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Review

Advances in agricultural machinery management: A review

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The introduction of intelligent machines and autonomous vehicles to agricultural operations will allow for increased efficiency as well as for reduced environmental impact. Currently, innovative sensing and actuating technologies together with improved information and communication technologies provide the potential for such advancements. However, the full exploitation of these engineering advances requires the traditional agricultural machinery management process to be revisited. As a result, traditional agricultural operations planning methods, especially the job-shop planning methodology, must be supplemented with new planning features, such as route planning and sequential task scheduling. The objectives of this review are to outline current and required advances in agricultural machinery management to prepare for future intelligent manned and/or autonomous sustainable operations in agriculture. In the following sections, five key management tasks for agricultural machinery management are selected that span the various management phases and levels. These tasks are i) capacity planning (strategic level), task times planning (tactical level), scheduling (operational), route planning (operational level), and performance evaluation (evaluation level). For each of the management tasks, a definition is provided, and the most recent related literature is presented. Finally, the future requirements which will facilitate and set the framework for the development efforts necessary for fully implementing future agricultural management models and tools are discussed.

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1. Introduction

Physical optimisation has long been the primary driver for improving agricultural machinery productivity and efficiency. This evolution has been caused by the well-known benefits from economies of scale providing improved mechanical functionality; however, this trend is currently being impeded by environmental and biological factors that constrain the size and weight of the machinery (e.g., soil compaction) (Day, 2011). Thus, only marginal improvements to the effectiveness of modern agricultural machinery are possible. In this sense, further improvements to effectiveness are not available, but current engineering advances in innovative sensing and

Abbreviations: FSSP, flow shop scheduling problem; JSSP, job shop scheduling problem; ICT, information and communication technologies; PTO, power take-off; VRPTW, vehicle routing problem with time windows; 2D, two-dimensional; 3D, three-dimensional.

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actuating technologies, together with improved information and communication technologies (ICT), hold the potential for significant improvements in the efficiency of advanced machines. However, the full exploitation of these engineering advances requires the traditional agricultural machinery management process to be revisited. As a result, the traditional agricultural operations planning methods, especially the job-shop planning methodology, must be supplemented with new planning features, such as route planning and sequential task scheduling. Moreover, agricultural machinery management must be viewed in a different way than machinery management in the general industrial domain. Compared with the industrial setting, the bio-production domain is subject to a greater impact from the environment and the inherent uncertainty and risk (e.g., crop growth or weather conditions) that characterise any farm process. Additionally, the domain variables under consideration have relatively large variances, and the planning procedures have large time constants. In general, risky decisions are the norm for agricultural machinery operations.

The objectives of this review are to outline current and required advances in agricultural machinery management to prepare for future intelligent manned and/or autonomous sustainable operations in agriculture. This will facilitate and set the framework for the development efforts necessary to fully implement future agricultural management models and tools.

In the following sections, five key management tasks for agricultural machinery management are selected that span the various management phases and levels: capacity planning, task times planning, scheduling, route planning, and evaluation. For each of the management tasks, the definition is provided, and then, the most recent related literature is presented. Finally, future requirements are discussed.

2. Management phases and levels

According to ASABE Standards (ASAE S495.1, 2005), the following four phases are identified in the management of operations and tasks for agricultural machinery:

- **Planning**: System components are selected and the expected performance of the system is predicted
- **Scheduling**: The time when the various operations are to be performed is predicted taking into account factors such as availability of time, labour supply, job priorities, and crop requirements
- **Operating**: Executing the operations using labour and machines
- **Controlling**: The systems is controlled by utilising various productivity measures and standards

Although the above mentioned processes are not aligned with the ones generally defined in engineering management, they will be used in this review for the sake of recognisable historic categorisation schemes within the realm of agricultural machinery management. Such categorisations involve different management tasks for agricultural machinery that operate at different management levels (Sørensen et al., 2010). The following gives a description and a structuring of the agricultural production management activities within the different defined levels:

- **Strategic**: Design of production system for a period of 1–5 years or 2 or more cropping cycles – and specifically the labour/machinery system in connection with the selected types of crops
- **Tactical**: Setting up a production plan for a period of 1–2 years or 1–2 cropping cycles narrowing down the resource usage, i.e. labour input and machinery input adjusted to the current crop plan
- **Operational**: Determining activities in the current cropping cycle. It includes a short term timing of the activities, and the formulations of jobs and tasks
- **Execution**: Controlling the executed tasks and the work-sets performance
- **Evaluation**: Comparing planned and actual executed tasks

From the above listed agricultural production management levels, the examination of the execution level has been excluded from the present review since there is not sufficient work on related management tasks in the agricultural machinery domain (such as dynamic decision making and planning, reactive planning based on fault diagnostic systems, etc.). Furthermore, a number of decision making tasks at this level overlap with control tasks and covering such issues is beyond of the scope of the present review.

3. Agricultural machinery management tasks

Five key management tasks for agricultural machinery management were selected that span the various management phases and levels (Fig. 1). These management tasks are capacity planning, task times planning, scheduling, route planning, and performance evaluation. These selected management tasks cover the majority of the topics that have been addressed by ASABE Standards (ASAE EP496.3, 2006), including tractor performance, power requirements, field machine performance, reliability, cost of use, and selection of field machine capacity. However, the topic of “replacement” is not included in the present review, as it purely addresses economic attributes.[1]

3.1. *Capacity planning*

3.1.1. *Definition*

Capacity planning is part of the system design and concerns both a qualitative and a quantitative selection of production components (i.e., in the particular case, machinery and supporting equipment) as related to the demand. As in the case of factory floor production, the objective is a generic optimisation of the use of the components (including their dimensions). Capacity planning is governed by 1) demands of

[1] The authors are aware of only one recent study on the generalised topic of replacement: Aurbacher, Lippert, and Dabbert (2011).

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