

A Hybrid Approach for Milk Collection Using Trucks and Trailers

Urooj Pasha^{*a}, Arild Hoff^a, Arne Løkketangen^b

^a Molde University College, P.O.Box 2110, NO-6402 Molde, Norway

^b Arne Løkketangen passed away June 10th 2013

Abstract

Collection and transportation of milk from farms to production factories is a crucial issue around the world. This problem can often be seen as a special case of the Truck and Trailer Vehicle Routing Problem (TTVRP) in which a trailer cannot be driven along with a truck to the farms and must be parked in the nearest available parking place while the truck visits farms and collects milk. Then, the truck returns to the parking place, transfers milk to the trailer and starts a new subroute or continues the route with the trailer. In this paper, we solve a real world planning and distribution problem for TINE SA which is the leading dairy company in Norway. A method involving a clustering technique followed by a heuristic based on tabu search is developed to solve this problem. The proposed method is able to find a cost-effective solution by using natural geographical clusters and choosing vehicle types that fit better to the farms production and the dairy plants demand. The new suggested solution produces a more suitable vehicle mix and collecting frequency, a better utilization of vehicles and smaller variable costs than the current route structure of the company.

Keywords: vehicle routing, tabu search, clustering

1. Introduction

Collection of milk from farms is a challenging vehicle routing problem. Milk is perishable so it must be collected from the farms and transported to the production plants as soon as possible. This problem is handled differently from country to country due to the varying nature of geographical and environmental conditions.

Geographically, milk farms are mostly located in the rural areas of a country. Due to the perishable nature of milk and the limited storage capacities at farms, it must be collected and transported to production factories within a given time limit. The production quantity of milk depends on the size of each farm, as the number of cows varies.

Trucks and trailers with different capacities/sizes are used for collection and are owned or hired by the company. Transportation companies usually desire to acquire fleet of vehicles which are not too expensive but have a high degree of reliability and durability and that will be optimally utilized. It is not economical to invest in a fleet mix which remains idle or unutilized in a given period. Thus the objective of the company is to choose an appropriate combination of trucks and trailers which could reduce the total transportation cost. In addition to the fleet composition problem, there are also weights and accessibility restrictions on the roads that make this problem more difficult. As a result of this added complexity in the problem constraints, the distribution planning decisions are harder to make. Transportation cost is a central aspect to be considered in distribution planning. It generally involves driver's cost, truck and trailer's acquisition cost, variable routing cost, toll road/ferry taxes and others. Thus, milk collection normally incurs a major transportation cost. Still, this type of problem is solved manually in most countries, like many other problems. In this paper, we provide a simple cost effective technique to this vehicle routing planning and distribution problem.

This paper describes a real world problem where TINE SA, the leading dairy company in Norway, collects and delivers raw milk from different farms to the production factories. The

* Corresponding author. E-mail: urooj.pasha@himolde.no

methodology developed and explained in this paper provides an economic solution to this type of problem. The special case of Truck and Trailer Vehicle Routing Problem considers four major aspects: fleet composition, multiple depot, routing decisions and location of parking places for trailers. Due to road limitations, a loaded truck with a trailer cannot be driven on roads leading to the farms and thus the routes are constructed such that the trailer must be temporarily parked in designated parking places while the truck has to be driven on a subroute to collect milk at the farms.

Routing decisions are concerned with assigning farms to a truck that is able to fulfill the farm's demand while satisfying the road restriction constraints. Farms may be serviced by one of three possible depots in this specific region. Here, depot is represented as a dairy / plant. Various types of trucks with or without trailers are available on the production factory. The capacity of each truck varies in terms of volume and weight.

The remainder of this paper is structured as follows. In Section 2, a brief overview of research related to the milk collection problem is presented. Section 3 gives a detailed description of the real world problem while the solution methodology is explained in Section 4. Information about real world data and tuning of parameters are demonstrated in section 5. Computational results are presented in Section 6, and conclusions and future recommendations have been made in Section 7.

2. Literature Review

The real world problem explained in this paper is a special type of truck and trailer vehicle routing problem which has not been directly addressed in the research literature. In last two decades, some work has been done related to this problem.

Chao (2002) and Scheuerer (2006) describe The Truck and Trailer Routing Problem (TTRP) with three underlying possibilities where customers are allocated to different types of truck or trailer combination. Under the first situation, a truck without trailer visits customers. In the second option, a truck carrying a trailer visits all customers on any route (main route or subroute). In the third and last condition, a truck with a trailer will visit all customers on the main route with the possibility of creating subroutes where the trailer will be decoupled and parked in any available parking place. A trailer is coupled and picked up when all customers are visited on a subroute. There can be one or more subroutes in one main route.

There are two sets of customers. The first set is defined as truck customers who can be visited by trucks only. The second set of customers can be visited by the whole vehicle. Both Chao (2002) and Scheuerer (2006) have developed a tabu search heuristic to solve the problem, and test their heuristic on 21 modified test instances taken from the literature on Vehicle Routing problems.

Gerdessen (1996) demonstrates another variant of the TTRP where a truck with a trailer is having exactly one subroute on a current route. The customers on a subroute are served by a truck only while the trailer is parked. It is assumed that each customer is having unit demand. She referred to another application area in the real world where the Dutch dairy industry distributes their products and customers can be located in any urban cities.

According to the problem description given in this paper, all customers are accessible with a truck carrying trailer, but some are located in places where maneuvering the truck and trailer combination is difficult and will increase the service time considerably.

Butler et al. (1997) introduces the Two-Period Travelling Salesman Problem (TP-TSP) for an Irish dairy plant in the county of Dublin as an extension of the Symmetric Travelling Salesman Problem (STSP). It comprises of two assumptions. The first assumption says that some farms are visited daily and covered by exactly one route for milk collection. The second assumption is that the remaining farms are covered once by only one of the routes, which require

a visit every second day. The combination of polyhedral theory with branch and bound approach is used and results are reposted.

Tan et al. (2006) lays out the Hybrid Multi Objective Evolutionary Algorithm (HMOEA) to find the optimal Pareto routing solutions for a variant of TTRP which deals with the movement of unloaded or loaded containers for a logistical company. A truck carrying a trailer services a customer and a trailer (emptied or laden) is left for two days at a customer's location and later picked by the same or any other vehicle.

Claassen & Hendriks (2007) highlighted the periodic goat's milk collection problem for the Dutch dairy industry. It envisions the importance of possible rhythms for processing of goat's milk along with a constricted schedule of cow's milk. According to them, the presented decision support system provides a starting point in the formulation of the Vehicle Routing Problem (VRP). The objective is to create a feasible two-week schedule for visiting farms to collect milk and also meet the demand at the production plants. Most of the farms process a large quantity of cow's milk. There are also a limited number of dairy plants processing goat milk and need to have set up time to process goat milk once or twice in a week at maximum depending on the demand. The methodology used is the Special Ordered Sets (SOS) of type I to find the rhythm combination when to visit farms.

Nag et al. (1988) describes the Site-Dependent VRP which incorporate different types and capacities of vehicles and restrictions about which vehicles can serve each of the customers.

Semet & Taillard (1993) focused on the usage of trailer with some accessibility restrictions and developed a mathematical model for the Partial Accessibility Constrained Vehicle Routing Problem (PACVRP) (Semet, 1995). They have worked on real world problem which deals with the distribution of goods to its retailers for a Swiss grocery chain company. A loaded vehicle with a trailer can visit some retailers and some of them cannot be reached with a loaded trailer so it must be parked before visiting them. A vehicle can have only one subroute in an existing route.

The idea of mobile depots is discussed by Del Pia & Fillipi (2006) and shown on the problem of waste collection in Due Carrare, northern Italy. In this problem two types of routes are constructed i.e. one with compactors (large vehicles) and other with satellite (small vehicles). Due to the compactor's size, it cannot go through narrow streets. The objective is to make a routing plan such that the compactor and satellite meet at a customer's place at a specified time and the waste is transferred from the satellite to the compactor. The same concept is used in the milk collection problem, as it is more practical to have a trailer attached to a truck while on the routes to farms located in remote areas. Such a trailer and truck can visit more farms in the same area and does not need to return to the plant when truck's tank is full.

3. Problem Description

TINE SA is the largest dairy producer in Norway. It is cooperatively owned by around 15850 farms all over the country. The company's core business is production and processing of dairy products such as milk, cheese, yoghurt, butter and cream etc. The TINE company is organized in five different regions covering Norway and there are several dairy plants in each region. In this paper, we will look at a subproblem for region TINE Midt Norge where milk collection is considered for the northern part of Møre and Romsdal county in western Norway. This particular region has three dairy plants covering 990 farms in twenty different municipalities and these plants are located in three different areas.

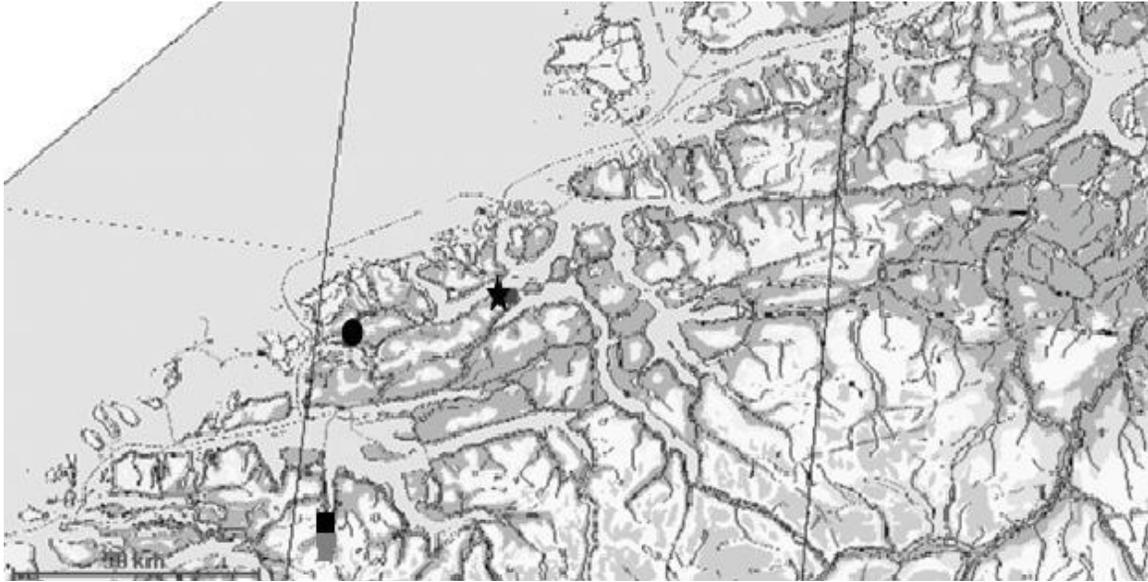


Figure 1. Locations of three dairy plants in the northern part of Møre and Romsdal County.

The locations of the three dairy plants are shown on the map in Figure 1. The largest plant, which accommodates 77.2% of the total delivery from all suppliers, is located in Elnesvågen and is represented by a circle. The second largest plant which covers 17.4% of the total is located in Høgset and is represented by a star. The smallest plant is located in Tresfjord and is indicated by a square. It handles the remaining of the total delivery which is 5.4%. All farms have a given production amount each day depending on the actual number of cows on the farm. The strategic decisions regarding transportation planning are considered with the average milk production per day.

For milk collection, a number of heterogeneous vehicles are available in each plant, and the vehicles vary in capacities and costs. The trucks can be used with or without trailers of different sizes. There are two types of major costs associated with the use of a vehicle; vehicle acquisition cost and variable driving cost. Vehicle acquisition cost is not considered in our problem as trucks and trailers with various capacities are owned by the TINE Company itself, and we can assume that the needed vehicles are available. The vehicle fleet is continuously upgraded when old vehicles are phased out and new vehicles are acquired, and the decision of what type of vehicles to purchase will be decided by the favorable collecting strategy.

The variable driving costs are calculated depending on the type and size of each truck and trailer. The driver's wage is added to the objective function value for a truck but not for a trailer as a trailer cannot be driven alone. A number of trucks with or without trailers are allocated to each dairy plant and drive daily routes which return to the same plant after visiting all farms on the particular route that day. It is not allowed that a parked trailer is picked by other truck which is collecting milk in a nearby area. Regardless of the size and type of truck/trailer combination, it makes a single route, and all farms can be visited by trucks only.

The milk produced in the largest farm can easily be collected by the smallest truck type so there are no restrictions on which type of truck that can serve a farm. Each farm has a cooler-tank for storing milk until the vehicle collects it. However, the maximum time for storing milk in these tanks are three days, and thus routes should be planned such that each farm is visited at least every third day. The company uses three different frequencies for milk collection and these frequencies are not standardized in their current policy. The frequency codes are named as 6x2, 7x2 and 7x3. The routes using a 6x2 frequency will be driven every second day but not on Sundays. For frequency code 7x2 a two day frequency is also used and Sundays are considered

as a normal working day. In frequency code 7x3, the routes will be driven every third day and all days are considered as working days.

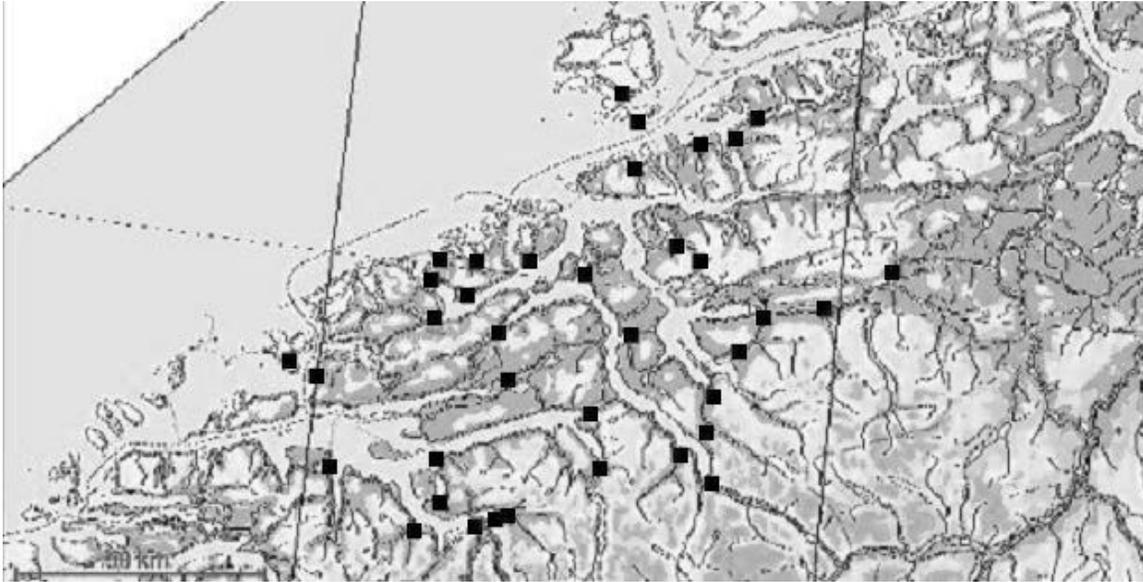


Figure 2. Parking places in the northern part of Møre and Romsdal

Western Norway is a region which consists of mountains, fjords and islands and it is not always easy to go from one place to another with very large vehicles. Due to the distinctive nature of the problem, trucks cannot be driven with trailers on some roads, so routes must be planned including a parking place for the trailer. The company rents thirty seven prearranged parking places at petrol stations or large parking lots in this region. The locations of these parking places are shown by black squares in Figure 2.

These parking places are used to park the trailer while the truck drives a subroute to collect milk. Since this region consists of several fjords and islands, ferries are often used to connect the different municipalities in the county. In the last decades, bridges and tunnels have been constructed to replace ferries and to pass these bridges and tunnels one have to pay toll taxes. Thus, when calculating the cost of a route one has to consider both toll taxes and ferry prices in addition to other variable costs. The main objective for the company when deciding the route structure is to minimize the total transportation cost which includes the variable driving costs \acute{u} , driver's wage for each vehicle $\acute{\omega}$ and extra costs \acute{o} which arise when passing a toll road or taking a ferry. Thus, the objective function defined in Equation 1 will give the total cost produced by a solution. Any solution s can then be evaluated and compared with others by looking at the objective function value $f(s)$.

$$f(s) = \acute{u}(s) + \acute{\omega}(s) + \acute{o}(s) \quad (1)$$

The partial structure of a solution is presented in Figure 3. This figure represents one route in a solution having four subroutes and in which three parking places denoted by squares are used. An empty truck carrying a trailer leaves the depot represented by the outlined square, then parks the trailer on a prearranged parking place and visits farms which are represented by circles for collection of milk. Then the truck returns to the parking place, transfers milk to the trailer and starts on a new subroute either from the same parking place or by moving the trailer to a new parking place which will be the starting point for the next subroute.

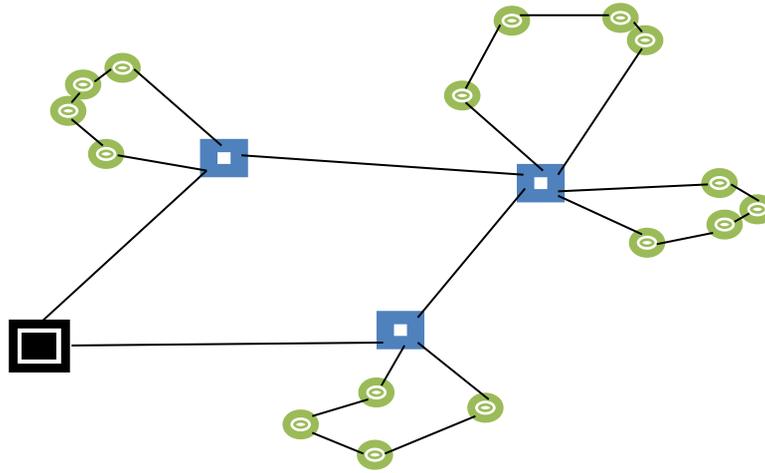


Figure 3. Partial route structure when a truck carries a trailer

4. Proposed Methodology

A method based on the well-known meta-heuristics tabu search (Glover & Laguna, 1997) was used to solve this problem. The solution to the problem is represented as a series of routes where each vehicle drives different routes within a given frequency such that all farms are visited once during this period. As suggested by Hoff & Løkketangen (2008), all routes in our solutions are planned with a 7x3 frequency where each farm is visited every third day.

The following section explains the main distinctive features of methodology used to solve this problem.

4.1. Initial Solution

Construction of an initial solution is an important step for creating a good starting point for any searching procedure. Hoff & Løkketangen (2008) used a technique which chooses seeding orders for each route according to preliminary knowledge represented by the routes in the company's current solution and clustered other orders around these. Knowing that the current route structure partly has historical reasons and that a new fleet mix would probably need another way of organizing the routes, several other ways of constructing the initial solution were tested.

Initially, a technique of allocating farms to the nearest plant on the basis of minimum distance from the plants, and then creating the single routes on the same basis were tried. However, this technique was not able to utilize the clusters created by natural borders like mountains and fjords, and the resulting routes became both longer in distance and contained several unnecessary ferry and toll road crossings. By using this technique to create initial solutions and run a similar search as presented later in this paper, the resulting solutions turned out to be 21 % more costly than the current company solution. Results are shown in Table 3 in the computational results section. Rather than using distance alone, a combination of distance and clustering approach was considered to be a better way of constructing an initial solution.

Clustering farms into groups or subgroups are typically done on the basis of similarities, which in this problem can be defined as travelling distance, geographical location and demand required for a cluster/subcluster. A new technique was created by defining each municipality as a major cluster and thus the natural boundaries between the municipalities would be utilized. Then the next step would be to assign the municipality clusters to the appropriate production factories depending on minimum travel distance. The size of the clusters would however vary very much as the number of farms varies between two and one hundred and fifty in each municipality.

To assign clusters to plants, the distance from each plant to the closest farm in each cluster is stored. The total production of milk in each cluster would be summed up and on the basis of the distance; one cluster at a time is allocated to the closest plant. When a plant reaches its capacity, it is removed from the possible plants for allocation of the remaining clusters, and the process continues until all clusters are assigned to one plant. Clusters will rarely fit exactly into the demand of a plant, and thus the last cluster to be assigned to a plant will violate the plant capacity and needs to be split. Thus, the farms in that cluster which is furthest away from the plant are transferred to the second closest plant until the capacity is met.

The fleet mix is chosen on the basis of the individual plant's demand. To minimize the total transportation cost, it is considered that the number of crossings required for toll taxes or taking ferries has to be reduced. This is because some of the farms are located on islands where vehicles need to pass through some bottlenecks to reach the farms for milk collection.

The municipality clusters are also used to determine the trucks and trailers mix at each plant. A truck and trailer combination with capacity of 33500 kilograms is used as the standard vehicle type for the different routes as this loaded capacity will make the vehicle's weight close to the upper limit given by the Norwegian road authorities. It is recommended by Hoff & Løkketangen (2008) that a large truck should be used with a smaller trailer rather than the opposite as this combination will reduce the necessary number of subroutes and consequently the total travelling distance. Thus, a truck with capacity of 18500 kg. carrying a trailer with capacity of 15000 kg was considered as the best option. The number of vehicles with this truck and trailer combination is calculated by dividing the total demand of each plant with the capacity of this standard vehicle. The last vehicle at each plant is selected as an appropriate truck or truck and trailer combination which fits well to the remaining demand at the plant.

Algorithm for construction of initial solution for TTVRP

1. Calculate the demand from each plant D_i
2. Find the distance from each plant to the nearest farm in each municipality M_i and sort municipalities according to that distance
3. Calculate the total production p_j in each municipality M_i
4. Find the number of standard vehicles required for each plant and calculate the remaining demand.
5. Loop through all vehicle types with larger capacity than the remaining demand. Choose the vehicle with capacity closest to the remaining demand for each plant. In case of a tie, the vehicle combination with the largest truck is chosen in preference to a vehicle with a smaller truck and larger trailer.
6. Loop through the sorted list of municipalities
 - i. Allocate municipalities one by one to the closest plant D_i as long as the capacity is not exceeded.
 - ii. if (municipality production > remaining plant capacity) move farms furthest away from the plant to the second closest plant
7. Calculate the number of routes to each plant as the number of vehicles multiplied by the visiting frequency
8. Assign a vehicle to each route
9. Loop through all plants
 - i. Loop through all routes assigned to that plant
 - ii. Loop through all municipalities assigned to that plant
 - iii. Choose the farm furthest away from the plant in a municipality as the seeding farm.

- iv. Assign farms with shortest distance from the seeding farm to the same route until the vehicle gets full
10. Loop through all routes
- i. A TSP-tour is created among the farms on the routes by selecting the closest unselected farm as the next on route and returning to the plant when all farms are chosen.
 - ii. A local search using the 2-opt neighborhood is performed on the TSP-tour as described in Lin (1965)
 - iii. Subroutes are created by following the TSP-tour and adding the farm's production together until the truck capacity is reached.
 - iv. Then the closest parking place to the last farm is inserted and a new subroute is created from the next farm.
 - v. The procedure is repeated until the TSP-tour is divided into subroutes which all can be served by the single truck.
 - vi. A local search with a 2-opt neighborhood is performed on all subroutes.
 - vii. The parking place with the closest combined distance to the first and last farm on the subroute is selected.

4.2. Neighborhood

Based on the initial solution found by the algorithm presented in Section 4.1, a search to improve the solution is implemented with a simple λ -interchange neighborhood using $\lambda=1$. This neighborhood is proposed by Osman (1993) and consists of shift or swap moves where one farm is either shifted from its existing route to another route or swapped with a farm in another route.

Although using this neighborhood gives a large number of possible moves, it still keeps the neighborhood structure very simple. After a move, a re-optimization procedure consisting of a 2-opt local search and selection of the most appropriate parking place, is applied on the subroutes affected by the shift or swap move. Unlike the farms, the parking places do not have to be visited separately, but will only be used when it is considered favorably.

4.3. Reduction of Neighborhood

In this real world instance with 990 nodes, the number of possible moves will be very high if all farms should be able to move or swap with all possible farms in all other routes. However, it is not advisable to check all possible moves in this neighborhood as some moves can be rejected directly since it is unlikely that they can lead to a good solution. This idea about not considering moves which contains attributes that probably will not be included in a good feasible solution is described by Toth & Vigo (2003) as *Granular Tabu Search*. Scheuerer (2006) has utilized this idea by introducing an *h-neighborhood*. In the technique, each node is registered with the given number h of its closest nodes, and moves of a node to a route not containing any of its h closest nodes are not considered as relevant.

In our problem, we use the *h-neighborhood* to select farms that should be considered for a move or swap to another route according to the procedure given in section 4.6. By counting the number of *h-neighbors* outside its own route, we will get an indication of which farms could be favorable candidates to move to another route. Together with tabu and diversification criteria described below, this number is used to compare the candidate farms and select one for moving or swapping in the current iteration. The selected farm is tried with both shift and swap moves and the move leading to the best solution is performed. Searching for the best value of the parameter h in the *h-neighborhood* is done during preliminary testing.

4.4. Tabu Criterion

Tabu tenure is an important parameter in tabu search and is described as the number of iterations a farm will be kept tabu after a move. It is represented by symbol τ . A variable tabu tenure suggested by Glover & Laguna (1997) is implemented as it will prevent the search from going into loops. A farm that is shifted or swapped in a single iteration will be kept tabu for the next τ number of iterations. These farms will not be considered for a move in the coming iterations unless it meets the aspiration criteria, i.e. leads to a new overall best solution. One tabu farm can however be chosen in combination with a non tabu farm for a swap move.

4.5. Penalty Function for Infeasible Solutions

Our search explores both the feasible and infeasible space. It is commendable to allow the search to ascertain good quality solutions around the boundary between feasible and infeasible solutions. In this problem, the aspects mentioned below can lead to infeasibility.

1. A plant gets less delivery of milk than its required demand.
2. A route surpasses a distance which represents the limit of a normal working day.
3. A vehicle serving a route has a total demand that exceeds its capacity.

For solutions violating the first two constraints, a large static penalty is used to avoid such solutions to be chosen. Preliminary tests showed that including these types of infeasibilities was not able to improve the search. A solution violating the last constraint where the load exceeds the vehicle capacity is however considered to be a crucial and interesting type of infeasibility which can lead to better feasible solutions if included in the search. Thus they should be observed and penalized in a proper way. A dynamic penalty is used to make the search oscillate between feasible and infeasible solutions and it is attuned during the search. The penalty is calculated for an overload in a solution in same way as introduced by Gendreau et al. (1994) and is adjusted according to our problem. The penalty is given by:

$$\beta(s) = \alpha(\sum_r(L_r - Q)^+ + \sum_r \sum_{i \in R_r}(L_{ir} - Q_t)^+) \quad (2)$$

In the above given Equation (2), α is an adjustment factor which is multiplied or divided with a value κ depending on feasibility or infeasibility of the solution respectively. The total load of a route r is represented by L_r and the total capacity of the vehicle allocated to route r is denoted as Q . L_{ir} is the truckload on subroute i in route r . Routes in a solution are denoted by r and all subroutes in a route are symbolized by R_r . A vehicle can carry a trailer and the total capacity is represented by Q while the capacity of the truck is indicated by Q_t . The positive difference is denoted as $(x)^+ = \max\{0, x\}$ where x represents $(L - R)$ in the formula. That is if there is an overload either on the route or a subroute, the positive difference is the difference between the load and the capacity, otherwise it is zero. $\beta(s)$ is the penalty for a solution s which is added to the objective function given in Equation (1) for the evaluation of different solutions.

4.6. Diversification and Move Selection Procedure

The effect of the diversification strategy can be understood by its naming convention. It aims to diversify the search and try to lead it in another direction to explore a new area of the search space. This is done by penalizing moves that are performed often during the search. A counter $\theta(f)$ is used to count the number of times a farm f is selected to be moved from one route to

another. Thus, the idea is to make it less probable to choose a farm with a high value on this counter.

Every iteration of the search each route is analyzed and one farm is selected for a possible move or swap to any of the other routes. The selection criterion for which farm to choose is based on a fitness function $\xi(f)$, and in addition to the diversification counter, the fitness function includes a factor $\psi(f)$ which is calculated for each farm. This factor describes the number of *h-neighbors* of that farm that resides inside its current route. A move including a farm with a high number of its closest neighboring farms on the same route is less likely to lead to a good solution than if the number is low, i.e. other routes are serving the area close to that farm. The fitness function is shown in Equation (3) given by:

$$\xi(f) = \psi(f) + v \cdot \vartheta(f) \quad (3)$$

A diversification factor v is multiplied with the counter $\theta(f)$ and added to the factor $\psi(f)$. The non tabu farm which will be considered for a move is the one that gives the lowest value of $\xi(s)$. In case of more than one farm with the same value, one of them will be picked at random.

4.7. Merging and Splitting Technique (MST)

As the different possible vehicles vary according to capacity and variable cost, it is vital to select the most appropriate truck and trailer combination to get effective routes and then minimize the total transportation costs. This technique is devised to change the existing truck and trailer vehicle mix during the search for exploring different combinations than the one selected while creating an initial solution.

The MST is based on a basic and simple concept where the route with the biggest slack is chosen for a change of vehicle after a given number of non-improving iterations in the search. This technique helps to identify the most proper fleet mix as suggested by Pasha et al. (2013). If that route is using a large truck and trailer combination, it will be split into two routes with smaller vehicles which can cope with the total demand. If the route is already being served with a small truck, it should be merged with another similar route and a larger vehicle should be assigned to a route serving the farms in the two merged routes.

To implement the technique, the plant which has maximum deviation from the required demand for production is selected first. Then all routes assigned to this plant are evaluated and the route with the biggest difference between capacity and actual demand is selected for splitting or merging depending on the vehicle assigned to that route. In our tests, we tried to implement this technique with different calling frequencies, but this did not improve the solution quality from the initial fleet mix. As a result, we come to the conclusion that the initial way of selecting vehicles must be considered as a good strategy for deciding which vehicle types to use. Comparisons are shown in the computational results Section 6, Table 3.

4.8. Insertion of Parking Places

The decision about which parking places to use for the subroutes is crucial for evaluating the quality of the routes. In addition to the thirty seven places hired from land owners around the county, the dairy plants should be considered as additional parking places.

When the plant assigned to the route is considered as the optimal parking place for a subroute, it means that a trailer is superfluous on that subroute since the milk can be transferred directly to the dairy plant from the truck tank. Thus the variable costs can be reduced on that route as driving a single truck will be less expensive than when a trailer is attached to the truck.

To decide which parking place to use on which subroute, farms are grouped together in clusters with a total demand corresponding to the capacity of the truck. Then the routes serving the farms in the clusters are optimized as a Traveling Salesman Problem with different parking places included, and the parking place which gives smallest variable costs are chosen. This optimization process is performed with a simple local search using a 2-opt neighborhood, and a re-optimization is done every time a route is changed by a shift or swap move.

A 2-opt neighborhood is described by Lin (1965) and can be briefly explained as swapping position between two farms in a route and visiting the farms between them in the reverse direction. Hoff & Løkketangen (2008) showed that the option of using different parking places for different subroutes gave better solutions than if the same parking place had to be used for all subroutes in one tour. However, this option will use some extra time when it comes to coupling and decoupling the trailer.

4.9. Termination Criterion

The tests are run by using a fixed number of iterations η as the termination criteria.

5. Company's Data and Tuning of Parameters

The final computation is done on Intel Pentium(R)-IV machines with a 2.4 GHz processors and using the Windows XP Professional operating system. The solver for the milk collection problem is coded in Microsoft Visual studio 2007 using C++.

5.1. Data Section

The TINE SA Company's data is provided in Table 1.

Table 1. Problem instance data

Data	Number	Range
Plant's demand	3	[15570, 49660, 221217] kg.
Truck types	7	[5000-18500] kg.
Trailer types	8	[11000-19000] kg.
Number of farms	990	[7-2121] kg / day.
Municipalities	20	
Possible parking places	37	

There are three plants available in this county to cover the demand of 990 farms. These plants vary in production capacities. The smallest, medium, and largest plants have a daily demand of approximately 15570, 49660 and 221217 kilograms to meet their production plans. The company has seven types of trucks and eight types of trailers having different tank capacities. The trucks can accommodate between 5000 to 18500 kilograms of milk. Trailers capacities range from 11000 to 19000 kilograms. However, due to road and engine restrictions, all combinations of these trucks and trailers are not possible and one reckons twenty one different legal combinations of truck and trailers with a minimum weight of 21000 and a maximum of 34000 kilograms.

A vehicle is allowed to carry 34000 kilograms at maximum and more than this weight are not allowed to be driven on the Norwegian roads. A truck can serve a route alone, or it can carry one trailer which has to be parked before the truck visits the farms since the roads leading to those will have an even smaller weight limitations. The farms are located in twenty different

municipalities, and the location will be in rural areas around a city, town or village, or on an island, in a valley or at a hill-side. TINE SA is hiring thirty seven possible parking places in these municipalities, typically in petrol stations or larger parking areas. These parking places can be used to park the trailer when the single truck visits the farms to collect the milk.

5.2. Tuning of Parameters

A careful selection of parameters is essential to take advantage of the tabu search procedure based on the clustering technique in the best possible way. Numerous tests have been performed to find suitable parameters values for the given problem for 1000 iterations. The results are shown in the following section.

5.2.1. Standard Vehicles

When constructing the initial solution, one vehicle type needs to be defined as standard for the majority of the tours. Hoff & Løkketangen (2008) recommend that a vehicle combination should have as large capacity as possible and when the total capacity is equal, a large truck and small trailer should be preferred over a smaller truck and larger trailer. To confirm the suitability and robustness of this combination of truck and trailer selection, a test has been performed with two truck and trailer combinations with the same total capacity. The results are presented graphically in Figure 4.

The objective function values for the solutions are determined using the function in Equation 1. Vehicle types represent different naming conventions i.e. V-71 or 14.5/19 and V-39 or 18.5/15.

The truck and trailer combination named as ‘V-71’ and ‘V-39’ both have a total capacity of 33500. The difference between these vehicle types is that for truck type 71 the tank’s capacity is 14500 kilogram and the trailer’s tank capacity is 19000 kilogram. On the other hand, the tank capacity for truck type V-39 is 18500 kilogram and the trailer’s tank capacity is 15000 kilogram.

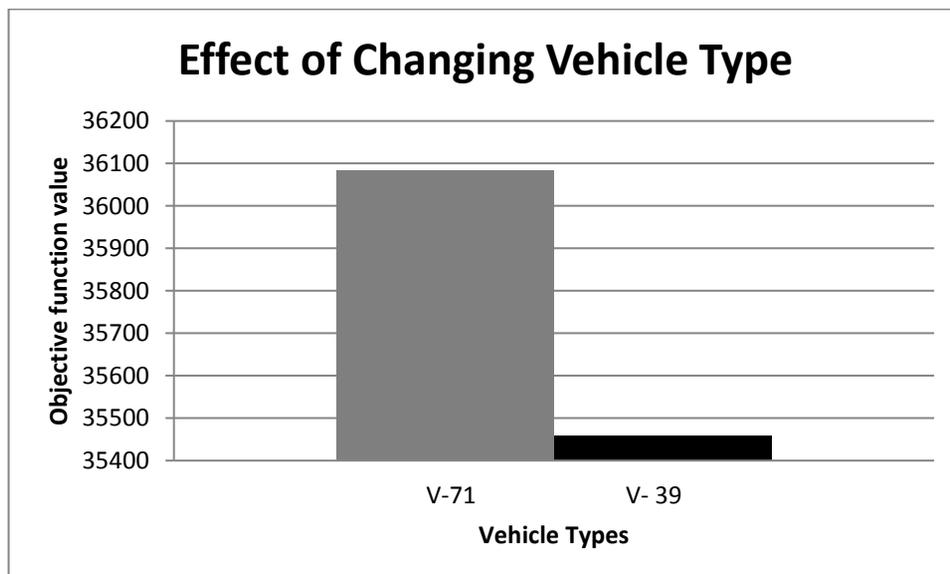


Figure 4. Different truck and trailer combinations with the same total capacity

From the graph in Figure 4, it can be seen that using the 18.5/15 combination as the standard vehicle gives a significant lower total cost than using the alternative 14.5/19

combination. Even if the total capacity is equal, the routes with the larger vehicles will make larger subroute tours before returning to transfer the milk to the trailer. This produces solutions with a smaller number of subroute tours and also less extra costs of ferries and toll road. The transportation cost includes fixed vehicle acquisition cost, variable driving costs and toll taxes / ferry rates. In order to minimize the total transportation cost these ferry and toll roads which typically leads to islands or distant areas, can be considered as costly bottlenecks which should be reduced to a minimal required level. A larger truck might be able to serve the necessary number of farms on the other side of the crossings and avoid a new visit to the same area. Hence, our tests confirm the conclusion from Hoff & Løkketangen (2008) that using a truck with a larger tank is more rational and economic to use.

5.2.2. Plant Shortage

Each plant has a certain requirement of milk per day to meet their planned production and the current routes are constructed to meet this requirement. This is also considered when assigning farms to dairy plants in the initial solution. Still by allowing some flexibility regarding the exact amount of milk delivered to the plants, it could be possible to find more effective routes during the search. Then the cost of transportation can be reduced and this reduction should be evaluated against the inconvenience of a possible reduced production.

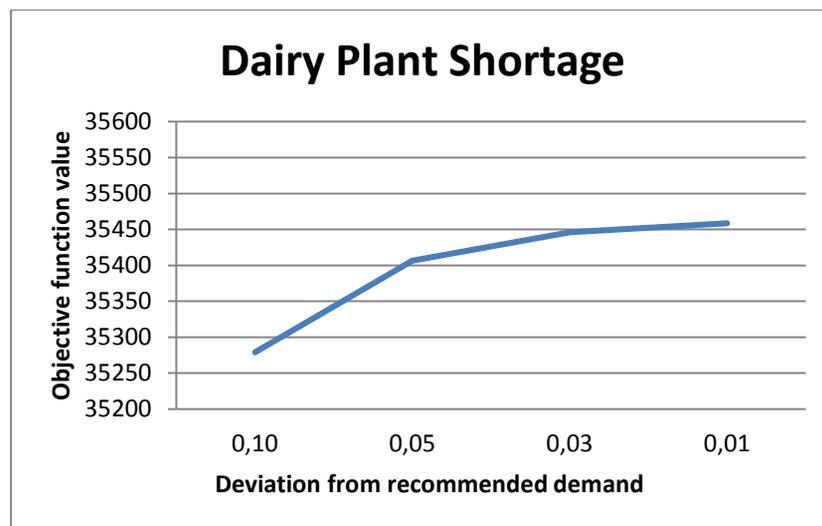


Figure 5. Effect of allowing reduced delivery on some plants

Figure 5 shows the objective value for searches with different allowed shortages at the plants. The objective function value is calculated by using the function described in equation (1). In our test we used a maximum shortage of 5 % deviation from the recommended demand as this is within the acceptable slack for the company.

5.2.3. Number of Nearest Neighboring Farms

As explained in Section 4.3, the size of the neighbourhood was reduced by introducing the h -neighborhood with a given number of the closest neighbors to each farm. Thus, when selecting an appropriate move, all possibilities do not need to be explored as moving a farm to a route far away logically will not lead to a better solution.

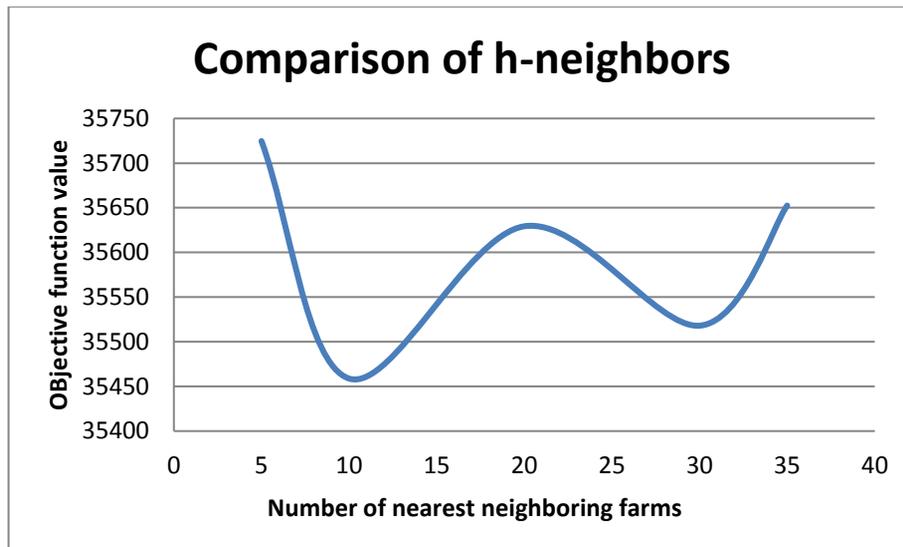


Figure 6. Effect of using different number of h -neighbors

The decision about the value of h , i.e. about how many of the neighboring farms should be considered to be close would then be subject to thorough testing. Figure 6 shows the resulting objective value for different values of h . As can be seen in the figure, the minimum costs are found with an h -value of 10. Increasing the number of h -neighbors for move evaluation from that value would not give any better solution and only lead to longer processing time per iteration. The reason for the poorer result for the higher values of h is probably the increased size of the neighborhood which makes it more difficult to identify the best moves.

5.2.4. Other Parameter Values

Some of the parameters mentioned below were used and recommended by Hoff and Løkketangen. For further details, see Hoff & Løkketangen (2008).

- *Tabu Tenure.* A variable tabu tenure between 8 and 16 iterations is used.
- *Visiting frequency.* Using a three day visiting frequency for this milk collection problem is the best decision.
- *Penalty and Penalty factor.* A dynamic penalty factor is implemented and it is adjusted automatically during the search.

6. Computational Results

The parameters used for final implementation are shown in Table 2.

Table 2. Initial values of parameters

Parameters	Notation	Initial Values
Tabu tenure	τ	Randomly [4, 16]
Neighborhood structure	λ	1-interchange
h -neighbors	h	10
Initial penalty factor	α	1
Penalty adjustment factor	κ	1 .1
Visiting frequency	δ	7x3

Diversification factor	χ	0.75
Termination criterion	η	5000 iterations

The first column of Table 2 lists the necessary parameters required for the successful implementation of the algorithm used in this paper. The corresponding notations are given in the second column, and the values of the parameters are presented in the last column.

In Table 3, the different types of distance or associated costs are explained in the first column. TINE SA's current solution, Hoff and Løkketangen's (see Hoff & Løkketangen (2008)), and the solution explained in Section 4.1 with the minimum distance initial solution are presented in column 1, 2 and 3, respectively while the solutions by the current paper of Pasha et al. (2014) with or without MST are presented in columns 4 and 5 respectively. Costs are given in the currency Norwegian kroner (NOK).

It can be seen that the solution found by using our methodology will decrease the company's current solution cost by 12.86% per day. The company's current solution uses different truck and trailer combinations and also has different visiting frequencies, while our solution uses a three day frequency and standardized vehicles on most of the routes. The best option in our tests show that vehicles of capacity 33500 kg are most economic to use as standard vehicles on most of the routes as this weight is close to the upper limit on the road restrictions.

Table 3. Comparison of solutions

Distance/cost	1	2	3	4	5
Distance driven per day	2888.17	2664.23	4022.71	2628.50	2655.93
Variable driving cost per day	16056.70	15985.39	22019.58	15566.00	15652.03
Extra cost per day	5257.14	4900.00	7657.14	5100.00	4750.00
Driver's wage per day	18642.90	16500.00	18642.86	15000.00	15000.00
Total cost per day	39956.74	37385.39	48319.58	35666.00	35402.03

Columns 1, 2, 3, 4 and 5 in the first row of the table represent the following solutions:

1. TINE SA's current solution cost.
2. Cost of solution found by Hoff & Løkketangen (2008).
3. Cost of solution found by Pasha et al. using minimum distance initial solution.
4. Cost of solution found by Pasha et al. with MST.
5. Cost of solution found by Pasha et al. without MST.

By using the Merging and Splitting Technique (MST) in the search, a solution with a more diverse fleet mix is achieved, but this solution is not better than the solution found without this technique. However, this solution is also significantly better (12.03%) than the existing solution used by the company. The distance driven and corresponding variable costs per day is 2628.5 and 15566 respectively which actually are less than the best solution obtained without using this technique. However, the extra costs for using ferries and toll road have been increased, which means that the routes served with smaller vehicles will have to cross these bottlenecks more often than necessary.

The road structure in Western Norway is in an extensive construction phase. New bridges and tunnels are built to replace ferries or to pass natural boundaries like mountains and fjords. These projects are to a high degree financed as toll roads, and when the projects are paid off, the tolls are removed. Consequently the optimal solution might change when a new project is completed or a toll road is made free of charge. In real world problems the searching method described with or without MST can give a company an opportunity to choose between different solutions depending on what fits best to the existing situation. In geographical areas without

ferries and toll roads, the solution might better utilize a diverse fleet mix which can be identified by using the MST strategy.

Our method of using municipality clusters to construct initial solutions was able to find an acceptable solution to use as the starting point of the search. In our tests the partial neighborhood examination strategy proposed by Semet (1995) and used by Hoff & Løkketangen (2008) to reduce the searching time, resulted in significantly poorer results and was omitted in our final solution method. We have found that using the clustering approach combined with a method based on tabu search can lead to good decisions about the fleet mix and optimization of routes for this planning and distribution problem.

One route associated with the largest plant in Elnesvågen (denoted as A in the map) is graphically represented in Figure 7. The particular route uses the V-39 truck and trailer combination with a total capacity of 33500 kilograms and a truck capacity of 18500 kilograms.

The main route is shown in bold lines in the figure, while the two subroutes are shown in thin lines. The vehicle first visits the northern island of Smøla where it can park the trailer at the parking place at position C. Then the truck drives a subroute to visit thirteen farms on that island before it returns to the parking place and transfer milk to the trailer.

The demand on that subroute is 14400 kilograms which fits easily into the tank's capacity. Then the vehicle will return on the same road as it came and make a new stop at a parking place on position B at the southern island of Averøy. It starts another subroute and visits twenty five farms with a total demand of 17796 kilogram of milk before picking up the trailer and going back to the Elnesvågen plant. The utilization of the vehicle is approximately 96.7% with slack of approx. 3.3%. The route is driven every third day and makes a total cost of NOK 5178 which gives a day cost of NOK 1726.

By analysing this particular route, we can see that the structure of the main route is not a cycle shape, but is rather following the main roads from the dairy plant to the particular islands. In this case the driver should consider leaving the trailer at the parking place at Averøy when it passes that island first. Even if it is a small detour, the truck would not have to carry the trailer all the way to Smøla and would also save the extra inconvenience of coupling/decoupling the trailer.



Figure 7. Route attached with Elnesvågen plant using the V-39 vehicle type

7. Summary, Conclusions and Future Research

7.1. Summary

In this paper, a clustering technique is used to create an initial solution as a starting point for a search based on the tabu search heuristic. We have used a simple idea of considering natural boundaries between municipalities to define clusters. Clustering technique in combination with a strategy for selecting a truck and trailer fleet mix can be used to create an initial solution. This technique gave rise to an initial fleet mix which turned out to be a good basis for creating routes for visiting farms and collecting milk. From the initial solution, a tabu search procedure is run to improve the solution and the final result turned out to be a good suggestion for a less expensive routing strategy for this large real world problem for milk collection in the Norwegian dairy industry.

7.2. Conclusions

The methodology used in this paper is simple and effective and is able to identify a good solution for collecting milk in this area. The idea of using a trailer as a mobile depot is cost effective, and a large truck carrying a smaller trailer is better than any other arrangement or than any other truck-trailer combination. Also the visiting frequency should be increased to every third day. In the company's current solution, some routes still use the two-day frequency.

In this region with a lot of bottlenecks such as ferries and toll roads, the use of the Merging and Splitting Technique did not lead to a better solution, as the initial solution with mostly large vehicles turned out to be the best fleet mix. When a bottleneck is crossed, it is better to visit as many farms as possible to avoid more crossings than necessary. However the search in which this technique is used, produced a solution with a slightly smaller driving distance, but with higher extra ferry and toll road costs. This may indicate that in areas without such bottlenecks, the possibility of changing the fleet mix might be better to identify vehicles with a capacity adjusted to the total demand for a group of farms. Thus, this strategy should not be abandoned but rather, it should be used as an alternative method of creating solutions.

7.3. Suggestions for Future Research

We have solved a real world problem related to the well-defined Truck and Trailer Routing Problem. Further research in this area will consider the problem of meeting ferry times and the possibility of extending routes beyond the maximum given distance for a higher cost, i.e. overtime payment for drivers. It is also possible to consider uncertainties in both daily production and driving times. Other problems that are not addressed in our research but are very important in the real world is the inclusion of the transportation of whey from the dairy plants and back to the farms. Whey is a waste product from the production of cheese and is used as animal food. The combination of the transport of whey with the collection of milk would make the problem even more complex by including the pickup and delivery aspect. It will be an interesting and challenging research topic.

References

- Butler, M., Williams, H. P., & Yarrow, L. A. (1997). The Two-Period Travelling Salesman Problem applied to Milk Collection in Ireland. *Computational Optimization and Applications*, 7, 291-306.
- Chao, I. M. (2002). A tabu search method for the truck and trailer routing problem. *Computers & Operations Research*, 29, 33-51.

- Claassen, G. D. H., & Hendriks, Th. H. B. (2007). An application of Special Ordered Sets to a periodic milk collection problem. *European Journal of Operational Research*, 180 (2), 754-769.
- Del Pia, A., & Filippi, C. (2006). A variable neighborhood descent algorithm for a real waste collection problem with mobile depots. *International Transactions in Operational Research*, 13, 125-141.
- Gendreau, M., Hertz, A., & Laporte, G. (1994). A Tabu Search Heuristic for the Vehicle Routing Problem. *Management Science*, 40, 1276-1290.
- Gerdessen, J. C. (1996). Vehicle routing problem with trailers. *European Journal of Operational Research*, 93, 135-147.
- Glover, F., & Laguna, M. (1997). *Tabu Search*, Kluwer, Boston.
- Hoff, A., & Løkketangen, A. (2008). A tabu search approach for milk collection in western Norway using trucks and trailers. *Molde University College*, Working Paper 2008:6.
- Lin, S. (1965). Computer solutions of the traveling salesman problem. *Bell System Technical Journal*, 44, 2245-2269.
- Nag, B., Golden, B. L., & Assad, A. A. (1988). Vehicle routing with site dependencies. In B. L. Golden and A. A. Assad, (Eds.), *Vehicle routing: methods and studies* (pp. 149- 159). Amsterdam: North-Holland.
- Osman, I. H. (1993). Meta-strategy simulated annealing and tabu search algorithms for the vehicle routing problem. *Annals of Operations Research*, 41, 421-451.
- Pasha, U., Hoff, A., & Løkketangen, A. (2013). The Shrinking and Expanding Heuristic for the Fleet Size and Mix Vehicle Routing Problem. *Communications - Scientific Letters of the University of Zilina*, No. 1 2013, 6-13.
- Scheuerer, S. (2006). A tabu search heuristic for the truck and trailer routing problem. *Computers & Operations Research*, 33, 894-909.
- Semet, F. (1995). A two-phase algorithm for the partial accessibility constrained vehicle routing problem. *Annals of Operations Research*, 61, 45-65.
- Semet, F., & Taillard, E. (1993). Solving real-life vehicle routing problems efficiently using tabu search. *Annals of Operations Research*, 41, 469-488.
- Tan, K. C., Chew, Y. H., & Lee, L. H. (2006). A hybrid multi-objective evolutionary algorithm for solving truck and trailer vehicle routing problems. *European Journal of Operational Research*, 172, 855-885.
- Toth, P., & Vigo, D. (2003). The Granular Tabu Search and Its Application to the Vehicle-Routing Problem. *INFORMS Journal on Computing* 15, 333-346.