Information Systems and Management for Future Farming

Claus G. Sørensen[1] and Dionysis D. Bohtis[1]

[1]University of Aarhus, Faculty of Agricultural Sciences, Department of Agricultural Engineering, Blichers Allé, 8830 Tjele, Denmark, Claus.Sorensen@agrsci.dk

ABSTRACT

Agriculture and farmers faces a great challenge in effectively manage information both internally and externally in order to improve the economic and operational efficiency of operations, reduce environmental impact and comply with various documentation requirements. In order to meet this challenge, the flow of information between decision processes must be analysed and modelled as a prerequisite for the subsequent design, construction and implementation of situated information systems and decision support systems. The results from the study have included the derivation of a baseline farm management information system (FMIS) supporting operations management and the use of farm management standards for production as well as monitoring and compliance. An analysis of the farm manager has identified the internal as well as external conflicts and problems that the farm manager currently faces. Based on this analysis, the boundaries of the FMIS were defined and within the context of these boundaries, a description of the proposed system was derived and a conceptual model was set up. Specifically, it is shown how an operational management tool like fleet management can be integrated with the overall FMIS, supporting both off-line and on-line planning and scheduling.

Keywords: System analysis, enterprise resource planning, fleet management, field logistics, farm activity monitoring, Denmark

1. INTRODUCTION

The managerial tasks for arable farming are currently transforming into a new paradigm, requiring more attention on the interaction with the surroundings (e.g. environmental impact, terms of delivery, and documentation of quality and growing conditions) (e.g., Sigrimis et al., 1999; Auernhammer, 2001; Dalgaard *et al*., 2006). Among other things, this managerial change is caused by external entities (government, public) applying increasing pressure on the agricultural sector to change production from a focus on quantity to an alternate focus on quality and sustainability (Halberg, 2001). This change has been enforced by provisions and restrictions in the use of production input (e.g. fertilisers, agrochemicals, etc.) and with subsidies as an incentive for the farmer to engage in a sustainable production. In general, this change of conditions for the managerial tasks on the farm has necessitated the introduction of more advanced activities monitoring systems and information systems to secure compliance with the restrictions and standards in terms of specific production guidelines, provisions for

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environmental compliance, management standards as prerequisites for subsidies, etc. Until now, the farmers most often have dealt with this increased managerial load by trying to handle a bulk of information in order to make precise decisions. The increasing use of computers and the dramatic increase in the use of the internet have to some degree improved and eased the task of handling and processing of acquired external information but still, the acquisition and analysis of available information have proven a demanding task, since information can be scattered over many sites and not necessarily interrelated and collaborative. Specific attempts to improve this situation has included the launch of "web-based collaborative information system" developments, combining different information components (models, data, text, graphics) from different but collaborating sources (Jensen et al., 2001). However, such systems still has to be enhanced in terms of collaboration with automated acquisition of operational farm data and integration with the overall Farm Management Information Systems (FMIS).

Advances in information and telecommunication technologies (ICT), like positioning system and sensors for monitoring of machinery performance or biomass status, will allow farmers to acquire vast amount of site-specific data which ultimately can be used to enhance decision-making (Blackmore, 2000; Cox, 2002; Fountas et al., 2006). Currently however, much information collected by use of sensors or by manual registrations is not used, due to data logistic problems, leaving a gab between the acquiring of such data and the efficient use of this in agricultural management decisions making (Atherton *et al,*. 1999; Pedersen et al., 2004; Reichardt & Jurgens, 2006). Costs of time managing the data in many cases outweigh the economical benefits using data, why, for example, future use of wireless communication is very much in the demand (Speckman, 2001; Jensen et al., 2007). In all a refined and integrated solution to analysing and transformation of the acquired data is needed to improve decision making in the future (Fountas et al., 2005).

With the current transformation of the agricultural sector, additional demands on the precision and integration of the planning and control functions have occurred, requiring that the planning tasks needs to consider the dynamic interaction of machine, biological, and meteorological conditions. This resembles the industrial adoption of computer-integrated manufacturing (CIM) and it's embracing of customised production followed by dynamic operations planning and control of operations. The industry has demonstrated how effective an integrated control of work operations can be, based on on-line measurements combined with database and decision support information. In this regard, it has been shown that the enhancement of FMIS is more influenced by common business factors and drivers than specific farming activities (Lewis, 1998). Plan generation and execution of farm operations must be linked with a system monitoring effects of actions, unexpected events and any new information that can attribute to a validation, refinement, or reconsideration of the plan or goal. Plans must be presented in a conditional way, such that supplementary knowledge from observations, databases, sensors, and tests can be incorporated and integrated to revise the plan in the light of new information. This involves an extended use of modelling and simulation as opposed to providing a generalized optimal solution (Attonaty et al. 1999; Ohlmer, 1998).

By specifying in detail the information provided and the information required for the information handling processes, 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 supporting service information systems. The information flows may be contextualised on different levels and in different details (e.g. Fountas et al., 2006, Sørensen et al., 2007).

The perspectives of applying modern information technologies in bioproduction involve a novel integrated information and decision support framework for planning and control of technology in crop production. The framework will guide the evolutionary process of adapting new technologies and their connection with decision making as a way of supporting the goals of optimised resource inputs, reduced environmental impacts, increased product quality and reduced costs. At the same time, an increased IT-adoption as a function of management proficiency is envisioned.
The vision is conditioned on the current and future advances in information technology, which are creating the potential for substantial change in management and decision making concerning the planning and use of field machinery. These advances include improving possibilities for automatic geo-referenced and time stamped data acquisition during fieldworks (e.g. Steinberger, 2009). The hypothesis is that such data could be used in a new setting, enabling a nearly automatic and substantial better system oriented operations management on all planning levels, ranging from the strategic through the executive level. Also, viewed as a significant novel approach, it is expected that it will be possible to establish on-line control of field operations based on sensor measurements combined with information from databases and decision support. The required information must be valuated and structured by arranging in suitable databases related to the different planning levels, machinery items, fields, crops, etc. Concurrently, decision support models, involving decision making under uncertainty, must be developed and integrated in the information system.

2. MANUFACTORING VS. AGRICULTURAL OPERATIONS

The basis for the following description is the operations management task found either within the commodity oriented or the service oriented firm. Further more, this description provides the foundation for a comparison with the principles of operations management in agriculture, and specifically in arable farming. Differences and equalities are presented and used as guidelines when the requirements to which a model for the operational planning and control of field operations has to apply are identified.
At specific times in the crop-growing season, the farmer will face the problem of deciding which operations to invoke, as well as when to do so and with what intensity. In practice, the farmer can solve this problem by using his experience to decide when to start executing a specific operation and by assigning labour and machinery to such an operation. Once the execution of operation has been initiated, it may be stopped due to events like rainy weather, shortage of crop to process, machine failures, etc. The dynamic nature of this domain requires from the farmer to constantly reassess the previous strategies and make new ones. At each decision stage, a decision will be made on the basis of the current state of the system, some dedicated prognosis and according to some implicit decision criterion. The results of the executed operations are a transformation of the crops or soil, thereby changing the state of the system.
This planning process goes on throughout the whole growing season, but decision support will be required most in the so-called peak load periods, where one or perhaps a number of operations have to be executed within a narrow time limit, determined by the development of the crop, the weather, etc. Analyses have shown that as much as 40-50% of the annual work load may be concentrated in the period of harvesting and sowing of winter crops, while in the period of soil preparation and sowing 10-15% will be required (Sørensen, 1999)

An important aspect of agricultural operations management is that it has to comply with the constraints formed by the stochasticy of the production system in terms of availability and capacity of the labour and machinery resources, the biological attributes of the crop and soil, and the development of the weather. Specific uncertainties abide to:

- Weather as the cause of varying crop-specific and machinery-specific workability, timeliness, trafficability, etc.
- Unknown yield or input demand for plant care, due to uncertainty factors inherent to the pant as a living organism (different response to the same conditions).
- Machinery performance and reliability
- Labour availability (e.g. seasonal low-wage labour and productivity (unskilled labour)

In manufacturing, the machines are stationary while the object to be processed is moved around by transport systems. In an agricultural setting, the machinery items are highly mobile and are relocated to the object (e.g. plant, soil, etc.) which is to be processed. In spite of the conceptual equivalence, there are fundamental differences between industrial and agricultural production processes. In an industrial production process, the environment is controlled. Also, the manufactured products of a certain type are identical with respect to their significant parameters. In agricultural processes, neither of these characteristics is true. The resource demand may be unknown at the planning stage, or only a probability estimate is available. For example, the yield map is not known before harvesting but it drives the entire process evolution by influencing the time instants when a harvester's tank is filled and must be unloaded. Furthermore, many of the process parameters depend on the field coverage patterns and the skills and coordination of the machine operators.

On a general level, the agricultural management task is different from the industrial one in a number of aspects:

- The preponderant role of the environment, and the inherent uncertainty and risk (e.g. crop growth, weather conditions), characterising any farm process by incomplete information or by uncertainty.
- Agricultural processes involve continuous processes as well as discrete events
- The domain variables have relatively large variances
- The planning procedure has large time- constants
- Complexity in evaluating risky decisions
- Agricultural operations can be halted by the weather conditions, and consequently the job will be divided into part jobs

However, it is also important to note that in industry there is an increasing recognition that planning and scheduling requires for the consideration of random fluctuations, uncertain environmental influences, etc. (Sørensen., 1999). Managing such uncertainties is becoming more and more important in an era of "time-based" competition, where, for example, manufacturing is increasingly becoming order-driven introducing more uncertainty into the planning process. Thus, in that sense the characteristics of industrial planning approach the one of agriculture, and new planning approaches involving uncertainties have been attempted.

In agriculture, there is only a sparse tradition for using formalised planning tools. That is contradictory to in industry, where there is a long tradition for explicit planning schedules comprising formalised documents passed down to the shop floor by the management section for implementation. Farmers, on the other hand, in general, both generate and execute any plan made, and their decision making process associated with the planning remains very much implicit and internal. The efforts aimed at developing agricultural planning support must be aimed at externalising and formalising the farmers planning effort, i.e. in this case the scheduling of field operations.

The generation and execution of plans must be linked in a system monitoring effects of actions, unexpected events and any new information that can attribute to a validation, a refinement, or a reconsideration of the plan or goal. The planning in a dynamically and non-predictive world like arable farming needs to be more robust than classical planning in a more static and deterministic domain. Plans must be presented in a conditional way, so that supplementary knowledge from observations, databases, sensors and tests can be incorporated and integrated to revise the plan in the light of such new information.

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.

3. FARM MANAGEMENT INFORMATION SYSTEM (FMIS)

Management information systems (MIS) is an integral part of the overall management system in an purposeful organisation comprising tolls like enterprise resource planning (ERP), overall information systems (IS), etc. ERP is an industry notion for a wide set of management activities which support all essential business processes within the enterprise. The management system support management activities on all levels as well as provide for the identification of key performance indicators (KPI's) (Folinas et al., 2009). Typically, ERP is integrated with a database system and will often include applications for the finance and human resources aspects of a business.

As a part of the ERP, the information system (IS) refers to data records and activities that process the data and information in an organization, and it includes the organization's manual and automated processes supporting the business processes (e.g. Buckland, 1991; Bidgoli, 2002). Information systems are the software and hardware systems that support data-intensive applications. Especially, information systems provide the possibility to obtain more information in "real-time" enabling a close monitoring of the operations performance and enhance the connection between executed operations and the strategic targets of the enterprise (Lyons, 2005; Folinas, 2007). However, in terms of deriving the requirements for the information system design, often targeted information systems lack a definitive formulation. Different stakeholders have different perspectives on what is and what is not the most important to be included in the design of an information system.

MIS differ from regular information systems because the primary objectives of these systems are to analyse other systems dealing with the operational activities in the organization. In this way, MIS is a subset of the overall planning and control activities covering the application of humans, technologies, and procedures of the organisation. Within the field of scientific management, MIS is most of ten tailored to the automation or support of human decision making (O'Brien, 1999). Figure 1 shows the conceptually decomposing of the different management systems in an organisation.

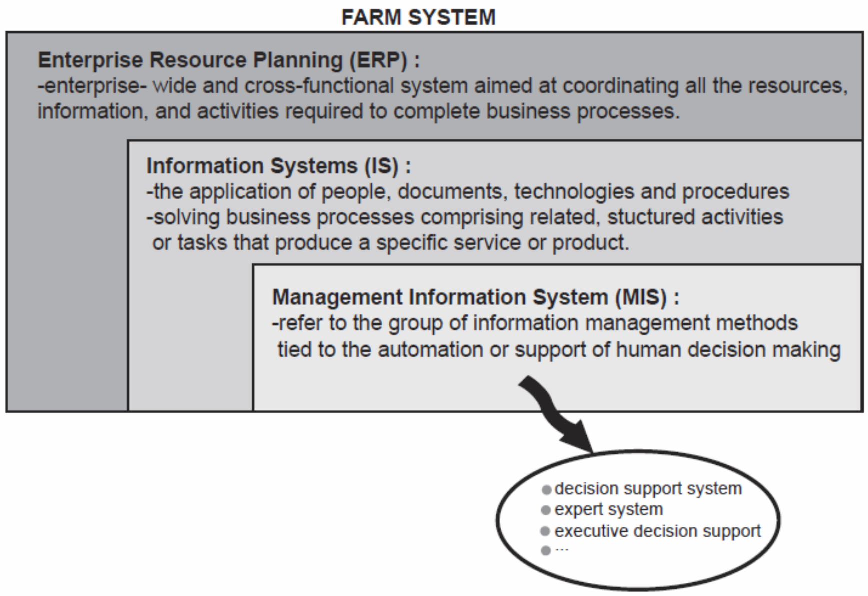

Figure 1. Concept of management information systems.

By following this conceptual framework and notation, a FMIS is depicted as a planned system of the collecting, processing, storing and disseminating of data in the form of information needed to carry out the operations functions of the farm.
Conceptual models of the system are built on the premises laid down in the definition of the system. The derivation of a conceptual model is the first step, indicating the concept of the information system to be designed. Although the analyse and model process can be elaborated in rather clear points, the outcome of each point is actually continuously changing as more knowledge is generated as a consequence of the improved understanding of the system.

3.1 Result

3.1.1 The current situation

The rich picture shown in Figure 2 illustrates the current situation with its problems and conflicts. As can be seen, system structure is very complex and many external as well as internal entities and partners have an interest in farming system.

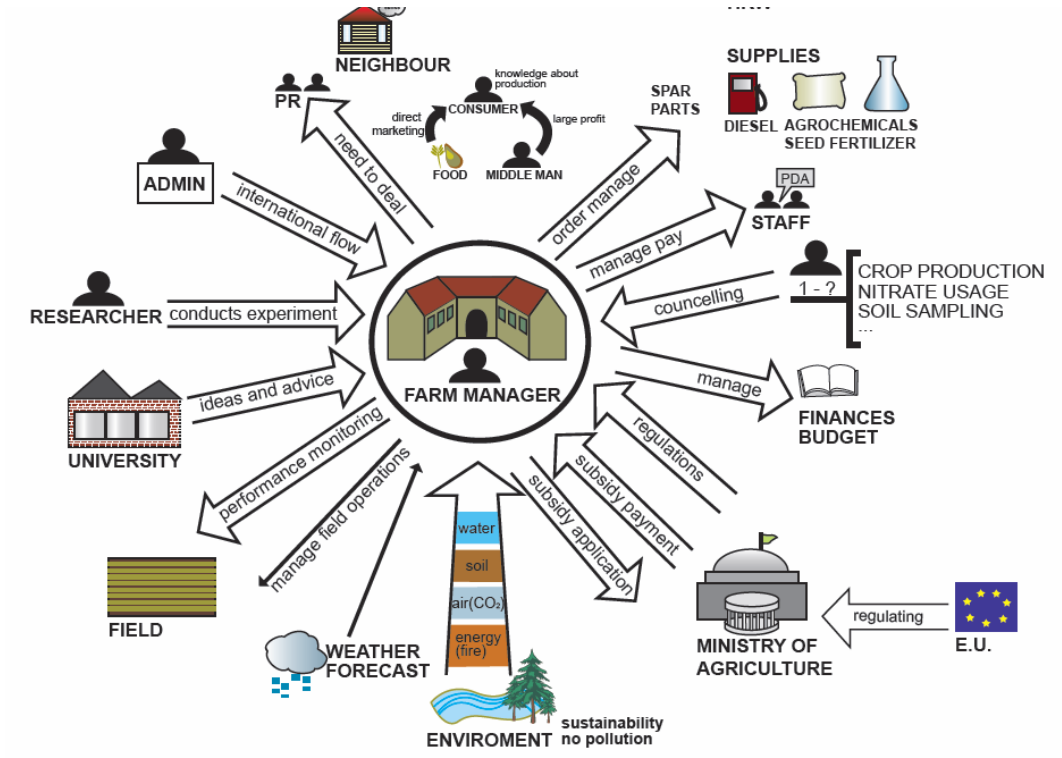

Figure 2. The current situation with internal and external conflicts and problems. The drawing is based on general elaborations and answers to questions posed to farm mangers and the point of view of external partners involved in the study. SW = soft ware, the dark clouds symbolise conflict or problems, whereas the think bobbles represent wants or need for the future.

In terms of information handling, the farmer needs to manage a lot of information in order to make economical and environmental sound decisions. Currently, this process is very labour intensive and for most parts, executed manually. The important concerns and problems voiced by the farm manager include the time consuming tasks of monitoring field operations, manage the finances and application for subsidies which is further complicated by the lack of integrated soft and hardware to manage this work and the lack of coordination when such programs do exists. Also, the farmer voice a need for additional information and advanced technologies to manage monitoring and data acquisition on-line in the field. When looking at the external concerns, it is seen that this mostly concerns the need for sustainable production of farm products, which is further pursued by regulations and the possibility to receive subsidies when more sustainable management practises are abided by. Table 1 lists some of the voiced concerns.

Table 1: Voiced concerns

System components	Description	Problem, considerations
Farm manager	Central decision maker at the farm	- often engulfed in routine tasks - no time to concentrate on strategic issues
Performance monitoring	Tasks or tools capable of collecting data/ information on activities and processes at the farm	- data/ information overload - no cross-linking of information - needs information in an automated and summarised fashion
External entities	Administration, district office, farmers' association, local affairs, customers (e.g. direct marketing), press and media, research facilities, producers of agricultural equipment (direct or through distributer), supplier of operating materials (like diesel, fertiliser, pesticides, etc.), EU	lack of synergy effects - understanding of farming is missing - markets very dynamic causing harm - communication with external entities not optimal - very complicated regulatory framework imposed - good communication with commercial partners - positive experience with direct marketing
Acquisition and marketing	The acquisition of auxiliary materials and the marketing of farm products	- lack of information on market - acquisition of auxiliary material confusing
Employment management	Planning and control of farm employee	- lack of easy accessible information employee performance, etc.
Counselling	Extension services, etc.	- lack of user-friendly software tools
External component The surroundings	the environment and relation with neighbours etc.	- low environmental impact - limited pollution - limit odour

3.1.2 Definition of the system

Definition of the system
Based on the boundaries identified above, the system will be defined. For this purpose, the elements of CATWOE is used (Bergvall_Kareborn et al., 2004). CATWOE is a mnemonic word representing the terms Customers (C), Actors (A), Transformation process (T), World-view (W), Ownership (O) and Environmental constraints (E). The derived situational elements of CATWOE are listed below.
Customers: The primary customer of the proposed information system is the farm manager and management system as the demanders of data for production and operations management. The secondary customers is the EU, certification bodies, retailers, etc., understood as entities setting up and imposing standards and other regulatory frameworks for the farm production, and benefitting from the improved crop production.
Actors: The actor is the one operating the information system, which in this case is the farm manager or other farm staff.
Transformation process: The transformation process involves the transformation of operational field data into a form, which can provide the foundation for decision making in crop production.
World view: The world view is the hypothesis that drives the information system development. In this case, the view is that operational data is easily acquired and can be use to improve management decision-making though out the production cycle.
Ownership: The farm manager is the owner in the way that he has every day decision maker responsibility, and decides whether the system is of use or not.
Environmental constraints: The constraints influencing the usability and performance of the information system includes the expectations of the entities imposing the standards and regulations on the farm, the requirements of the standards, the required data quality, the reliability and regulations of the information technology (communication devices, server, databases, etc.)
Summarised root definition
The root definition of the purposeful activity handled here is: “a farm management information system (owned and operated on farm level) to support real-time management decision-making and compliance of management standards, by means of automated acquiring and contextualising of operations data and external parameters (e.g. regulations, best management practices (BMPs)), market information, etc.) to form a foundation for operations management. In order to improve the quality of decision-making and reduce time effort”.
The conceptual model as derived from the definition of the system is shown in Figure 3. It depicts how the operational field data needs to be collected and transformed in an automatic way. The filtration of information (external as well as field operation data) is initiated by the manager according to the operational activity which is to be planned. Based on the obtained facts, the farm manager plans the operations and prepares for execution (e.g. the equipment or staff that is to carry out the operation) and a record of the actual executed operations will be stored. Subsequently, the farm manager can retrieve documentation reports using a dedicated search in the internal information.

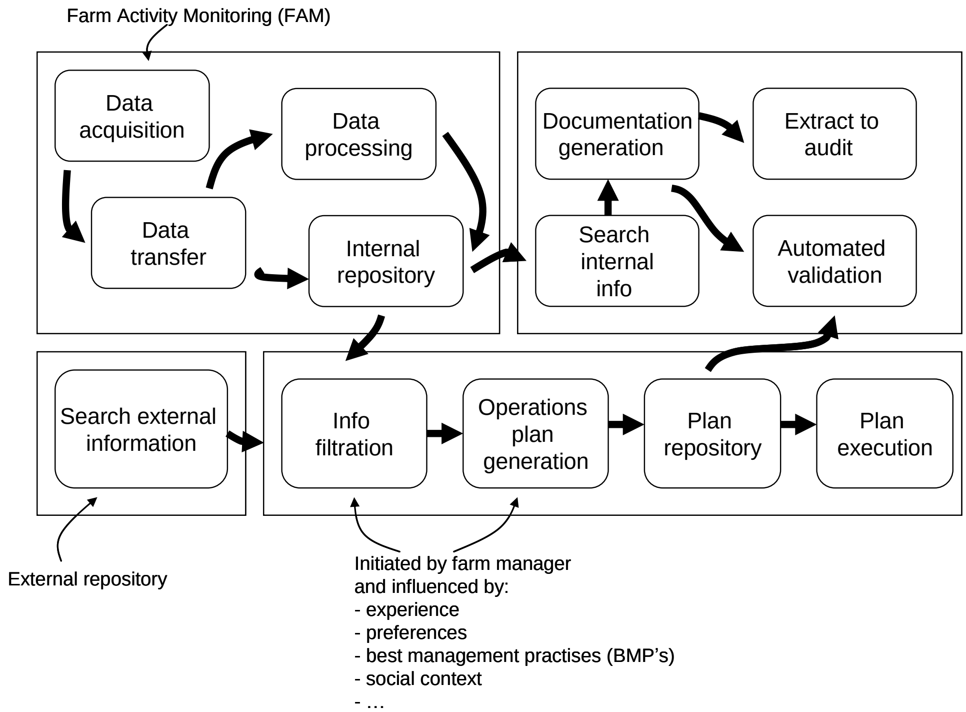

Figure 3. The concept of the FMIS to be developed with the needed processes (rounded squares), it is divided into four subsystems, internal data collection, external information collection, plan generation and report generation. The data collection and processing is an automated monitoring system, whereas the report and plan subsystems are to be initiated by the farm manager.

4. FLEET MANAGEMENT

As part of the management of the logistics, fleet management may be used as the practical tool managing a fleet agricultural machinery units to improve scheduling, operational efficiency, and effectiveness (Auernhammer, 2001). Additional, fleet management involves the process of supervising the use and maintenance of vehicles and the associated administrative functions including the coordination and dissemination of tasks and related information for the solution of scheduling and routing problems for teams composed of homogenous as well as heterogeneous units (Bochtis, 2008).

Recently, GIS-based (Geographic Information System) technologies have been developed to support agricultural fleet management decisions. In these systems, data are collected in real time and transferred via telemetric technologies to a central server providing the data base and the up-dated information to the decision maker which can be the farm manager or automatic decision systems. In the current GIS-based systems the following information, related to fleet management decisions, is monitored and transferred to the decision maker:

- Information regarding specific on-board mechanisms such as reel speed, chaff speed, threshing drum speed, concave position, cutting height etc. This information is used for the detection of blockages and the evaluation of the performance and healthiness of the mechanisms.
- Yield-specific information such as grain moisture and yield measurements for the documentation and traceability of the product uses.

- Geo-referenced information. The evaluation of the GPS selected data provides the performance of each individual unit (area coverage/ time unit, harvested biomass/ time unit, idle times, travel times between fields etc.) and consequently of the whole system.
- Unit's remote diagnostic check. Information is transferred regarding the engine hours, engine load, diesel tank level, engine speed, hydraulic oil temperatures, engine coolant temperature etc.

In these multiple-machinery GIS-supported systems two different management types should be addressed: off-line management and on-line fleet management.

4.1 Off-line vs. On-line

The off-line planning for agricultural fleet operations includes three layers of activities: search of operations history, rules identification, and initial planning. The first layer regards the historical data management on critical factors such as the labour and machinery input and the biological and meteorological conditions adhering to the operation in question. The second layer consists of the identification of the thresholds and events that are important to monitor, note and / or will activate automatic behaviours. Based on the identified rules, the evaluation of the historical data and the available recourses, an initial planning has to take place before the execution of the actual operation concerning required operations, operations urgency, formulation of jobs, operations specification, etc. Initial planning provides the appropriate machinery fleet size and composition, the machines allocation and scheduling of the given operation. It also allocates the fields (or field parts) to the currently available primary machines (e.g combines) of the fleet, it assigns these machines to the available supporting units (e.g. transport carts to combines) and to the number of the facility units (e.g. deposit or refilling units for the cases of harvesting and spraying / fertilizing, respectively) that will be used taking into account their type (e.g. mobile, non-mobile), their localization, capacity, cycle time etc.
Recently, powerful optimization methods have been adopted in order to deal efficiently with the inherent large number of the decision and state variables. Søgaard and Sørensen (2004) presented an approach involving the development of a non-linear programming optimisation model based on a level of aggregation consistent with the accessible and existing data related to machinery sets, crops, weather and timeliness of operations. Busato et al. (2007) developed a dynamic discrete event simulation model in order to optimise the wheat harvesting and transport operation accounting for field size and shape, field distance to silo, yield and resources available. A further approach of this system is presented in Berruto and Busato (2008) where the event-oriented simulation is combined with linear programming for biomass supply chain evaluation. The developed model considers the interaction among resources and the effect of a number of limiting factors on the performance of the whole chain. The tool is suitable for detailed evaluation of the system efficiency under many viewpoints (field yield, shape, size, transport distance and working chain composition). Furthermore, algorithmic approaches that can be the base for the previous tools have been presented related to field representation and coverage planning (Oksanen and Visala, 2007) and modelling for multi-machinery operations (Bochtis et al., 2009).

In order to incorporate the dynamic nature of the field operation, and the inherent uncertainties in many parameters (e.g., yield distribution), the adoption of a closed loop control system, which results in a sequence of planning, execution and re-planning, is suggested (Sørensen and Bochtis, 2009). As indicated, plan generation and execution must be linked in a system monitoring effects of actions, unexpected events and any new information that can attribute to a validation, a refinement, or a reconsideration of the plan. An important aspect is that supplementary knowledge from observations, databases, sensors, *etc*., can be incorporated in order to revise plans. The closed loop approach makes feasible the implementation of an on-line decision support system for the coordination of mobile machinery units operating in a field or in a number of geographically dispersed fields. This type of approach should be supported by algorithmic methods that can provide optimal solutions very fast (Bochtis and Vougioukas, 2008).

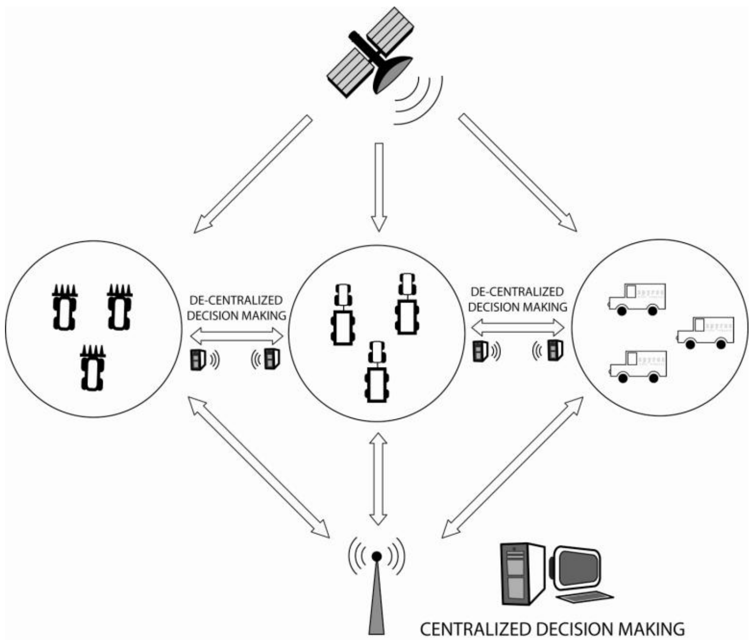

Figure 4. Basic architecture of an agricultural fleet management system

4.1 Centralized vs. De-Centralized Management

Centralized management systems provide the key advantage of globally optimal plans due to the fact that decision maker (human or automated system) can take into account all the relevant information conveyed by the members of the team. However, centralized approaches often involve intractable solutions for large machinery teams due to the complexity of the required algorithms for optimal global planning generation. Also, the requirements in terms of extensive machine-to-machine and centre-to-machine communication often mean that the real-time response is not feasible. On the other hand, a de-centralized management approach to agricultural fleet management architecture provides the advantages of a fast response to dynamic conditions and decreased communication requirements. In this way, an improved adaptation of the machines to the changing operational conditions is achieved, since this adaptation is carried out by locally sensing and responding to the environment.

Algorithms for scheduling, task allocation, machinery assignment, area coverage and route and path planning, should be distributed efficiently in terms of the balance between communication and computational requirements. For example, dynamic planning tools for area coverage planning for main units – *e.g*. harvesters, fertilizers, seeders- path planning for in-field service units- *e.g*. material transport carts- and routing for inter-filed transport units – *e.g*. transport carts- (Fig. 4) should be placed on-board in order to plan using both the a priory information provided by the centralized GIS system as well as the updated information of the local sensing measures.

6. CONCLUSIONS

The results from the study have included the derivation of a baseline farm management information system (FMIS) supporting operations management and the use of farm management standards for production as well as monitoring and compliance. An analysis of the farm manager has identified the internal as well as external conflicts and problems that the farm manager currently faces. Based on this analysis, the boundary of the targeted system was defined and within the context of these boundaries a description of the proposed system were derived and a conceptual model were set up. Specifically, it is shown how an operational management tool like fleet management can be integrated with the overall FMIS, supporting both off-line and on-line planning and scheduling.

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