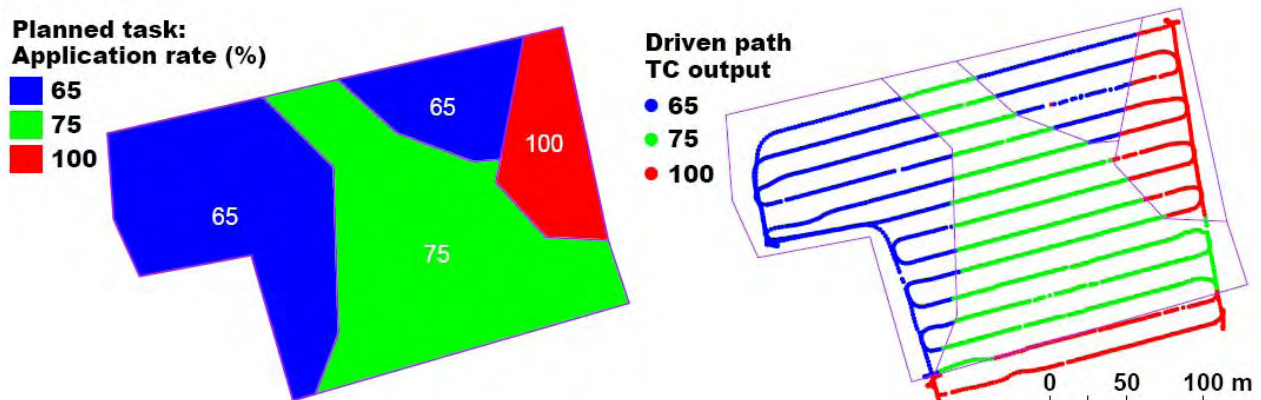


Figure 2: The planned task and the graphical presentation of the realised spraying work result in the field (MTT Vihti / Utela field).

Appendix V

Internet questionnaire; introduction and questions

InfoXT future scenario site (*introduction*)

Objective of InfoXT project is to create the basic recommendations and guidelines for a novel, intelligent integrated information and decision support framework (system architecture, etc.) for planning and control of mobile working units. The work is done through developing and extracting Nordic knowledge and know-how concerning the use of modern ICT and information management in a mobile environment of crop production.

New automation, ICT and GIS technologies provide solutions for steering and controlling mobile working units in site-specific production systems to fulfil requirements of safe, efficient, environment friendly and traceable production. Enhanced quality and efficient performance of work tasks require, however, organizing a user-centric on-line support which is based on open system solutions.

A scenario in the video below describes how a fungicide spraying work could possibly be executed in the future. Fungicide spraying is a demanding, complicated and very information intensive work task. Therefore, it has been chosen here as a study case. The technological system shown in the video is a prototype, so, please, do not pay too much attention to the layout of the user interfaces, but to the functional features of the system concept.

[Watch the video](#)

We would like to invite you to evaluate in the video described spraying technology by answering to the multiple choice questionnaire below.

[Questionnaire](#)

Thank you for your effort!

InfoXT project group

Questionnaire

The questions cover evaluation of the partial functions of the spraying work and the whole system. It is assumed in the questions that in the video described solutions will be standard technology in agriculture.

Please, watch the video first. (You can open it from the link on InfoXT future scenario site).

After watching the video, please, answer the following questions.

Answers: yes/no

Preparations in the farm

- Receiving spraying task and weather information wireless to tractor cabin is useful. (*Top claim 1,3, CTD 1 2, 4 in the conceptual map of AFMIS usability case*)
- Downloading of spraying task and weather information to tractor cabin is fluent. (*Top claim 1, CTD 2*)
- Possibility to choose the field to spray just before tank filling is a necessary feature. (*Top claim 1, CTD1*)

Tank filling in the farm yard (Top claim 1, 2)

- A feature to change spraying task in the tank filling situation has a lot of use. (*Top claim 1,3, CTD 1, 4*)
- Automatic calibration increases trust in the system. (*Top claim 2, CTD 5*)
- Automatic calibration makes work easier and speeds it up. (*Top claim 2, CTD 6*)
- The system keeps the user aware of the situation during the calibration. (*Top claim 2, CTD 5*)
- Tank filling instructions given by the system help to use fungicide efficiently. (*Top claim 2, CTD 6*)

Beginning the work in the field

- The system's separate transport and field modes improve the managing certainty. (*Top claim 2, CTD 5*)
- The system makes it fluent to begin the work. (*Top claim 2, CTD 6*)

Spraying

- The driver is able to follow that the work proceeds in an expected way. (*Top claim 1, 2*)
- Site-specific application is important from the point of view of efficient use of inputs. (*Top claim 2, 3, CTD 4, 6*)
- Comparison between the appearance of the growth and executed application rates site-specifically during the driving helps the driver to deepen the knowledge of the farming process. (*Top claim 3, CTD 4*)
- Collecting notes in the connection of spraying brings added value to farm management. (*Top claim 2, CTD 3*)

Finishing the work in the field

- Summary of the executed work generated by the task controller already in the field is important from the point of view of organizing the further work tasks. (*Top claim 1, CTD 2*)
- Summary of the executed work generated by the task controller is important from the point of view of evaluating the success of the work. (*Top claim 2, CTD 5*)
- Sending document information of the spraying task to farm database straight from the field is a desired feature. (*Top claim 1, CTD 1,2*)
- Exact site-specific data from the spraying execution and during the spraying made notes together support the cultivation planning. (*Top claim 2, CTD 3*)

Overall evaluation (Choose one of the choices)

Do you find execution of the spraying task in a video described way meaningful? (*Top claim 3, CTD 5*)

- The described way of executing a spraying task will be common in the future.
- The described way of executing a spraying task will be used by only a few farmers.
- I do not see this way of action to become common.
- Does the described way of spraying execution support the development of professional know-how? (*Top claim 3, CTD 4*)
 - It creates new kind of professional know-how.
 - It does not have any effect to professional know-how.
 - The farmer will need less professional know-how when using the describer way of spraying.
- Does the described system support the information exchange between farmers? (*Top claim 3, CTD 5*)
 - Sharing farming process data controlled between the farmers brings additional value to farming business.
 - Sharing farming process data does not have any effect on farming.
 - Sharing farming process data insults farm's privacy.

Obligatory

I belong to the following group:

- Farmer
- Contractor
- Agricultural advisor
- Machine or device manufacturer
- Software manufacturer
- Communication services
- Other organization or person

Following facts describe my background as a farmer: (only to farmers)

- Size of the farm: < 50, 51 – 100, 101 – 200, 201- 300, > 300
- Number of workers in the farm: 1, 2-3, 4-10, >10
- I have experience of using precision farming techniques: Yes/ no

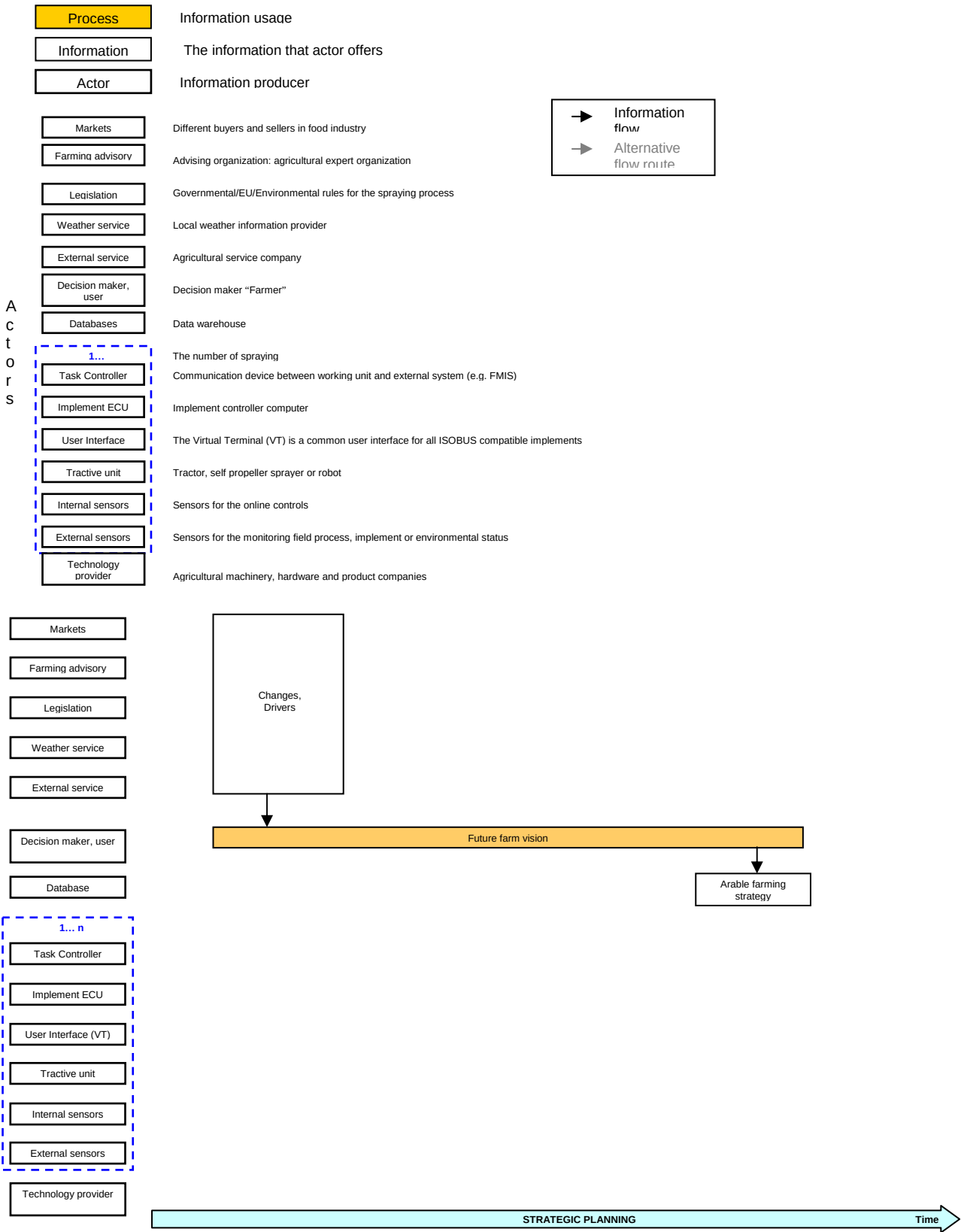
I got information about the answering link from:

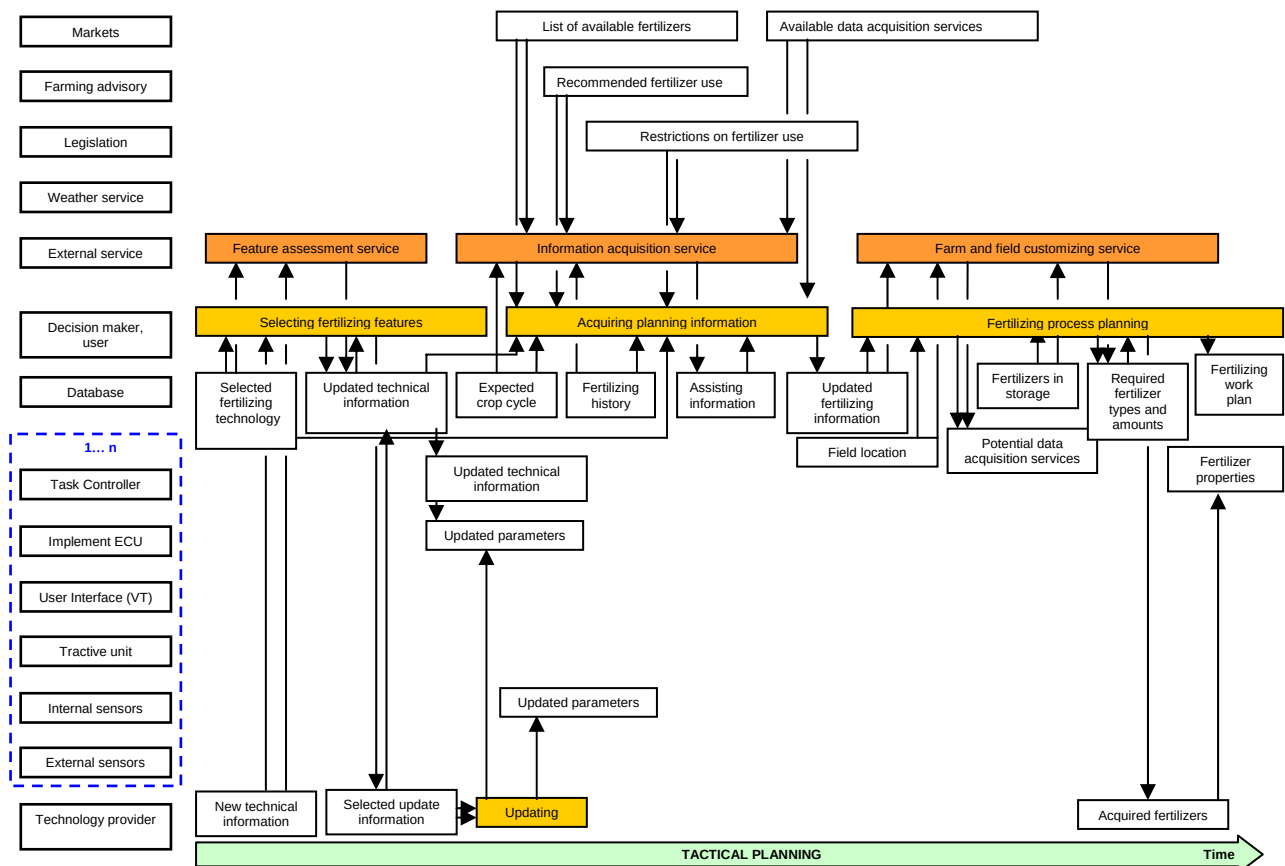
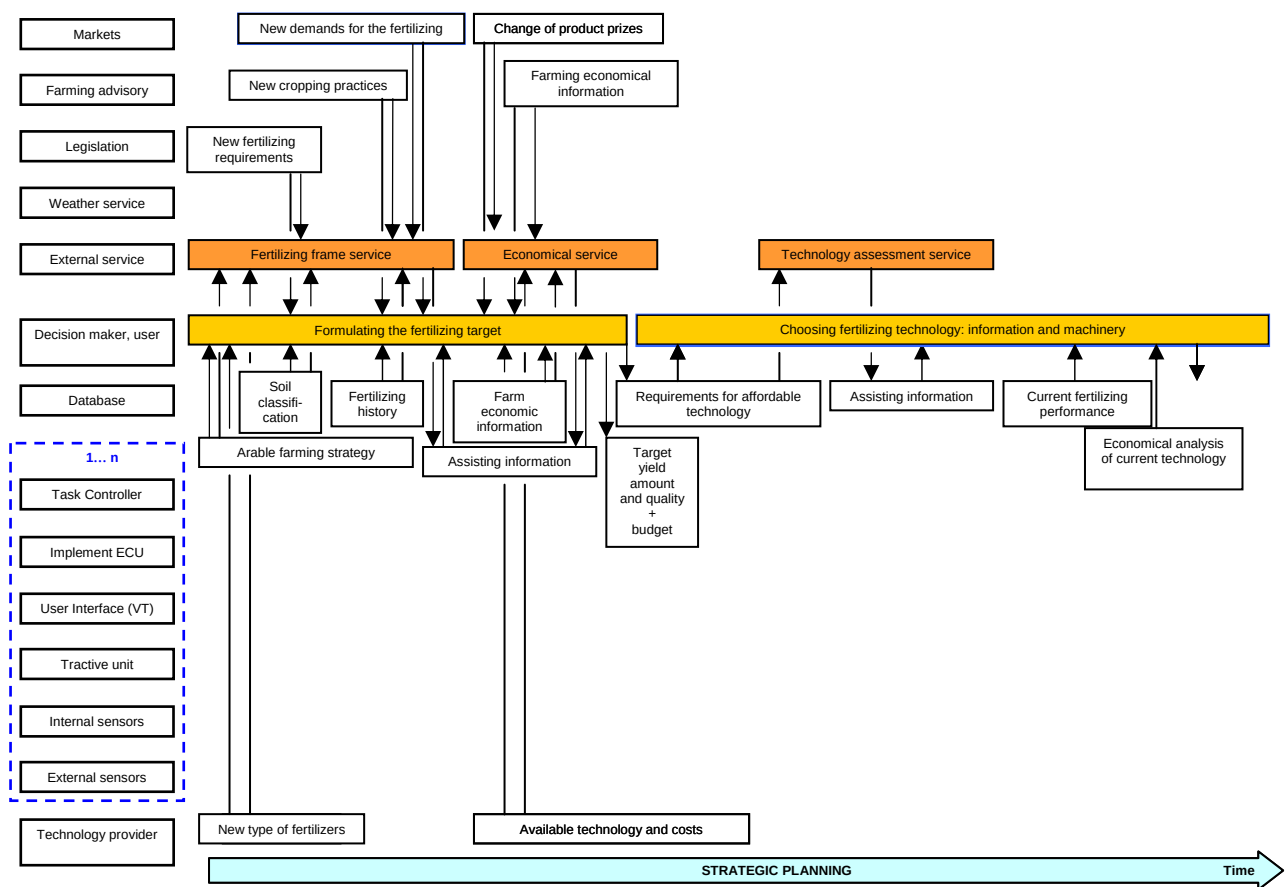
- professional magazine
- to the profession connected net sites
- public event
- acquaintance's/colleague's hint

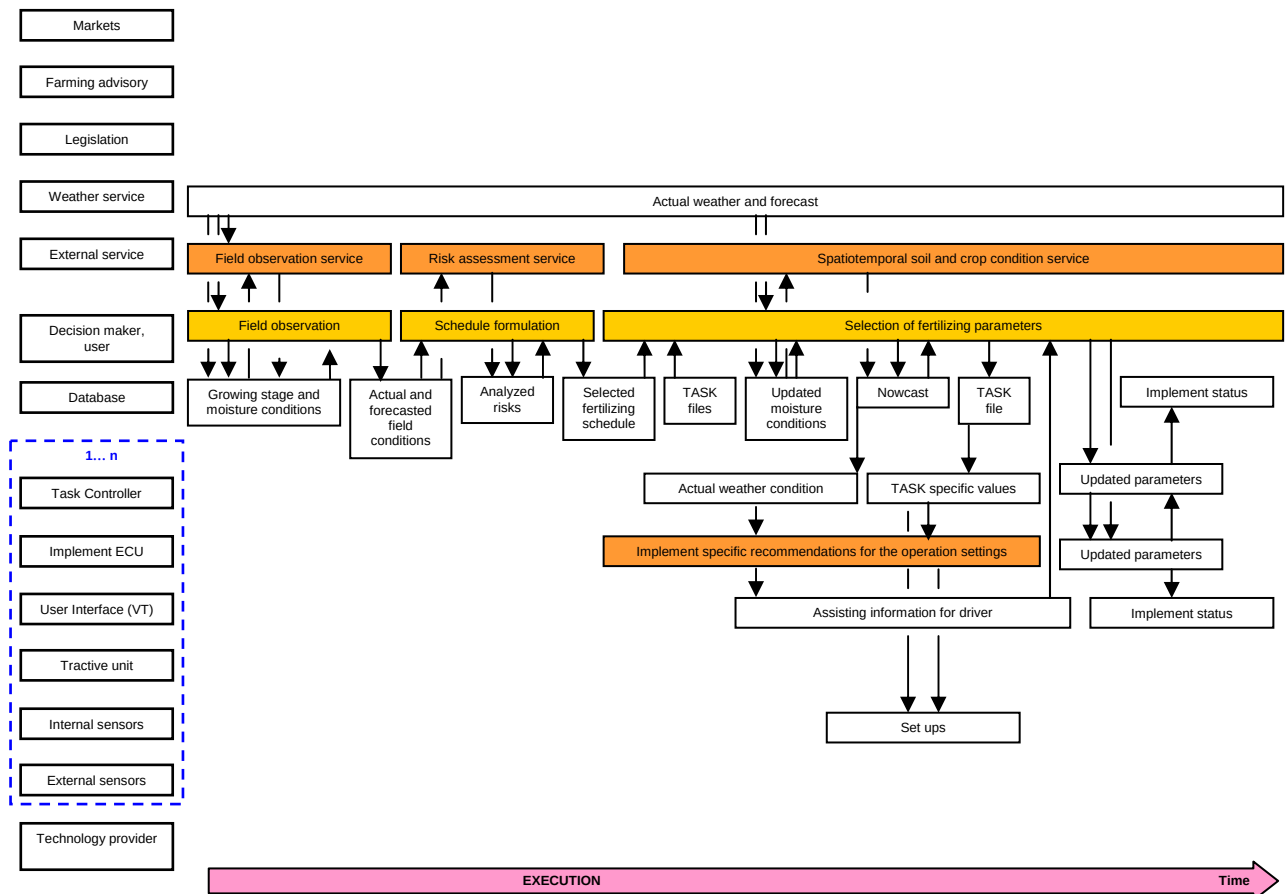
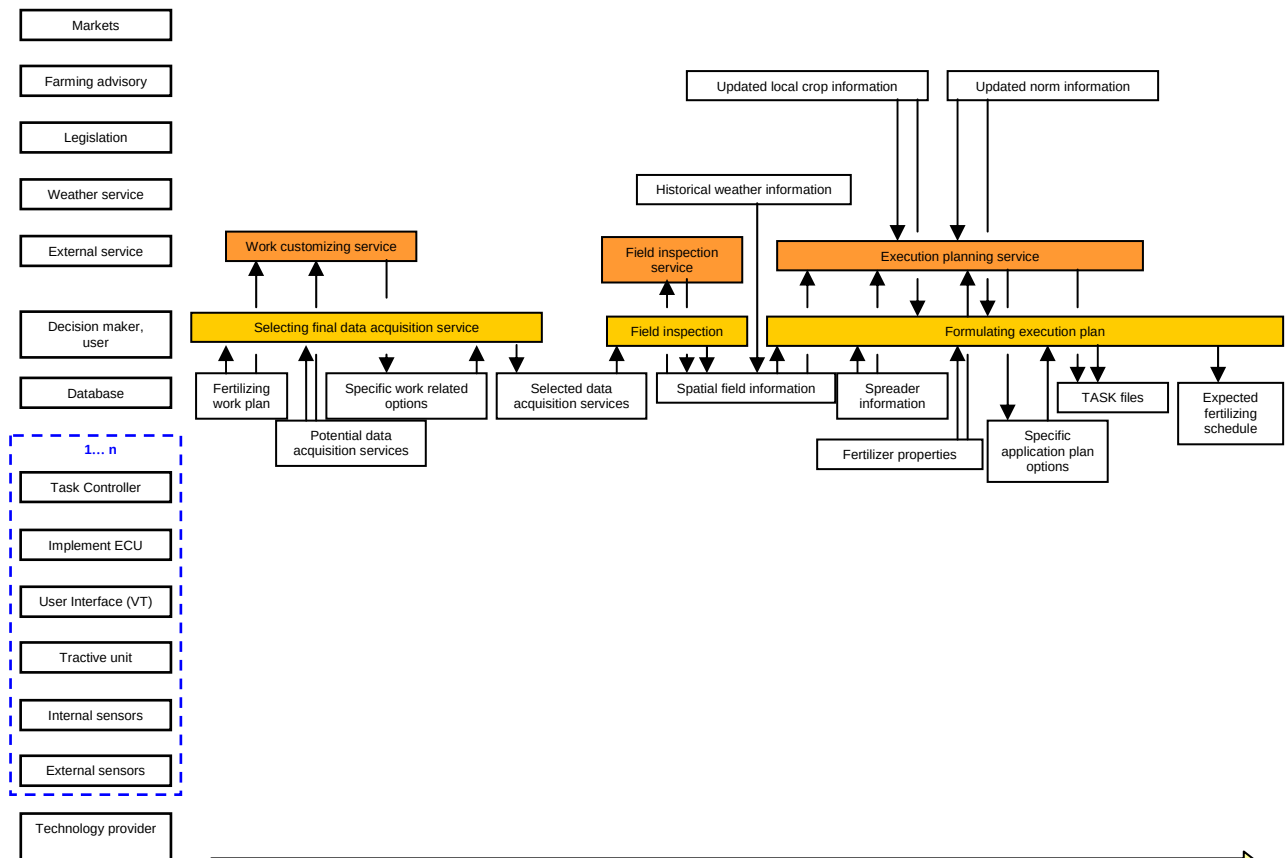
My home country is:

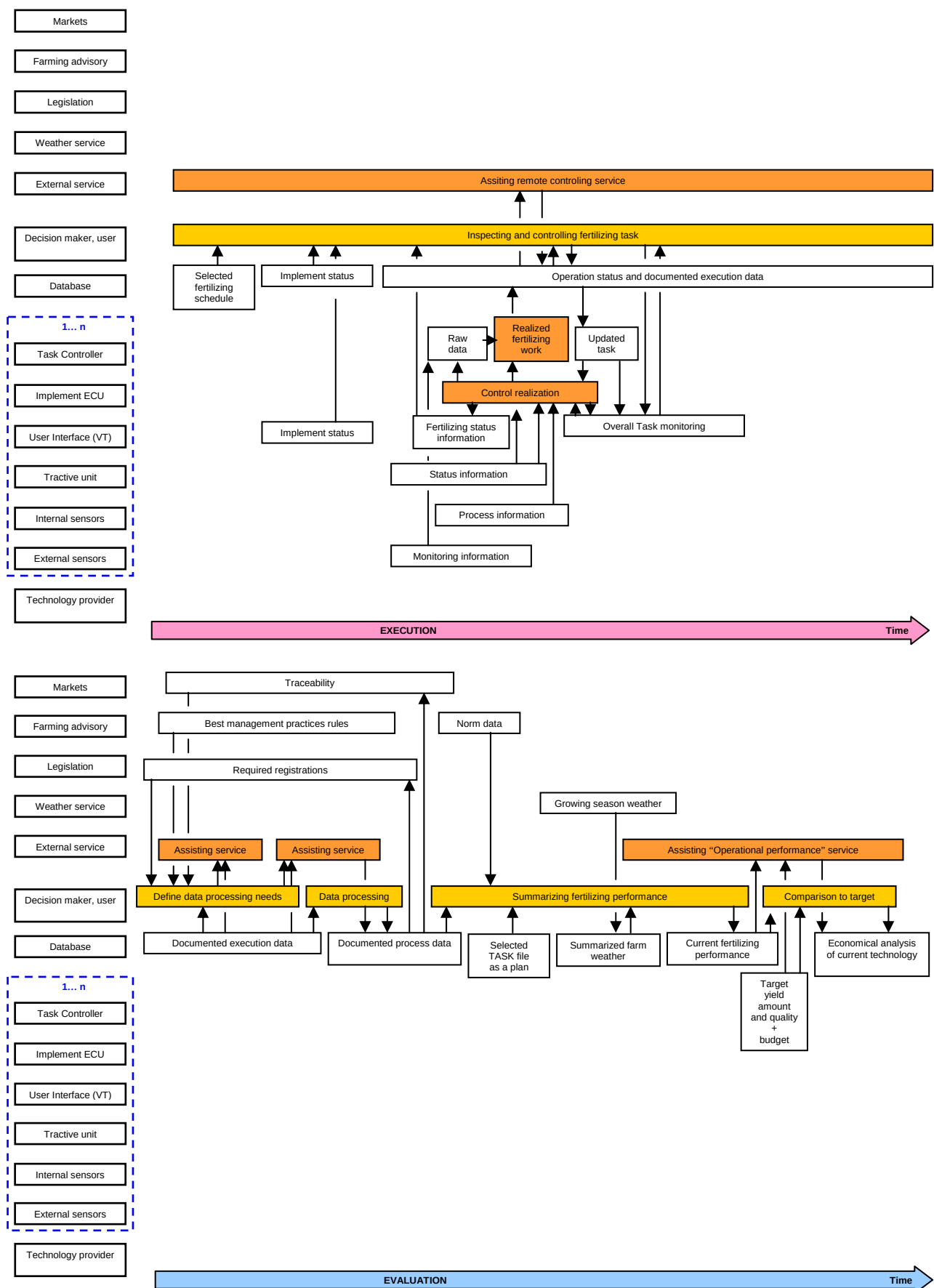
Appendix VI

Information flow model of fertilization according to the new information management system concept











norden

Nordic Innovation Centre

Nordic Innovation Centre

The Nordic Innovation Centre initiates and finances activities that enhance innovation collaboration and develop and maintain a smoothly functioning market in the Nordic region.

The Centre works primarily with small and medium-sized companies (SMEs) in the Nordic countries. Other important partners are those most closely involved with innovation and market surveillance, such as industrial organisations and interest groups, research institutions and public authorities.

The Nordic Innovation Centre is an institution under the Nordic Council of Ministers. Its secretariat is in Oslo.

For more information: www.nordicinnovation.net