Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

Reducing field work time using fleet routing optimization

*Hasan Seyyedhasani**, *Joseph S. Dvorak*

Biosystems and Agricultural Engineering Department, University of Kentucky, 128 C.E. Barnhart Building, Lexington, 40546-0276, USA

ARTICLE INFO

Article history:
Received 7 March 2017
Received in revised form
8 October 2017
Accepted 17 January 2018

Keywords:
Agricultural operation
Path planning
Computer model
Optimized routing
Field completion time

Agricultural producers seek to complete their field work operations as quickly as possible. This is achievable through the simultaneous use of multiple vehicles for an operation. However, path allocation and scheduling then must be considered. Transforming the field work problem into a Vehicle Routing Problem (VRP) and using optimization procedures designed for this problem provides a method of allocating paths. In this work, the accuracy of a VRP representation of field work is confirmed and the ability of this optimization system to reduce field work times is verified. Experiments were conducted using three tractors during a rotary mowing operation. First, the traditional routes used by human drivers were recorded. Then, a VRP representation of this operation was created, and new routes generated by a Tabu Search optimization procedure. Finally, the field operation was repeated using the optimized routes. Using these routes, the time to complete the field work was reduced by 17.3% and the total operating time for all tractors was reduced by 11.5%. The predictions by the VRP representation for completion time and total time were both within 2% of the actual times recorded when the tractors followed the computer-generated routes in the field. These reductions illustrated the ability of the route optimization procedure to improve effective field efficiency.

1. Introduction

Agricultural producers seek to complete their field work operations as quickly as possible. This drive to increase field capacity, the rate in terms of area per time that work is done (American Society of Agricultural and Biological Engineers, 2011), has led to larger agricultural machinery and many producers to use more than one machine in a field at a time. It has also led researchers to seek methods to improve the efficiency of these field operations. Many researchers have tested methods to improve the way in which paths are generated in fields. Other projects have focused on the order in which these paths are worked and, in the case of multiple vehicles, which vehicles are assigned to each path. One issue with these improved path generation and routing systems is that the solutions they generate often appear random and arbitrary. These solutions do not follow any easily recognizable rule. However, modern advances in sensing, information and communication technologies have provided automatic steering and navigation systems that enable following these more

* *Corresponding author*. Fax: +1 859 257 5671.
E-mail addresses: hshasaniT@uky.edu (H. Seyyedhasani), joe.dvorak@uky.edu (J.S. Dvorak).
https://doi.org/10.1016/j.biosystemseng.2018.01.006

complex paths through the field. As development continues in autonomous vehicles for both traditional field work and crop scouting, these path generation and routing techniques will become not only more feasible, but also more necessary as there will not be a human operator to generate paths and routes in the traditional manner.

Much agricultural machinery optimization research has been focused on improved algorithms for path generation (Palmer, Wild, & Runtz, 2003; Flann, Hansen, & Gray, 2007; Jin & Tang, 2010; Hameed, Bochtis, & Sørensen, 2011). Using discrete geometric primitives and operating in real time, Hameed, Bochtis, Sørensen, and Nøremark (2010) generated maps to represent the field on which field operations take place. In addition, various methods have been developed for automatic geometric representation of field sections such as headland generation (Sachs, Roszhart, Schleicher, Beck, & Bezdek, 2012), and headland turns generation (Birnie, 2006; Senneff, Leiran, & Roszhart, 2012). When path generation, planning and routing are combined, it provides a coverage path planning algorithm. A complete coverage path planning algorithm for one vehicle using a genetic algorithm for the solution has been developed by Hameed, Bochtis, and Sørensen (2013). In order to efficiently operate on the generated paths, along with operational planning also known as in-field machinery activities (Hameed, Bochtis, Sørensen, & Vougioukas, 2012), it is required to allocate and schedule the paths among the available vehicles. Researchers have shown that scheduling the paths efficiently can reduce the total non-productive travel up to 50% (Bochtis & Vougioukas, 2008). Bochtis and Sørensen (2010) investigated the scheduling and planning for the service units in harvest operations. They represented this operation as a Vehicle Routing Problem with Time Windows and used optimization techniques designed for this traditional computer science problem. Non-productive travelled distance can be decreased further by taking into consideration the impact of different types of headland turns (Bochtis, 2008; Jensen, Bochtis, & Sørensen, 2015). Ali, Verlinden, and Van Oudheusden (2009) reduced the non-productive travel time of combine harvesters by generating itineraries for the vehicles including the start location, the end location, and locations for unloading the harvester. In fertilizing operations, total travel distance was reduced up to 11.8% (Jensen et al., 2015) by following optimized plans instead of the conventional plans followed by farmers during the operations. Researchers have even explored routing optimization for vehicles to specifically reduce compaction potential (Bochtis, Sørensen, & Green, 2012). They could reduce the risk factor up to 61% using optimal paths.

The variants of the Vehicle Routing Problem (VRP) provide methods to represent mathematically the routing of a fleet used to visit and service customers, contingent upon specific constraints. There are a set of constraints incorporated in the VRP which necessitate that all the customers be visited and that each individual customer be visited by only one vehicle. In addition, various variants of the VRP have their respective constraints such as the vehicles start and end positions in designated locations, or customers be visited in a specific order or in a specific time window. When applying VRP for solving a problem a network graph is developed. Each customer is transformed into a node on the graph, and the travel cost between each pair of nodes is assigned to the connection between the nodes. In agricultural applications, casting the field routing problem as a mathematical optimization problem is a powerful tool to improve logistics (Bochtis & Sørensen, 2009; Conesa-Muñoz, Pajares, & Ribeiro, 2016).

Seyyedhasani and Dvorak (2017) proposed a VRP representation and optimization techniques that focused on enabling producers using multiple vehicles to complete a field operation as quickly as possible. The field representation began with a set of travel paths along which the agricultural vehicle drives. VRP nodes were assigned to the endpoints and midpoint of each path. In the next step, the travel time between each pair of location coordinates was assigned as the connection cost for the pair of the corresponding nodes. Connections that were considered unacceptable (e.g. from one endpoint to an endpoint at the other side of the field or from midpoint to midpoint) were penalized by assigning a very high cost. The outputs of the first two steps are a cost matrix (for optimization) and a transformation matrix (to map physical locations to nodes). An initial solution was generated using a modified version of the Clarke-Wright Savings algorithm (Clarke & Wright, 1964) and improved using Tabu Search. The Tabu Search procedure developed by Glover (1989) searches more broadly for solutions and prevents the optimization function from getting trapped at a local minimum. Each iteration of the algorithm (as the algorithm is an iteration-based procedure) utilizes all possible combinations of three operations: swap, insertion, and inversion. Tabu Search is a powerful optimization technique and has been used in other agriculture applications to improve enterprise-level planning such as calculating the sequence in which fields should be worked (Edwards, Bochtis, & Søresen, 2013).

According to the model developed by Seyyedhasani and Dvorak (2017), the simulation results provided feasible solutions through both the modified version of the Clarke-Wright algorithm and the Tabu Search algorithm. The modified Clarke-Wright solutions were similar to the Work Zone approach currently utilized by many producers. The Tabu Search provided less predictable routing that was unlike any route pattern currently used by producers. These simulation results proved that the proposed VRP conversion and its optimization method were feasible.

The goal of this project was to confirm the expected reduction in the time required for multiple vehicles to finish a field. To that end, field completion times to conduct an agricultural operation via conventional human-operator routing was compared to an improved routing provided by the optimization procedure in the same field. Within this larger comparison, it was also necessary to test whether the computer model was accurate and the times predicted by the optimized solution could be realized by tractors driving these routes in the field.

2. Materials and methods

Most of the field experiments in this study were performed on the University of Kentucky's C. Oran Little Research Center in