BIOSYSTEMS ENGINEERING 164 (2017) 110–123

Available online at www.sciencedirect.com

ScienceDirect

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

Research Paper

# Optimised forage harvester routes as solutions to a traveling salesman problem with clusters and time windows

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ARTICLE INFO

*Article history:*
Received 31 March 2016
Received in revised form
14 September 2017
Accepted 11 October 2017

*Keywords:*
TSP
Clusters
Time windows
Tabu algorithm
Simulated Annealing algorithm

In this work we study a variant of the traveling salesman problem with additional constraints of clusters, time windows, and processing times at the cities. We apply this model to a real-world problem related to an agricultural cooperative that needs to optimise the routes of several harvesters, and where getting the exact solution has been proved to be hopeless for large instances (see Carpente et al. (2010)). We introduce, implement and test two different heuristic algorithms based on tabu search and simulated annealing philosophy, respectively. An exhaustive experimental evaluation over several sets of real data shows that the simulated annealing approach exhibits a solid performance even on the most complex instances, while the tabu search based approach worsens with complexity.[1] Moreover, the optimised schedules corresponded to important economic savings. For this reason the cooperative has already successfully adopted the proposed heuristic in its regular planning activities.



## 1. Introduction

In this work we present a real-world forage harvesting problem that appears within an agricultural cooperative located on the North-west of Spain, and which has been first considered in Carpente, Casas-Méndez, Jácome, and Puerto (2010). We address the problem by modeling it as a constrained variant of one of the most recurrent problems in the optimisation literature: the Traveling Salesman Problem (TSP). In particular, we add to the usual constraints of the problem others of clusters, time windows, and processing times at the cities.

The cooperative has a big number of partners, each of them owning several smallholdings that have to be cropped

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[1] That is, when the number of decision variables increases.

https://doi.org/10.1016/j.biosystemseng.2017.10.002

**Nomenclature**

| | |
|---|---|
| $a$ | *aspiration*, expected improvement to allow a forbidden movement |
| $a_{ij}$ | minimal traveling time between smallholdings $i$ and $j$ |
| $\beta$ | *cooling* parameter |
| $C_p(j)$ | time shift, in number of days, with respect to the owner's request date |
| $d_p$ | total amount of traveling time spent by the harvester in path $p$ |
| $\Delta$ | cost increment of a solution |
| H | set of planning periods |
| $k$ | size of the *tabu list* |
| M | set of owners |
| N | set of smallholdings |
| NP-complete | non-deterministic polynomial-time complete |
| p | a path |
| T | temperature |
| TSP | traveling salesman problem |
| $w_j$ | arbitrary weight |
| $x_{ijk}$ | binary decision variable to indicate if the harvester starts to process smallholding $i$ in period $k$ and then goes to smallholding $j$ |

with self-propelled forage harvesters. The farm owns five equal self-propelled forage harvesters in its machinery fleet. These machines cover a large working area and can harvest about 5000 ha per year in 3000 fields located at distances as large as 90 km from the cooperative location. The situation was that 24% of the machines activity was *lost* mainly because of inter-field travel time or due to breakdowns. For these reasons, the proposed goal was to minimise the total working time of these machines. However, since the total processing time of all the smallholdings is fixed, the aim can be equivalently stated as to minimise the traveling time. Therefore, the goal is to design optimal route plans for these machines (i.e. the shortest route for each harvester[2]). Each partner requests a date in which he wants to crop his smallholdings. This date has a certain level of tolerance (time windows constraints). Moreover, the smallholdings of each partner have to be processed contiguously before starting to crop the smallholdings of other partners (clusters constraints). This is because the silos, in which grass or corn are garnered, are opened when the harvest starts and they have to be closed in one or, at most, two days in order to guarantee maintenance conditions.

Harvesting planning is a recurrent topic in optimisation literature. In Jena and Poggi (2013), authors determine the routing of cutting machines during harvest periods of sugar cane by using mixed integer programming techniques. Recently, Kusumastuti, van Donk, and Teunter (2016) published a review of harvest planning. In their work, one cannot find a model which involves routes, processing times, clusters and time-windows simultaneously.

As it is well known, the traveling salesman problem is NP-complete (see for instance Johnson and Pilcher (1985)). The introduction of time windows constraints into the problem can only make it harder as it is mentioned in Tsitsiklis (1992). In Kara and Derya (2015), authors explore the capability of exact formulations for this situation. Furthermore, we also need clusters and processing times constraints as in Chisman (1975). For this reason, the mathematical programming formulation of this problem can not be used to solve real world instances (as it is justified in Carpente et al. (2010)). The only alternative is to use heuristic algorithms to calculate near-optimal solutions.

There are many references related to heuristic algorithms for the classic TSP. For instance, Fiechter (1994) and Knox (1994) developed tabu search techniques, Malek, Guruswamy, Pandya, and Owens (1989) and Aarts, Korst, and van Laarhoven (1988) studied the performance of simulated annealing algorithms, and Lin and Kernighan (1973) designed an efficient and fast algorithm to solve the TSP. In Laporte, Potvin, and Quilleret (1997) a tabu search algorithm for the clustered traveling salesman problem in which the clusters are visited in a prespecified order is described.

In this work we modify (and enhance) the tabu search algorithm developed in Carpente et al. (2010) for solving the clustered traveling salesman problem with time windows, which has shown a good performance just for small scenarios, and also define different initial solutions (one of them based on the philosophy described in Lin and Kernighan (1973)) from which run the main algorithm. Moreover, we design a simulated annealing based solution to deal with the same problem, able to outperform the tabu search technique in larger instances of real data.

The paper is organised as follows. In Section 2 we introduce the parameters and a brief description of the problem. Then, Section 3 presents the heuristic algorithms to approximate the solution of the problem. These algorithms are evaluated, in Section 4, by solving real data sets from the cooperative. Finally, Section 5 concludes.

## 2. The problem

In this section we provide a general overview of the elements of the problem faced by the agricultural cooperative. An exhaustive description of the mathematical programming model of this problem can be found in Carpente et al. (2010).

**Data**

- The set of partners.
- The set of smallholdings, and their ownership.
- The set of periods of time to be considered in the planning.
- The matrix of distances, that keeps the minimal traveling time between any two given smallholdings. Since a harvester is a very heavy machine, it is assumed that the speed remains constant in all kind of roads, and that it is

[2] Please, note that the entire working area is divided into several fixed regions, each of which is assigned to one harvester. That is, there is a one-to-one correspondence between subdivisions and harvesters, which is already set by the cooperative. Hence, just one machine is considered to solve the problem.