Infield logistics planning for harvest operations

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1. Introduction

Crops are harvested by performing a series of operations with harvesting vehicles in the field. The harvest operation is performed with combines (harvesters). Supporting logistical activities of transferring and transporting harvest (grain) from the field to the farm are carried out with the help of tractors. This research focuses on detailed logistics planning of various infield harvest operations performed with harvesters and tractors.

The scheduling of the harvest operations is first performed at an intermediate level of planning. The objective of intermediate level scheduling is to allocate a crew of operators and equipment to a certain field requiring harvesting during the harvest season. Different approaches have been used for intermediate level scheduling. These approaches include traditional project planning techniques e.g. critical path method (CPM) and program evaluation review technique (PERT). Research has also been conducted to formulate mathematical models for resource allocation and scheduling problems. Fokkens and Puylaert (1981) [5] developed a linear programming planning model for the management of harvest operations at the large scale grain farm. Their model takes into account harvest requirements of each field and constrained resources: mainly operators and equipment and results in the allocation of operators and equipment to fields considered in the planning horizon. Recently, research has been conducted on scheduling of operations for overall harvesting processes, mainly for rape seed and hay fields (Foulds and Wilson, 2005; Basnet, Foulds and Wilson, 2006) [4], [1]. However, most infield harvest operations are still performed without any detailed planning and the efficiency of the process relies mainly on the experience of the workers performing operations.

The combines operating in a field have limits on the capacity to collect grain in their gain tanks. Therefore, in order to continue the harvest operation, harvesters need to unload grain to a tractor bin at regular intervals of time. There are two basic scenarios under which harvesters and tractors are required to operate and coordinate in a field. In the first scenario, once a harvester in the field reaches its specified capacity...
limit, a tractor approaches the harvester and moves in parallel with the harvester to receive grain. The harvester can unload the grain without interrupting the harvest operation. In the second scenario, tractors are restricted to approach harvesters operating in the field. Here, a harvester has to stop the harvest operation and approach the tractor located a fixed spot in the field to unload the grain. In this paper, optimization of operations under both harvest scenarios is considered. For operational planning, mainly two issues are important. The first issue is the optimization of path trajectory of harvesters and tractors in the field. The second issue is the determination of the optimal time for grain transfer to take place between the harvesters and the tractor. The general objective of planning is to minimize the overall duration of the process, while efficiently minimizing the total distance traveled by vehicles during their operations. Both planning issues are based on routing decisions of vehicles in a field. Routing problems are studied vastly in the discipline of operations research, where a routing problem subjected to various constraints is formulated with a mathematical model having a certain objective function.

2. Problem description

Crop harvesting is often carried out with multiple harvesters and tractors in the field. The allocation of the harvesters and the tractors to fields is performed during high level harvest planning in the harvest season. Various approaches have been developed and used to support allocation decisions of the constrained resources for crop fields. Elaborating details of these scheduling procedures are beyond the scope of this paper. Interested readers are referred to [5], [4] and [1] for further details on these procedures. Infield operations planning of multiple harvesters and tractors in a field includes decisions about starting positions of harvesters in the field, path trajectories and the suitable moment for the grain transfer to take place between the harvesters and the tractors.

3. Modeling the problem

The goals of infield operations planning, as discussed in the previous section, are i) determining the path trajectories for the harvesters and the tractor, while minimizing the non-productive time in the field and ii) minimizing the total distance traveled by vehicles, taking into account grain transfer requirements of harvesters.

This research attempts to formulate the planning problem described above as a node routing problem in operations research. An analysis of the problem shows that harvest operations planning can be very well represented by the vehicle routing problem (VRP), which is a well know integer programming problem of NP-hard nature. In vehicle routing problem a set of delivery/collection routes are designed for a fleet of vehicles to serve a number of customers from one central depot. The customers are distributed with the travel distance $d_{ij}$ between them. The objective the VRP is to find a minimum distance tours for each
vehicle such that each customer is served exactly once by a vehicle and the route of each vehicle starts and ends at the depot. An overview of the VRP and different solution approaches is provided by Eiselt et al. [3]. The VRP exists in several variants and the one which is of best relevance to harvest operations planning problem is the capacitated version. In capacitated vehicle routing problem (CVRP), each vehicle has a certain capacity limit and when a vehicle reaches the specified limit, it returns back to the depot.

In harvest operations planning problem, harvesters operating in the field represent vehicles with capacity constraints. The depot is represented by a tractor to which harvesters need to return once their tank becomes full with grain. The field is considered as undirected graph $G(V, E)$ with vertex set $V$ and edge set $E$. Each vertex $V$ in the field provides a certain amount of yield to a harvester. The distance between two adjacent vertices $c_{ij}$ is constant. Additional constraints are defined to restrict generation of irregular, random paths for the vehicles in the field. Solving harvest problems with this model will provide minimum distance paths for each vehicle in the field.

One limitation of modeling harvest operations planning problem as CVRP is that the model allows each vertex in the field to be visited only once during a tour. Whereas in many particle situation, a vertex in a field may have to be visited more than once by a harvester. This depends mainly on the field geometry and turning requirements of harvesters. This additional requirement can be included in the model by introducing an addition cost of traversing a vertex without performing the harvest operation. The objective of the model will be to minimize this extra cost of traversing the vertex or the edge without performing the harvest operation. This is also known as dead-heading problem in operations research literature. The computational complexity of this logistics planning problem can be reduced sufficiently by transforming the capacitated vehicle routing problem into the capacitated arc routing problem (CARP). This can be done by placing the supply of the original vertex (node) on the new defined edge (arc) in the field. The detailed procedure to transform capacitated vehicle routing problem into capacitated arc routing problem is discussed by Golden and Wong (1981) [6].

4. Conclusions and expected results

The problem of planning infield harvest operations can be formulated as one of the routing problem in operations research. The general objective of routing problems is the minimization of the total distance traveled by vehicles subjected to various constraints. This approach, when applied to harvest operations planning, will identify minimum distance paths for each harvester and tractor in the field. The CVRP generates paths in which each vertex in the field is visited exactly once by a vehicle. For situations where a vertex or an edge in a field is required to be visited more than once by a harvester, the approach of dead-heading distance will be used. In this approach, an additional cost factor will be introduced for traversing the vertex without performing the harvest operation. The objective function of the model will minimize the
non-productive path of harvesters in the field. Furthermore, the idle time in the harvest process resulting from lack of coordination planning for operations of harvesters and tractor will also be minimized.

As results of detailed planning of infield harvest operations, the total duration of the harvest process for a field will decrease. The utilization of harvester and tractor will improve. This will eventually result in reducing the overall duration of the harvest process. Infield operational planning can provide more accurate estimates of operation times for resources. This information can provide useful input for scheduling and allocating resources at the high level planning stage (bottom-up planning approach).

References


