Vehicle Routing for Exhausted Oil Collection

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Abstract—**In this paper we present a Vehicle Routing Problem for the collection of exhausted cooking oil in Bali (Indonesia). This is an integral part of a recycling project initiated by the Caritas Suisse, where cooking oil is collected and recycled to obtain bio diesel fuel. The main goals of this project are to help the people in this region, to protect the environment and to make a contribution to combat climate change. In our work we present the underlying real world problem and show how it can be modeled as a Vehicle Routing Problem. We propose a heuristic to tackle this problem and show that we could support the decision process about the optimal location for the processing plant and the optimal number of vehicles with our approach.**

Index Terms—**Vehicle routing, heuristic algorithm, oil collection, sustainability**

I. INTRODUCTION

In 2010 the Caritas Suisse started a project for the recycling of used cooking oil into bio diesel fuel in Bali. In this region large quantities of used cooking oil are accumulated in restaurants and hotels. The appropriate disposal of this cooking oil is still an unsolved problem and an inappropriate disposal could lead to some problems, ranging from the pollution of water up to health risks caused by reusing old cooking oil. The basic idea of the project is to organize and perform an appropriate disposal of the exhausted cooking oil by recycling it into bio diesel fuel. The quantities of oil that are accumulated in cooperating hotels and restaurants are regularly collected and brought to a processing plant. At that plant the oil is transformed into biofuel. In this way an appropriate disposal of the old cooking oil is ensured. An overview about the region of Bali involved and the cooperating hotels and restaurants (in gray) is given in Fig. 1, together with the three potential locations for the processing plant (in red).

Additionally, there are a lot of other important benefits resulting from this project. By ensuring an appropriate disposal of the oil, the environment in Bali is protected and risks for the health that are caused by reused oil are removed. Furthermore, the project helps the people living in Bali by creating new job opportunities. Finally, a contribution for the combat against climate change is made. Conventional fuel can be substituted by the bio diesel obtained during the recycling process. Summarizing the benefits, it is a project with a huge potential for helping the local people and protecting the environment.

The remaining part of this paper is organized in the following way. In the next section we will show how the transportation component of our real world problem can be modeled in terms of a Vehicle Routing Problem. Using our experience from the optimization of various Vehicle Routing Problems we then propose a heuristic to tackle this problem. We continue with computational studies, applying our heuristic on the original data and varying important parameters like the location of the processing plant and the number of vehicles used. Finally, we finish the paper with a discussion and with conclusions.

II. THE FORMAL MODEL

As stated in the Section I, the goal of the project is to organize and perform an appropriate disposal of exhausted cooking oil by recycling it into bio diesel fuel. This recycling process is performed at a plant and one important component of the project is to provide an efficient transportation system for the collection of the oil. In this section we discuss the process of deriving a formal model for this transportation component.

More abstract we can see the transportation problem in the following way. We have been given a set of 308 different locations for the collection of oil. For each location we know the expected amount of oil that accumulates within one week (ranging from 1 to 22 cans). Additionally, the location for the processing plant is given. The travel times between any two of the locations are known. The task is to collect the oil and to transport it to the location of the processing plant. For this purpose cans with a capacity of 25 liters are used. The vehicles start at the processing plant, filled with empty cans. Then they proceed to the different locations and exchange the empty cans with full cans, which are at the end delivered to the processing plant. The total capacity is 18 cans for each vehicle. The goal is to obtain a collection plan for a time horizon of two weeks (10 working days), which is then executed iteratively. For each vehicle and each working day routes have to be computed, such that all the accumulated oil is collected from the different locations and such that the workload between the single routes is balanced. The total travel time is not the main optimization objective, but it should be in a reasonable domain. Therefore, our problem can be modeled as a variant of the Periodic Vehicle Routing Problem (PVRP, see [1], [2], [3]) and in the remaining part of this section we will derive a

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variant of the Periodic Vehicle Routing Problem that can then be used to model our original real world problem.

Figure 1. Bali, Indonesia, The region where the project is run, with cooperating hotels and restaurants highlighted in gray and potential locations for processing plants in red.

First of all, our real world problem allows us to choose among three potential locations for the processing plant and to specify the number of vehicles used. Since we only have very few choices for those parameters, we do not model them as decision variables. Instead, we assume that the location of the processing plant and the number of vehicles is known. With some experiments a proper choice can be made for those two parameters, which are then used as fixed parameters for subsequent experiments. Another difference to the PVRP is that we do not have the frequencies with which the different locations have to be visited. Therefore we derive the number of visits for each location from the given amount of oil that accumulates at that location within one week. With those modifications our model can now be formulated in the following way.

We have been given a time horizon of 10 working days, a depot and a set of locations together with the travel times between the locations. For each location we additionally know the required number of visits within the given time horizon as well as the total amount of goods that have to be collected. For this collection a fixed number of vehicles with a fixed capacity are available at the depot. The optimization goal is to compute routes (starting at the depot, visiting the locations and finishing at the depot) for all the vehicles in the given time horizon, which minimize the standard deviation of travel times between the different vehicles, such that all goods are collected from the different locations and such that the locations are visited exactly for the specified number of times.

III. A Heuristic Approach

Our background in the development of efficient heuristics for different Vehicle Routing Problems is strong and the considerations for obtaining a heuristic for the problem in this work are based on this experience. Various such Vehicle Routing Problems are tackled in [4], [5], [6], [7], [8], [9], [10]. At the end we decided to use a Local Search Algorithm to tackle the problem in this work. Different variants of Local Search Algorithms could be applied successfully for many Vehicle Routing Problems (see [11], [12] for representative examples) and considering the similarities to our problem, such an approach seems very promising.

Preliminary experiments have shown that the number of locations that are visited by the same vehicle at the same working day are usually quite small and mainly in the range between 6 and 12. Having an assignment of between 6 and 12 locations for one vehicle, the optimal route can be computed in a straightforward way. For this reason we propose a two level approach similar to the assign first strategy used for Periodic Vehicle Routing Problems [13]. On the first level the idea is to optimize the assignment of customers to vehicles and working days using the Local Search Algorithm. An inner optimization mechanism is then used on the second level to optimize the routes of the different vehicles and working days. An additional benefit of the hybridization between the Local Search Algorithm and an inner optimization mechanism is the following. The changes imposed by the Local Search Algorithm affect a solution locally and this can be exploited by the second level optimization mechanism, which only has to re-optimize the parts that have changed. In the following we discuss our approach more in detail. Additionally, a high level description of the algorithm is given in Algorithm 1.

Algorithm 1 High level description of the heuristic.

```
Create a random assignment of locations to vehicles / working days
for each vehicle and working day do
    Compute the optimal route for the corresponding assignment using the
    second level optimization mechanism
end for
Use the resulting solution to start the Local Search Algorithm
while the current solution is not a local optimal solution do
    for each neighbor solution (explored in a random order) do
        Perform the local search move
        Re-optimize the routes which were changed
        if the neighbor solution improves over the current solution then
            Replace the current solution with the neighbor solution
            Start a new iteration (go to 7)
        end if
    end for
end while
return The local optimum obtained by the Local Search Algorithm
```

The heuristic starts by randomly assigning the different locations to vehicles and working days. Then for each vehicle and each working day an optimal route is computed using the second level optimization mechanism. The resulting solution is the starting solution for the Local Search Algorithm. For the local search neighborhoods we use a shift operator and a swap operator. The shift operator takes a location assigned to a specific vehicle and a specific working day and shifts it to another vehicle and/or another working day. The swap operator considers two different locations and interchanges their assignments to vehicles and working days. At each iteration the Local Search Algorithm explores all the solutions in the local search neighborhoods induced by those two operators in a random order. Note that both operators change only the assignment of locations to vehicles and working days for exactly two pairs of vehicles and working days. Therefore, the second level optimization mechanism is used to re-optimize the routes for only those two assignments that differ from the current solution. Here the second level optimization mechanism computes an optimal route in the case where at most 8 locations are assigned to a specific vehicle and working day, whereas a fast heuristic approach is used if more than 8 locations are involved. This heuristic approach tries to insert the new location in the best possible way without changing the order of the locations that are already visited by that vehicle on that working day. The resulting solutions are then evaluated and compared to the current solution. If an improving solution is found, this solution replaces the current solution and a new iteration is started immediately. If there is no improving solution in the neighborhood of the current solution, the Local Search Algorithm terminates and the local optimal solution is returned by our approach as the final solution.

IV. Computational Studies

In this section we show the results of a computational study performed with our heuristic. For this purpose we use the original data of the problem. There are still two very important properties that need to be decided. One of them is the location of the processing plant. Here we can chose between three different locations: *Serangan, Jl. KargoPermai* and *Green* School (see Fig. 1). The other one is the number of vehicles used. The main purpose of the computational study is to support the decision process about the location of the plant and the number of vehicles used.

We have implemented the algorithm in ANSI C. For the experiments an Intel Core2 Duo machine running at 2.53GHz was used. Due to feasibility constraints, we have used values between 4 and 7 for the number of vehicles. Together with the three different locations for the processing plant this results in a total of 12 experiments. Each experiment was performed for a total of 10 runs. The results are summarized in Table I. Here we report for each combination of the number of vehicles and the plant location the average values obtained in the 10 different runs for the total travel time, the travel time standard deviation and the minimum/maximum travel time over all vehicles and working days (all values in hours). Note that feasible solutions are printed in boldface. Additionally, we have visualized the total travel times and the travel time standard deviations for different vehicle numbers and different plant locations in Fig. 2 and Fig. 3. Note that this visualization contains only the feasible solutions.

TABLE I. COMPUTATIONAL RESULTS (ABSOLUTE VALUES IN HOURS). FEASIBLE SOLUTIONS ARE PRINTED IN BOLDFACE.

plant location	vehicles	travel time			
		total	standard deviation	minimum	maximum
Serangan	4	**279.40**	**0.12**	**6.67**	**7.39**
	5	**299.85**	**0.12**	**5.64**	**6.37**
	6	**308.32**	**0.18**	**4.72**	**5.97**
	7	**307.79**	**0.21**	**4.05**	**5.92**
Jl. Kargo Permai	4	339.30	0.11	8.13	8.87
	5	**352.60**	**0.14**	**6.68**	**7.62**
	6	**354.35**	**0.20**	**5.52**	**7.04**
	7	**365.49**	**0.22**	**4.88**	**6.76**
Green School	4	411.68	0.14	9.95	10.77
	5	418.67	0.18	7.78	9.09
	6	**425.95**	**0.27**	**6.36**	**7.79**
	7	**436.24**	**0.25**	**5.80**	**7.19**

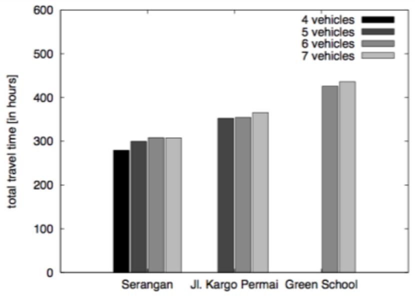

Figure 2. The total travel times for feasible solutions using different numbers of vehicles and different locations for the plant. The results are given in hours, grouped by plant locations.

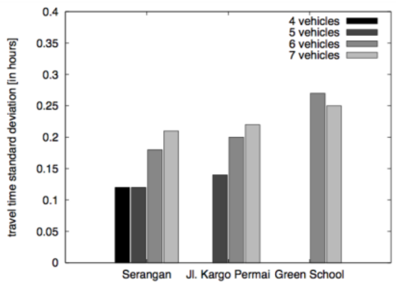

Figure 3. The travel time standard deviations for feasible solutions using different numbers of vehicles and different locations for the plant the results are given in hours , grouped by plant locations.

First of all, we see that not all of the experiments result in feasible solutions. Using 4 vehicles for the location *Jl. KargoPermai* and 4 or 5 vehicles for the location *Green School* leads to infeasible solutions. One of the main goals in our work is to balance the workload while maintaining efficient routes in terms of travel times. This goal has been reached for the solutions using 4 or 5 vehicles for the location *Serangan* and 5 vehicles for the location *Jl. KargoPermai*. In terms of route length, solutions using the location *Serangan* seem to be slightly better than solutions using the location *Jl. KargoPermai*. Nonetheless, for a final decision additional economical considerations and constraints (which are not part of our study) have to be respected. Based on our results we are able to exclude the location *Green School* for further considerations and to support the decision process. It is interesting to report that the location finally selected by Caritas Suisse has been in fact *Jl. KargoPermai*.

We want to finish this section with a short discussion about the performance of our heuristic. The computational time for a single run is in the range of between 3 and 10 minutes, depending on the number of vehicles and also on the plant location. Additionally, our heuristic is able to fairly balance the workload between single routes, especially if the number of vehicles is 4 or 5. In those cases the difference between the longest and the shortest route over all vehicles and working days is less than one hour. This is a remarkable achievement, in particular because the single routes consist only of very few locations.

V. Discussion & Conclusions

In this work we showed how to model the transportation component of a real world oil collection problem as a VehicleRouting Problem. This problem is an integral part of a recycling project in Bali, helping the people in this region, protecting the environment and making a contribution to combat climate change. Based on our experience with Vehicle Routing Problems we proposed a Local Search Algorithm for this problem. This algorithm assigns the different collection points to the vehicles and the working days. An inner optimization mechanism is then used to optimize the routes for the different vehicles and working days. With this approach it is possible to obtain solutions in which the workload among the vehicles and working days is balanced. Additionally, we could gain useful information for the decision process about the number of vehicles and the location of the plant.

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