GRASP-VNS for a periodic VRP with time windows to deal with milk collection*

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Abstract. This paper considers the planning of the collection of fresh milk from local farms with a fleet of refrigerated vehicles. The problem is formulated as a version of the Periodic Vehicle Routing Problem with Time Windows. The objective function is oriented to the quality of service by minimizing the service times to the customers within their time windows. We developed a hybrid metaheuristic that combines GRASP and VNS to find solutions. In order to help the hybrid GRASP-VNS find high-quality and feasible solutions, we consider infeasible solutions during the search using different penalty functions.

Keywords: Periodic Vehicle Routing Problem with Time Windows, Quality of Service, Milk Collection, GRASP, VNS, Penalty Functions.

1 Introduction

Logistics and transport management systems for perishable products have operational specificities associated with demands, handling, storage equipment and transport infrastructure. Models to solve the problems of collecting, sharing and distributing these products must adapt to new objectives and constraints. The minimization of total travel cost is an important logistics and transport objective and is the main criterion for the optimization of supply and distribution chains. Nevertheless, there are further important aspects to consider than just the special importance of the costs in perishable products. Quality assurance of service of perishable products constitute the main criteria for the optimization of supply and distribution chains for this kind of goods.

In this work we specifically address specifically the problem of planning the collection of fresh milk from local farms through a fleet of refrigerated trucks. The scattered small-scale family farms type have limited isothermal facilities for storing milk. In these circumstances the collection by the industry demands a precise temporal organization to preserve the quality of the product [4]. Milk collection needs not be daily because the farms have facilities to store milk for one to three days. The collection planning is done in weekly periods [2].

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The problem to determine the most appropriate routes for collecting milk from a set of known farms in a given planning period of several days, including a time window for each pick up, is modelled as a Periodic Vehicle Routing Problem with Time Windows (PVRPTW).

The rest of the paper is organized as follows. The next section describes the PVRPTW model and the objective function. Section 3 explains the proposed solution approach to solve the problem. In section 4 computational experiments and results are described and analyzed. Finally, some conclusions and future works are included in the last section.

2 Periodic Vehicle Routing Problem with Time Windows

The PVRPTW, first mentioned in [3], ask for a number of routes for each day over a given planning horizon with the aim of minimizing the total travel cost while satisfying the constraints on vehicle capacity, route duration, customer service time windows, and customer visit requirements [5, 6].

The PVRPTW is defined on a complete directed graph $G = (V, A)$, where $V = \{v_0, v_1, ..., v_n\}$ is the vertex set and $A = \{(v_i, v_j) : v_i, v_j \in V, i \neq j\}$ is the arc set. The planning horizon considers t days, also referred to as set $T = \{1, ..., t\}$. Vertex v_0 represents the depot with time window $[e_0, l_0]$ at which are based m vehicles that have capacity limited to Q and maximum working time D. Each vertex $v_i \in V$, $i \neq 0$, corresponds to a customer and has an associated demand $q_i \geq 0$, a service duration $d_i \geq 0$, a time window $[e_i, l_i]$, a service frequency f_i and a set $C_i \subseteq T$ of allowable combinations of visit days. For each arc $(v_i, v_j) \in A$ there is a cost $c_{ij} \geq 0$. The problem then consists in selecting a single visit combination per customer and designing (at most) m feasible vehicle routes for each of the t days on G [5], [6].

With respect to our application in milk collection, we consider a special version of the PVRPTW with an objective function focused on quality of service, since it is in practice hard to meet the farms ideal milk collection time windows. The quality of service is improved by reducing the time that farms have to wait to be served within their time windows. This new objective is based on variables s_{ik} representing the time when vehicle k arrives at farm i, and e_i and l_i corresponding to the the earliest start time of service and the latest start time of service at the farm i, and n is the number of farms.

The consecutive values of the variable s_{ik} are computed iteratively in each route by $s_{jk} = \max(e_i, s_{ik}) + u_i + c_{ij}$, if vehicle k goes from v_i to v_j, with u_i as the time it takes to perform the service on the farm i. The objective function of the S solution is defined as follows:

$$f(S) = \min \frac{1}{n} \sum_{k} \sum_{j} \frac{\max\{(s_{jk} - e_j), 0\}}{l_j - e_j} \qquad (1)$$

The objective function thus aims at maximizing milk quality by minimizing the lateness of the collection at each farm.

3 Solution Method

VRPs in general are known to be also difficult to solve in practice. PVRPTW and obviously also our variant of the problem are NP-hard. Accordingly, metaheuristic methods are appropriate to optimize our model for the milk collection problem and a real-world process.

We propose a hybrid metaheuristic that combines GRASP (Greedy Randomized Adaptive Search Procedure) [7] and VNS (Variable Neighborhood Search) [8]. GRASP is an iterative two-phase metaheuristic made up of a construction phase, in which a feasible solution is produced, and a post-optimization phase, in which this feasible solution is improved. The GRASP solution construction mechanism builds a solution step-by-step by adding at random a new node from a restricted candidate list (RCL). We use a variant of VNS, VND (Variable Neighborhood Descent).

VND consists in changing the neighbourhoods each time the local search is trapped in a local optimum with respect to current neighbourhoods. VND is basically iteratively determining a better solution from the current solution by some transformation or movement. Standard VND considers several neighborhood structures of solution S as $N_k(S)$ for $k = 1, ..., k_{max}$, being k_{max} the number of neighborhood structures. Nevertheless, in our method we use the value of k for control the size of movements that will be described later.

This hybrid approach uses GRASP as an outer framework for diversification and VND for intensification, i.e., for locally improving and post-processing constructed solutions as shown in Fig. 1.

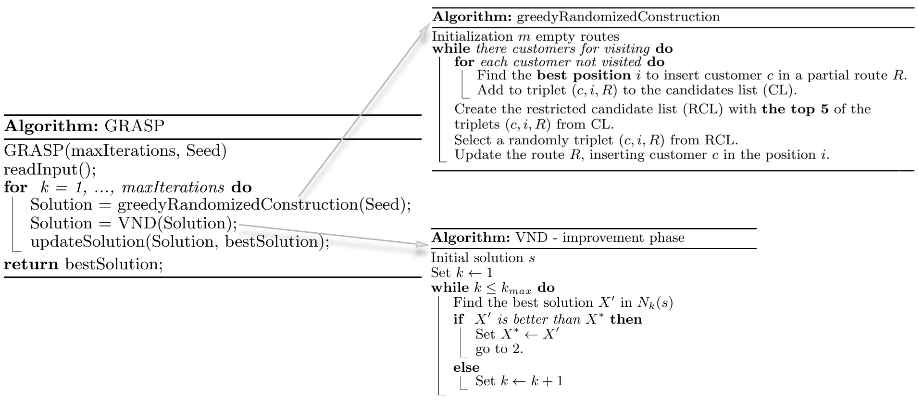

Fig. 1. General solution approach: GRASP-VND hybrid

Generally two approaches which deal with PVRPTW are offered in the literature. The first one begins by assigning days to dairy farms and in a second step the routing problem for every single day is solved using classical techniques for solving the VRP [9]. In the second approach, routes are developed and then assigned to days of the week. The method we present here follows the second approach and consists of the following two steps as shown in Fig. 2.

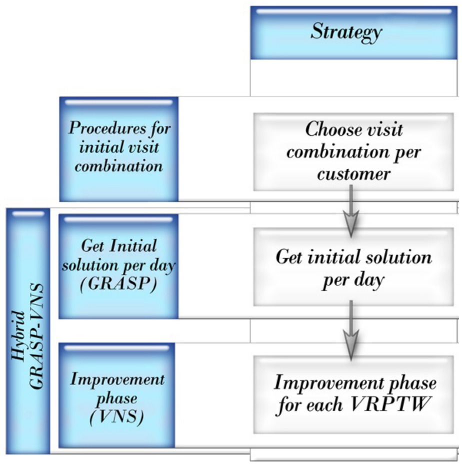

Fig. 2. General solution approach

The first step of our method consists in assigning a single visit combination to each dairy farm. Customers are then assigned to the corresponding days of the planning horizon. A list of customers is created in descending order relative to the time window size. Customers are assigned to a single visit combination alternatively in descending and ascending order with respect to this list.

In the second step, a hybrid GRASP-VND is used to solve the Vehicle Routing Problem with Time Windows (VRPTW) for each day of the planning horizon. In the first step we allow infeasible VRPTW due to violation of constraints as total duration of the routes, farm time windows or vehicle capacity. In order to help the hybrid GRASP-VND find high-quality and feasible solutions, we consider infeasible solutions during the search. Capacity, duration, and time window constraints can be violated and are penalized by including proportional penalty terms in the objective function. As a specific focus of our work, we experimentally compare different kinds of penalty functions. The penalty functions are described in the next subsection.

Following the second step, the GRASP is used to obtain an initial solution to each day of the planning horizon. This GRASP tries to satisfy the constraints. If this is not possible the GRASP procedure assigns customers that do not satisfy constraints to the last route. The initial solutions obtained by GRASP are improved by using a VND with three different movements:

- *Change visit combinations.* Change the visit combination of a farm with a new combination. The farm then has to be removed from routes of the days in the first combination that are not in the second one and inserted in the routes of the days that are in the new combination and not in the previous one.
- *k-chain moves.* Take a chain of k consecutive farms in a route of the solution and move it to another part of the same route or in other route.
- *k-swap moves.* Interchange the position of two chains with length k in the solution. Both chains can be in the same route or in different routes.

We consider a dynamic neighbourhood order to obtain high-quality solutions. We use a composition of h neighborhood structures, where $h = 9$, $N_1, ..., N_9$. The neighborhood structures *k-swap chain, k-move chain* and *change visit combination.* The nine neighborhood structures are the different combinations of the movements described above. A weight is assigned to each neighbourhood structure, this weight reflects the performance during the search.

This weight considers two measures; the improvement over time it_h^j and the utilization u_h^j of the neighbourhood structure. Given that a solution S^j at iteration j, let S^* be the solution obtained by $N_h(S^j)$ and t_h^j the CPU time spent, the measures are defined as follows:

- Improvement over time: $it_h^j = \frac{f(S^j)-f(S^*)}{t_h^j}$
- Utilization: u_h^j of N_h, the number of times neighborhood structure N_h has been applied.

In this way, when a neighborhood N_h is applied at iteration j, we calculate:

- $in_h^{j+1} = \delta \cdot in_h^j + (1-\delta) \cdot it_h^j, \delta \in [0,1)$ being a strategy parameter.
- $u_h^{j+1} = u_h^j + 1$

The corresponding weight of neighbourhood structure N_h is calculated as

$$r_h = \frac{in_h^j}{u_h^j} \tag{2}$$

. And the probability of selecting N_h as neighborhood structure to be applied is

$$p_h = \frac{r_h}{\sum_{h=1}^{k} r_h} \tag{3}$$

3.1 Penalized Cost Functions

To guide the search and help the hybrid GRASP-VNS find high-quality and feasible solutions we explicitly allow infeasible solutions during the search process.

We relax the constraints related with vehicle capacity Q, maximum working time D, and time windows.

For a solution S, we denote the quality of service objective function as

$$qos(S) = \frac{1}{n}\sum_{k=1}^{m}\sum_{i=0}^{n}\frac{s_{ik}-e_i}{l_i-e_i} \tag{4}$$

, total violation of load constraints as $q(S)$ calculated considering the maximum Q_k, total violation of time windows constraints $tw(S)$ calculated as

$$\sum_{k=1}^{m}\sum_{i=1}^{n}\max\{0, s_{ik}-l_i\} \tag{5}$$

, where s_{ik} is the time when vehicle k arrives to farm i, and total violation of duration constraints $rlt(S)$ calculated considering D_k. The objective function is defined as $f(S) = qos(S) + \alpha \cdot q(S) + \beta \cdot tw(S) + \gamma \cdot rlt(S)$, where α, β and γ are positive weight factors that depend on the kind of penalty function.

We propose two different kinds of penalty functions. The first one is a static penalty function where the penalty terms do not depend on the current iteration of the search process, therefore, remain constant during the entire search. Secondly a dynamic penalty function is proposed where the penalty term depends on the solutions obtained during the search. In both kind of penalty functions the values of α, β, γ are defined as follow:

- $\alpha = (q(S)_{max} - q(S)_{min})/q(S)_{avg}$
- $\beta = (tw(S)_{max} - tw(S)_{min})/tw(S)_{avg}$
- $\gamma = (rlt(S)_{max} - rlt(S)_{min})/rlt(S)_{avg}$

In the case of the static penalty function the maximum, minimum and average bounds of the violation of the constraints were obtained by preliminary computational experiments. In the dynamic penalty function the bounds are updated with the values obtained during the search.

4 Experimentation and Results

This section describes the results from the computational experiments that were carried out in our study. The aim of the experiment is to test the practical feasibility of the proposed hybrid procedure GRASP-VNS to solve the milk collection problem and compare the hybrid GRASP-VNS that considers infeasible solutions to the GRASP-VNS that discard infeasible solutions.

Only some characteristics from daily milk collection real-world data are known to us so far but no concrete instancdes are presently available. Therefore, we adapted benchmark instances for PVRPTW [3]. Specifically we use the instances p01, p07, p11 and p17 because the characteristics are similar to the real data. The data provides the position of a set of farms with service duration, demand and time windows, and we changed the visit combination for each dairy

Instances	Farms	Routes per day	Max. time per day	Max. load of truck	Days
$p01$	48	3	500	200	4
$p07$	72	5	500	200	6
$p11$	48	3	500	200	4
$p17$	72	4	500	200	6

Table 1. Characteristics of instances, taken from Cordeau et al [3]

farm by setting it as company data. The number of days of the planning horizon and the maximum number of routes for each day of the planning horizon is also included. For more details concerning the used instances, see Table 1.

Regarding the parameter of the hybrid GRASP-VNS, the size of the restricted candidate list is fixed to 5 and k_{max} for VND is set to 3. The solution approach was run 100 times for each of the instances and parameters used in experimentation. The results of the computational experiments can be seen in Table 2, where the hybrid GRASP-VNS with two kinds of penalty functions and the hybrid GRASP-VNS that discards infeasible solutions are compared. It can be seen that the results of the hybrid GRASP-VNS with dynamic penalized function are better.

		Penalty function	p01	p07	p11	p17
GRASP-VND	*Average*	Static	1.19	1.13	1.06	1.05
	Best		1.10	0.93	0.87	0.91
GRASP-VND	*Average*	Dynamic	1.17	1.05	0.98	0.95
	Best		1.06	0.89	0.81	0.72
GRASP-VND	*Average*	None	1.43	1.48	1.19	1.12
	Best		1.25	1.13	0.95	0.89

Table 2. Results on benchmark instances from Cordeau et al. [3]

5 Conclusions and Further Research

In this study, we presented a heuristic solution approach for the planning of the collection of fresh milk from local farms with a fleet of refrigerated vehicles, modeled as a variant of the PVRPTW. The proposed objective function is oriented towards the quality of service in order to preserve the quality of fresh milk. In order to solve the problem to get high quality solutions in reasonable time a hybrid GRASP-VNS metaheuristic has been used. The approach considers infeasible solutions during the search relaxing constraints and smoothing the search space, using two kind of penalty functions. The computational experiments confirm that the proposed approach is reasonable to practically solve this model. Future work will extend experimentation with other instances, among which some will be real cases. The behavior of other metaheuristics, other neighbourhood structures in VND procedure and other procedures for choosing initial visit combination per customer will also be studied. A special future line is related to using other kinds of penalty functions and other techniques to deal with infeasible solutions.

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