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Synchronization routing for agricultural vehicles and implements

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Introduction

Agriculture technology is experiencing a revolution to enhance efficiency, sustainability, and productivity. Autonomous agriculture mobile robots (agribot) are increasingly used. Current approaches for Agricultural Vehicle Routing Problems (AVRPs) focus on homogeneous fleets, dealing with a single type of task and crop [5]. In contrast, real-world farming requires coordination between different tractors/agribots and implements to manage different crops and tasks, such as plowing, fertilizing, and harvesting. The Agricultural Fleet Vehicle Routing Problem with Implements (AFVRPI) coordinates the routes for mixed fleets, optimizing the cost for covering task execution and synchronization in modern agriculture. Movement synchronization between two vehicle classes (tractors and implements) is necessary, where the tractors have autonomous movement capacity and implements depend on the tractors to move [3]. Various approaches in the literature address similar challenges. The Vehicle Routing Problem with Trailers and Transshipments [2] allows for the detachment and reattachment of trailers between trucks. The Active Passive Vehicle Routing Problem introduces a scenario with active and passive vehicles, where the active vehicles displace the passive ones [4]. Lastly, one of the first movement synchronization constraints in precision agriculture is the Synchronized Sprayer Tanker Routing Problem with Variable Service Time, which involves coordination between tender tankers and sprayer fleets [1].

Problem definition and solution approach

The Agricultural Fleet Vehicle Routing Problem with Implements (AFVRPI) is composed of a fleet comprising both tractors and implements ($\mathcal{F} = \mathcal{V} \cup \mathcal{M}$), and their compatibilities with each other. The transportation network is modeled by a directed graph $(\mathcal{N}, \mathcal{A})$. Nodes consist of four distinct sets: \mathcal{N}_{tasks} agricultural tasks, \mathcal{N}_{depots} tractor and implement depots, \mathcal{N}_{detach} detaching nodes and \mathcal{N}_{attach} attaching nodes. Each task has a given demand, service time, and time window. Arcs denote spatial and temporal connectivity and let us denote transfer arcs as $(d, a) \in \mathcal{A}_{transfer}$, including arcs where implements can be detached $d \in \mathcal{N}_{detach}$ /attached $a \in \mathcal{N}_{attach}$ to tractors. The goal of the AFVRPI is to find a set of compatible routes for tractors and implements that visit all the tasks minimizing the overall cost and respecting the movement constraints.

The proposed solution approach is composed of an extended master problem formulation with independent subproblems associated with each tractor and implement, and solved with column generation, which enables distributed and asynchronous problem-solving. Tractor subproblems are the Elementary Shortest Path Problem with Resource Constraints (ESPPRC) incorporating linear costs [4] with two resources: the distance, restricted by vehicle autonomy, and the time, constrained by task time windows. Implement subproblems are also the ESPPRC considering only demand constraints, limited by its capacities. Preliminary computational results demonstrate the efficiency of this approach.

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