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Scheduling for machinery fleets in biomass multiple-field operations

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ABSTRACT

In the light of the current development toward large, and consequently, complicated agricultural production systems, such as systems of biomass production as bioenergy resource, the demand for advanced management tools, such as fleet management tools for scheduling and coordination of multiple vehicles working in multiple-fields, will be increased. In this paper, a planning approach for scheduling sequential tasks involved in biomass harvesting and handling operations performed by machinery teams was presented. The approach determines in which fields each machine has to operate, in what sequence, in which period of time, and the total operational cost of the resulting optimised schedule, taking into account specific factors such as the location and area of fields, available agricultural equipment, and the task times estimation based on the specific machine performance. The cost was included as an additional feature of the individual schedules providing the decision maker the ability to assess the relationship and trade-off between cost and time for each potential derived machinery combination within the available machinery fleet.

1. Introduction

Reduced marginal earnings combined with the societal, biological, and environmental constraints imposed on agriculture puts increased demands on the operational efficiency in agricultural operations. However, in order to increase operational efficiency a renewed focus on the usage of formal management models in agriculture is needed (Sørensen and Bochtis, 2010). This requirement is especially important in the light of the current development toward large, and consequently, complicated production systems involving large scale operations. In parallel, the introduction of dedicated energy crops, such as perennial crops for example, will make the operational management more challenging and involve custom-hired operations as result of costly dedicated equipment, the lack of knowledge and limited experience on these specialised crop production systems. Such a development will increase the demand for advanced management tools, like fleet management tools for scheduling and coordination of multiple vehicles working in multiple-fields.

Scheduling is the decision-making process that deals with the allocation of resources to tasks over given time periods and its goal is to optimise one or more specific objectives Pinedo (2008). Especially for the case of agricultural field operations, according to ASABE Standards (1974), the concept of 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*".

The notion of scheduling field operation is pivotal in the case of large scale harvesting where biomass is used as a bioenergy resource which is currently attracting much focus in many countries. In this type of harvesting operations there is a number of sequential tasks that need to be considered depending on different factors, such as the type of biomass (plant residues, grass, and grain), the moisture content, and the final usage of the biomass (Sokhansanj et al., 2006), while the duration of these tasks determined of factors such as, machinery and labour availability, machinery capacity, agronomical factors, maturation schedule, and weather. The variability of these tasks combined with the involvement of machinery fleets make scheduling important in order to provide the machinery allocation to tasks and the time of execution of each specific task.

A number of approaches for scheduling in field operations have been proposed including stochastic programming (Darby-Dowman et al., 2000), hybrid petri nets (Guan et al., 2008) and metaheuristics (Guan et al., 2009). Nevertheless, these approaches do not involve the case of multiple-machinery systems for sequential tasks that compete for shared resources, such as the large scale biomass harvesting mentioned above. The only approaches that deals with this specific problem is the approach of Basnet et al. (2006) where a scheduling method for harvesting of renewable resources was introduced based on a Travelling Salesman Problem (TSP) approach combined with greedy and tabu search heuristics, and the approach of Bochtis and Sørensen (2010) where the scheduling problem for agricultural field operations was cast as a vehicle

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routing problems with time windows (VRPTW). Both approaches do not consider the capacity of the machinery as an integral part of the planning problem and they do not connect the derived schedule with the operational cost as a parameter to improve the manager's assessment on the trade-off between time and cost.

The aim of the presented work is to develop an approach for scheduling sequential tasks in biomass harvesting and handling operations in a number of geographically dispersed fields incorporating the estimating of the machinery variable cost for different circumstances and finding the best possible combinations according to the criterion of minimum completion time (makespan) or by assessing the trade-off between time and cost.

Specifically, the objectives of the presented work are:

(a) To determine in which fields each machine has to operate, in what sequence, and in which period of time taking into account specific factors such as the location and area of fields, available agricultural equipment, and the task times estimation based on the specific machine performance.
(b) To include cost as an additional feature of the resulting schedules in order to provide the decision maker the ability to access the trade-off cost and time for each potential derived machinery combination within the available machinery fleet.

This paper is a continuation of the work presented in Bochtis et al. (2013) where the problem of scheduling of multiple-fields sequential biomass handling operations was addressed the well-known industrial flow shop with set up times. The purpose of that paper was to identify the feasibility of applying industrial planning methods to biomass supply chain. Specifically, the results showed a significant case-based reduction of 9.8% in the total operations time for the optimal schedule as compared with a schedule based on the knowledge of the manager. The purpose of this paper is to extend this restricted scheduling problem into one involving multiple-machinery systems also to connect the derived optimal schedules in terms of operational time with the corresponding cost for their execution.

2. The approach

2.1. Assumptions

The pursued scheduling approach is based on the following assumptions:

- Tasks are sequential, meaning that they are always performed in the same sequence in all fields (e.g., mowing, raking, baling).
- There is the presence of the "precedence constraints" requiring that in order for a follow-up task to commence in a specific field, the preceding task has to have been completed in the same field.
- All machines executing a specific to task type are identical.
- The set up time of a machine depends solely on the task type.
- All machines depart from the depot and return back to it at the end of the last allocated task.
- There is not idle time during travelling from the depot to a field and from a field to the depot.
- All the equipment are assumed to be completely purchased without any interest rate.

2.2. Overview

The approach consists of three main phases (Fig. 1). The first phase regards the pre-processing of the input data in order to estimate the unit cost of each machinery type and the task times for each task type in each field. The unit cost estimation is based on the machinery system specifications for each machinery type (or equivalently for each task type) and regards the implement and tractor variable unit costs, and the fuel consumption unit cost. These estimations are used for the determination of the total cost of a schedule. The task times estimation is based on the machine type and the corresponding task type specification and the area of each field. These task times are used as input to the scheduling problem that constitutes the second phase of the approach. The output of the scheduling problem solution provides the makespan time of the whole operation, the allocation of machines to fields, the starting and completion times of each task, and the inter-field route followed by each machine. Based on this output and the unit cost estimation at the pre-processing phase, the total cost for the execution of the resulting scheduling plan is estimated in a third phase.

2.3. Input parameters

The input parameters of the planning approach include:

- Fields configuration inputs:
  - The number of the fields, $|F|$, where F denotes the set of (the indices of the) fields where the sequential tasks have to be scheduled
  - The area of each field, a_k, $k \in F$.
  - The distances between depot and each field, d_{ok}, $k \in F$.
  - The inter-field distances, d_{kl}, $k, l \in F$.
- Inputs for machine tasks:
  - The number of the task types, $|T|$, where T denotes the set of the different machine types or equivalently, the different types of tasks that have to be executed.
  - The field efficiency (%) for each task type, e_i, $i \in T$.
  - The agronomical optimum speed for the execution of each task, s_i^*, $i \in T$.
- Inputs related to machinery specifications:
  - The number of available individual machines per task, m_i, $i \in T$.
  - The operating width for each machine type, w_i, $i \in T$.
  - The repair and maintenance factor for each tractor, $RF1_i^{tr}, RF2_i^{tr}$, $i \in T$, and for each implement, $RF1_i^{im}, RF2_i^{im}$, $i \in T$.
  - The total use for each tractor and implement, u_i^{tr} and u_i^{im}, $i \in T$, respectively.
  - The power of each tractor, P_i, $i \in T$.
  - The set up time for each machine type, p_i, $i \in T$.
  - The inter-field travelling speed for each machine type, s_i^{tr}, $i \in T$.
- Inputs related to cost:
  - The labour cost rate, c_i^{la}, $i \in T$.
  - The unit fuel cost, c_i^f, $i \in T$.
  - The list price of each tractor and implement, pr_i^{tr} and pr_i^{im}, $i \in T$, respectively.

2.4. Pre-processing

2.4.1. Task times estimation

The effective capacity (field area operated per time unit) of an agricultural machine executing a field operation depends on three factors, namely, the optimum working speed (s_i^*, $i \in T$), the operating width of the implement (w_i, $i \in T$), and the field efficiency (e_i, $i \in T$), which varies according to different conditions, such as size and shape of the field, pattern of field operation, etc. (ASAE EP496.3, 2009). The effective capacity for field operation $i \in T$ is given by:

$$ec_i = s_i^* w_i e_i$$