Fleet management and coordination

by *Claus Grøn Sørensen*

DENMARK

1. Introduction

The structural development and the imposed requirements on agriculture imply that innovative technology and knowledge are decisive for the future arable farmer. Among others, the development is prompted by the invoking of EU regulation and actions plans (*e.g*. Environmental Technologies Action Plan, ETAP) as well as national environmental action plans increasingly marking the evolution of agriculture. In this regard, there is an urgent need for innovation and technological development, which will maximize the utilization of resources while at the same time maintain a sustainable development. The social importance of such a strategic development is significant as it may lay the ground for added value and jobs in adjacent businesses and other parts of the food sector.

A preliminary step in this direction is a renewed focus on the usage of advanced Information Technology and Communication in agriculture or other types of bio-production [1]. In many ways, this development may be compared with the mechanization of agriculture in the fifties and sixties. In those days, the introduction of the tractor, combine harvester and other machinery items radically changed the nature of agricultural operations. Currently, focus is on improved resource utilization and environmental considerations requiring improved process management, automation, and control involving, for example, logistics and fleet management.

2. Fleet management notions

<u>Logistics</u> may be defined as "*the provision of goods and services from a supply point to various demand points*" [2]. Other definitions include "*Logistics is the science of planning and implementing the acquisition and use of the resources necessary to sustain the operation of a system"*[3]. In an industrial context, a complete logistic system involves transporting raw materials from a number of suppliers, delivering them to the factory plant for manufacturing of processing, transporting of the products to different depots and in the end distributing them to the customers. In this case, both the supply and distribution transportation require effective management procedures in order to optimise routes and costs. These procedures are part of the overall Supply Chain Management of the company [4]. Potential costs savings include reduced transportation and labour costs.

Logistics within agriculture may be viewed as an inclusive management notion establishing a comprehensive view of the material flow in the production process. For example, in the diary operations the logistics concerns the location of the different functional units (stable parts, parlour, feeding storage, *etc*.) related to each other and combined with the employed management systems. A logistical improvement on the farm involves more rational work flows and operations. The basic logistical notion is that all operations and actions must create an added value in the process chain through the process of having the right thing, at the right place, at the right time.

As part of the management of the logistics, <u>fleet management</u> may be used as the practical tool managing a fleet of vehicles, using certain tools, to improve scheduling, operational efficiency, and effectiveness. 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 solving the heterogeneous scheduling and vehicle routing problem.

Agricultural fleet management can be seen as a farmers' or machine contractors' optimised decision making concerning e.g. resource allocation, scheduling, routing, real time monitoring of vehicles and materials and timely conducting field operations or customer orders. In this case, suitable decision support systems will help making optimised decisions and streamlining the whole process.

It is possible to identify different levels of functionality of the fleet management systems for agriculture (Figure 1). The first level includes passive surveillance and tracking functions like GPS position and simple time functions activated by the operator of the vehicle. The next level builds upon the first one and includes the possibility of interactive communication with the operator in terms of deploying task instructions directly on an "on-machinery" display. The third level includes comprehensive data acquisition functionalities by coupling directly to the electronic system of the vehicle (**Figure 1**).

3. Participatory approach

As a step in the procurement of new knowledge on ICT tools aimed at improved planning systems, specifically systems for integrated fleet management, a goal directed study involving relevant actors was carried out. The focus was on extracting the different specific approaches towards fleet management from selected agricultural stakeholders and service suppliers. Following the specific requirements, a more generalised approach toward ICT systems for the planning and execution of arable farm operations was derived. The focal point was to look at the different stakeholder's perceived problems within the area of ICT tools to be used for planning and monitoring of field operations (**Table 1**).

4. The future fleet management system for arable farming

The explorative study of the requirements for fleet management has provided the basis for the design of fleet management configurations. Two distinct configurations were derived, namely centralised and decentralised fleet management [5]. These notions emerge from a natural grouping in a centralised planning and execution of field operations and a more dynamic planning, on-line resource allocation and optimisation of field operations. The centralised fleet management is seen as a baseline system for planning, allocation and documentation of mobile units serving customers. A typical example is the coordination of the operations of machine contractors. Contrary to this, the decentralised fleet management is viewed as the future system for on-line coordination of mobile units cooperating on accomplishing a specific task within a field, like for example a team of cooperating robots. An example is the coordination of combines and matching grain trailers. The combines are serviced (in terms of grain unloading) in a process of efficiency optimisation, minimisation of driving distances, soil compaction, number of transport units, etc.

4.1. Centralised fleet management

Centralised fleet management involves an integrated system for agricultural fleet management. It will be a baseline system for planning, scheduling and documentation for mobile field units. The system will collect information on the fields and the operations actual to the farmers. The information is collected and processed in a central computer, which plans the sequence and route applicable to the individual vehicle in the fleet. During execution of the machine operations, continuous status information (position, time, etc.) is collected and transferred to the central processing unit as input in the on-going planning process. Centralised fleet management systems already are available on the market. For example, sugar beet harvesting in Germany is managed by machine contractors using such a system [6]. Benefits include improved global overview of the operational units, improved management and control, automatic documentation facility, and the possibility of enhanced global planning.

Inherent to many centralized approaches are difficulties such as intractable solutions for large groups (algorithms are exponential in complexity), and in general requires too extensive inter-mobile units communications and computation to be feasible for real-time response. Another weakness with this approach is that it produces a highly vulnerable system. That is, if the leader (the central planning unit) malfunctions, a new leader must be available or the entire team is disabled. Due to this reason, design of the architecture is made more complex because the designer must decide how many agents should be capable of functioning as planning units. The key advantage of centralized approaches is that they can produce globally optimal plans due to the fact that central unit can take into account all the relevant information conveyed by the members of the team [7].

4.2. Centralised fleet management

In contrast to the centralised systems, in the decentralised system each unit operates largely independently, acting on information that is locally available through its sensors. The decentralised system focuses on the interconnection of mobile units as well as the connection with the centralised fleet manager. The benefits from such a system include, fast response to dynamic conditions, decreased communication requirements, the mobile units are better able to respond to unknown or changing environments, since they sense and respond to the environment locally. However, the principal drawback of distributed approaches is that they often result in highly sub-optimal solutions because all plans are based solely on local information.

5. Planning elements of fleet management

Central planning and control elements of the fleet management include location monitoring, central equipment monitoring and control, route planning with sequence control, etc. These management activities for manned field machinery transforms into a full on-line coordination effort for unmanned vehicles in the forms of field robots. The aggregated research domain for fleet management issues is "*dynamic resource allocation and scheduling*" [8]. This research area develops methodologies for solving complex problems of scheduling tasks and allocating resources to specific jobs or customer requirements complying with a number of operational constraints. The central model for the classical fleet management problem is the Vehicle Routing Problem (VRP) comprising combinatorial optimisation problem determining the optimal routes for a fleet of vehicles based at a depot and serving a set of customers (*e.g*. [9]; [10]). The VRP problem may take on a variation of versions depending on the inherent constraints in the problem.

The fleet management problem to support the planning and execution of field operations may be defined in terms of the requirements as a Vehicle Scheduling and Routing Problem with Time Windows. In operational terms, this means that a manager located at a central facility receives orders on field operations to be executed at a specific location and at a certain time. The orders may come in the form of external customer orders to a machine contractor and it may come in the form of the farmer giving himself orders complying with the requirements of the soil, crop, and weather. The orders may specifically contain *operations specifications, urgency of operations, workability criteria.*

With regard to the specific task of timing work operations detailed job scheduling comes into play. In the agricultural context scheduling is defined as "*determining the time, when various operations are to be performed. Availability of time, labour and machinery supply, job priorities and crop requirements are some important factors"* [11]. Work scheduling is the formulation of jobs based on required operations. Jobs can be scheduled when soil, crop and weather conditions are within certain limits.

The manager will schedule the incoming orders taking into account operational constraints like the capacity of the individual machines in the fleet, the availability of machinery and labour, the urgency of operations, the weather forecasts, etc. This typically includes collection of information on the geographic positions of vehicles and customers in real time, the possible route structures and their limitations, the available capacity of the vehicles over the planning period, the optimal allocation of customer's orders to individual vehicles, and the optimal time windows and other limitations.

6. Components of a fleet management system

The principal components of a fleet management system are shown in Figure 2. The figure shows the elements of a dynamic scheduling and routing system that dispatches a fleet of vehicles according to customer orders arriving at random during the planning period. The database contains detailed geographical information on the relevant fields and possibly other customer information which might be relevant for the operator to know. Based on the initial order specifications and supplemental information already in the database a task is specified with relevant target values (e.g. route guidance, application dosage). These task specifications are transferred to the mobile vehicle (e.g. tractor, combine harvester) for display and communication to the operator (**Figure 2**).

During operation execution, the system will log machine and other operations data from implement controllers, tractor controllers, etc. together with possible manual observations keyed in by the operator. These data and information are continuously sent back along the communication chain ending up in the database for viewing by the manager or others. The logged data are used for documentation/traceability or for the continuous machine planning and control.

As part of fleet management construction efforts, improvements in the on-machinery communication interfaces and connection to the central managing unit are important. On-going work in this area include the ISO setting, which has the purpose of setting up an open interconnected on-board system, permitting electronic units to communicate, and to define the data exchange with the Farm Management Information System (includes software, decision support system, etc. for farm management).

7. Expected benefits

Improved planning tools combined with ICT systems for monitoring and documentation may increase the capacity utilization and subsequently improve the timeliness of the field operations. Studies have shown that the capacity utilization can be increased significantly and thereby reduce the unit costs by e.g. 20-30% by following a goal-directed planning and monitoring [12]; [13]). In terms of distance travelled, significant savings are reported as a result of optimized vehicle routing (e.g. [14]; [15];[16]).

Fully integrated fleet management systems with technical assets management in non-agricultural businesses (companies with operating vehicles or service-oriented companies with fleet objects) have experienced significant benefits [17]. For example, customer interviews reveal that up to 30% less administrative costs for fleet operations may be achieved together with up to 80% improvement in detecting of malfunctions or poor operational performance because of close monitoring. In the same connection, up to 60% minimised risk of malfunction by preventive maintenance is experienced. Also, in terms of streamlined stock management and integrated procurement 20% reduced costs were gained.

One of the challenges is to improve the fleet management for operations with multiple coupled work sequences, and in the case of simultaneously operation of multiple units with different implements, each directed towards its own variation within the work sequence. On example might be the selective harvest of malting barley complying with a predefined protein threshold versus harvest of the remaining crop for feeding. An ultimate goal would be to develop and configure a fleet of coordinated machines and tractors or self-propelled units.

Conventional management of field machinery is mainly carried out based on the manager's experience and standard data, applicable as average norms [18]. Considerable benefits in terms of costs and increased efficiency can be achieved by planning and control systems based on the unique conditions on the farm [19]. This supports a new paradigm, requiring more attention on a dynamic and on-line planning and control system capable of adapting to the changing conditions in the field . It puts new demands on the precision and integration of the planning and control functions, very much like the industrial adoption of computer-integrated manufacturing (CIM) [20]. Different forms of fleet management systems are expected to fulfil the requirements of such on-line resource allocation systems.

A number of expected benefits include:

- *increased operator productivity*
- *decreased overtime*
- *reduced fuel consumption*
- *improved customer service and interaction*
- *more precise invoicing*
- *reduced response time*
- *increased job flow processes*
- *continuous operations control*
- *offers real-time data sharing*
- *remote access via internet*
- *accelerates management decision process*
- *interfaces with existing financial software*
- *presumably increases profitability*
- *reduce administration time for operators*
- *reduced vehicle downtime*
- *eliminate costly errors due to poor communication*

8. Perspectives

The first generation of fleet management systems was relatively simple software applications coping with a number of simple functionalities [21]. Today, these systems have evolved into complete enterprise management tools linking together all parts of the business. However, the evolution continues and today's fleet management systems are just a step in the pursuit of progress.

The new trend clearly dictates increased management sophistication in terms of turning the tools into planning tools [22]. It includes real-time asset management comprising looking at current fleet locations and where it should be tomorrow integrating how the fleet behaved today. By increasing the analytical power of such systems it will be possible to analyse, in real-time, the cost implications of accepting or rejecting specific dispatch orders.

In the late 1990s and in the last decade, fleet management systems have evolved rapidly. These systems today offer a broad range of functionalities including tight integration with internal systems and systems located at the customer. Specifically, an extensive use of real-time data and wireless communications are seen together with increased intelligence for real-time planning. Industry developers identify those parameters as drivers for their development [23].

A characteristic feature of the agricultural operations management has been that different planning levels (strategic – tactical – operational) has been divided and not integrated (Sørensen *et al*., 2010). The use of extensive information technology options will enable data capture in real-time making it possible to integrate or combine the strategic planning with an updated operational planning obeying the current conditions of the soil, crop, machine, etc. Or in other words, the dividing line between long-range planning and carrying out those plans will disappear.

The planning procedure must start with devising initial plans for operational performance and route plans based on available information (a-priori information). Next, 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. Plans must be presented conditionally, so that supplementary knowledge from observations, databases, sensors, *etc*., can be incorporated in order to revise plans. Planning in this way adopt the principle of incremental progression where at any time the current planning is based on the best information available.

By the next decade, you may have a. device that gives continuous access to computing and communications resources on a machine intelligent enough to know what you're interested in, when to give it to you, and how to present it in the most appropriate manner. Figure 3 outlines the principles of automated data acquisition as part of a fleet management system. It includes data capture on in-field machinery and data transfer to a server accessible via the Internet. An additional functionality is “context awareness”. Context awareness is a term that is used for devices that have information about the circumstances under which they operate and can react accordingly. Context aware devices may also try to make assumptions about the user's current situation. For example: A context aware fleet management system may know that on of the mobile unit is currently approaching the storage facility. The system may then display information to the operator needed for the unloading procedure (**Figure 3**).

9. Conclusion

Fleet management has for many years been used as a central management tool within the transportation business and a number of commercial systems are available. The introduction of the technology into the agricultural domain might be question of choosing one of the existing commercial systems as a baseline system and then modify it to suit the agricultural conditions, In order to identify the necessary modifications in such an approach, there is need for testing existing systems in the agricultural domain.

There is a great need for the introduction of standards (e.g. a “black box”), which will enable a smooth communication between software entities and systems for the benefits of data transfer. An example could be an interface, which enable implement computers (e.g. a sprayer computer) to cooperate with a fleet management system.

Regardless of what fleet management systems will be launched in the future, the following must be fulfilled:

- *a demonstrated and positive cost-benefit analysis*
- *a clear flexibility in relation to specific applications of the system*
- *a simple user interface requiring no heavy learning efforts*
- *data logging and data storage is automatic and requires a minimum of human interaction*
- *integrations options with other internal management tools*

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Figure 1 - Different levels of fleet management

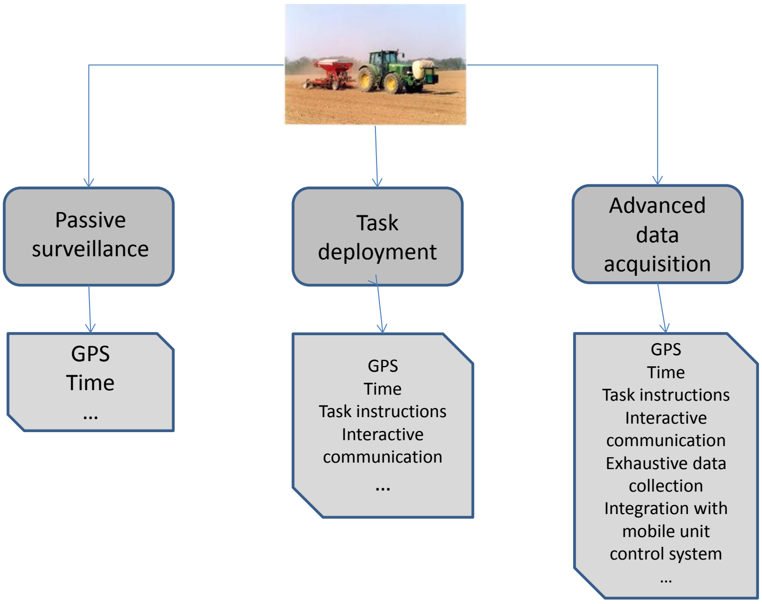

Figure 2 - Principal components of a fleet management system

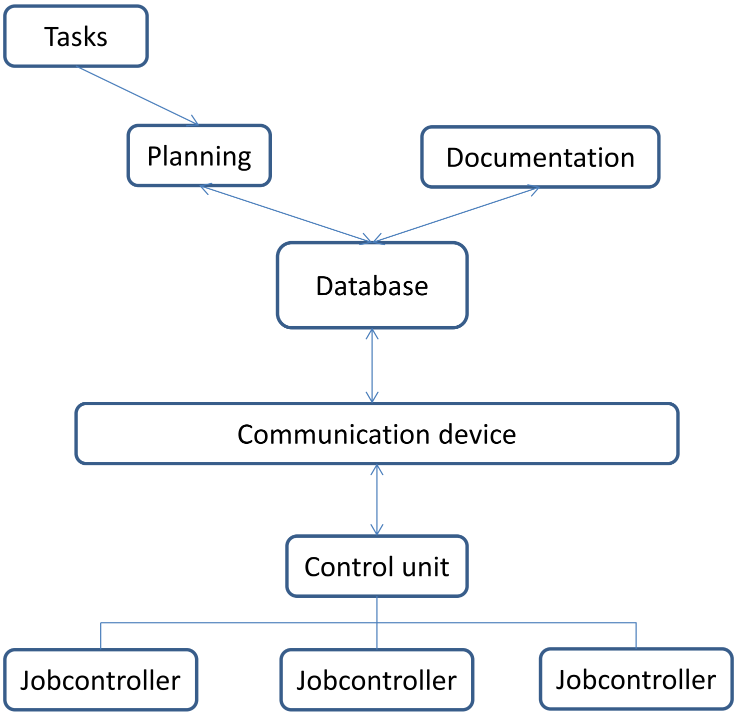

Figure 3 - Automated data acquisition as part of fleet management

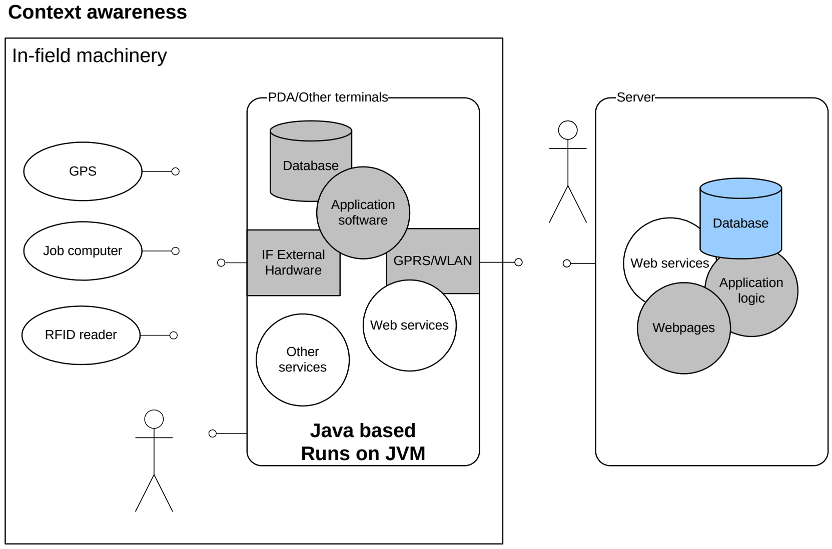

Table 1 - Voiced requirements

Data acquisition and control	- *on-line positioning of vehicles* - *machine monitoring/tracking* - *improved general knowledge of the production process and management* - *more effective invoicing and documentation system* - *detailed work time specification* - *on-line information search* - *Easy and quick access to information for employees* - *benchmarking* - *data exchange interfaces for existing tractor and implement computers* -
Predictive planning and optimisation	- *expediting of work orders* - *environmental benefits(e.g. soil compaction, resource usage)* - *resource minimisations(e.g. labour, fuel)* - *preventive maintenance (e.g. alarm settings for engine conditions)* - *coordination of multiple machines (farmers, contractors)* - *contextual awareness (automatic acquisition of data dependent on the vehicle situation)* - *route and path guidance*
Software/hardware	- *planning agent* - *user-interface* - *GPS equipment* - *implementation of research results on coordination and optimisation of the cooperation between manned and unmanned machines within the portfolio of existing company software solutions* - *mplementation of new exchange formats (like XML format) in the existing company software solutions, with the intent of improve the data exchange between different IT-systems*