There is an ever growing demand for alternative sources of petroleum-based fuel due to the depletion of the world's petroleum reserves and the increasing environmental concerns. Biodiesel, a renewable biofuel, can be used in any compression ignition engine without the need for modification. Therefore it has recently been considered as the best diesel substitute. Vegetable oils are renewable in nature, and can be produced on a large scale and environmentally friendly. These features make them promising feedstocks for biodiesel production. Vegetable oils include edible and non-edible oils. More than 95% of biodiesel production feedstocks come from edible oils since they are produced in many regions in large quantities (Gui et al. [7]). Used or waste cooking oil is not suitable for human consumption but is a feedstock for biodiesel production. Its usage significantly reduces the cost of biodiesel production.

Since the cost of raw materials accounts for about 60–80% of the total cost of biodiesel production, choosing a right feedstock is very important (Singh and Sing [9], Gui et al. [7]). Recovery of waste vegetable oil (WVO) plays an essential role in both the environmental and economic sustainability of biodiesel. A total of 108 billion liters of WVO is estimated to be generated annually worldwide, but still, out of this quantity only 6 billion liters are collected and used in biodiesel production (Albiyobir [3]). In addition to the economical savings, collecting WVO also benefits the environment by decreasing the contamination of rivers, lakes or oceans. WVO along with waste animal fat is an ecotoxic agent, and accounts for 25% of waste water pollution. One liter of WVO poured down the drain can contaminate one million liters of water and cause serious damage to the ecological life (Albiyobir [4]).

Albiyobir, Cemre, Deha, Ezici Biyoelektrik, Kolza, Nevbio and Tayaş are among the few companies in Turkey that have been licensed to collect WVO. According to the Environmental Law No. 2872 dated to 9/8/1983 and the WVO Control Regulations No. 25791 issued on 19/04/2005, businesses and institutions producing WVO are obliged to turn in their WVOs to the licensed collection companies (Deha Biodizel [5]). Turkey consumes approximately 1.5 million tons of vegetable oil every year. This consumption generates an estimated amount of 350,000 tons of WVO, only 15,000 tons of which is collected by licensed companies. The rest (335,000 tons) is discharged to drains damaging sewer systems and the nature (Deha Biodizel [6]).

The WVO collection problem: a selective and periodic inventory routing problem
Predojević [5] states that collecting and using WVO costs almost half the price of using virgin vegetable oil in the production process of biodiesel. This constitutes the actual motivation for our research. We started in 2010 working on the mathematical modeling of WVO collection. We contacted Ezici Oil Industry, Biodiesel and Energy Production, Inc. which collects and converts WVO into biodiesel (Aksen et al. [1]). The source nodes of WVO include businesses that consume cooking oil
in large volumes, such as restaurants, hotels, and catering companies. Ezici makes an agreement with the selected source nodes, and specifies on which days of the week they will be visited for WVO collection. The biodiesel production facility of Ezici in Gebze has a predetermined daily production plan, and needs to procure vegetable oil as raw material input to follow the plan. This creates the daily input requirements. Ezici can satisfy its vegetable oil need either from collection or from virgin oil purchases. The latter has a high marginal cost, but also the former carries a significant cost due to vehicle dispatching, driver wages, fuel consumption, etc.

**Operational constraints:** The company Ezici operates a homogeneous vehicle fleet. There is no limit on the number of collection vehicles that can be acquired for this job. There is no maximum tour duration or tour length constraint on the routes, either. However, there are several constraints to be fulfilled during the collection operations.

(i) Each vehicle must start and complete its tour at the production facility (depot) of Ezici in Gebze.
(ii) Vehicles can be dispatched from the depot not more than once a day.
(iii) A vehicle must collect the entire WVO accumulated at the visited source node since the last visit. Partial collection is not allowed.
(iv) The amount of WVO accumulation at a visited source node cannot be split between multiple vehicles. This implies that a source node cannot be visited by more than one vehicle on any day.
(v) The uncollected WVO inventory at a given source node or the depot by the end of a day becomes the beginning inventory of the next day. No WVO accumulation is allowed for disposal.

**A threefold decision problem:** The amount of WVO accumulating at the source nodes might be more than the capacity of the collection vehicle or the amount needed for production. In such cases visiting all source nodes is not necessary or not feasible. Hence, the facility manager is faced with the following threefold decision problem:

1. Which of the source nodes to select for the collection program.
2. How many vehicles to use each day and which periodic (weekly) routing schedule to repeat over an infinite planning horizon so as to collect the WVO accumulating at the selected source nodes.
3. How much virgin oil to purchase on each day.

The objective is to minimize the total collection, inventory and purchasing costs while meeting the production requirements and operational constraints. We defined this considerably hard routing and scheduling problem as the Selective and Periodic Inventory Routing Problem (SPIRP) in 2012 (Aksen et al. [1]). We introduced a commodity flow-based mixed integer linear programming (MILP) formulation, and solved it with the commercial solver Cplex v12.2 for 36 test instances, each with 25 hospitals which were treated as WVO accumulation nodes. In our latter paper (Aksen et al. [2]), we proposed an Adaptive Large Neighborhood Search (ALNS) method to solve large size SPIRP instances in less than one hour.

**Acquisition of the problem data**

We picked up to 100 restaurants on the Asian side of Istanbul as candidate source nodes. The restaurants and the recycling facility (depot) constitute a complete collection network (see Fig. 1). The asymmetric shortest path distances between each
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pair of nodes have been obtained from Google Maps. Besides the distances, there are several other input parameters such as the costs of inventory holding, transportation, purchasing, and vehicle operating; the vehicle capacity, the daily WVO accumulation rates at each restaurant, and the daily WVO requirement of the facility.

For the daily accumulation rates we prepared a simple questionnaire to estimate realistic values. Answers to the questionnaire show that large size restaurants accumulate approximately 50 liters of WVO per day, medium size restaurants around 30 liters and small size restaurants about 15 liters. These values are taken into account to generate relevant daily accumulation rates which are derived from a normal distribution with means 15, 30 and 50 with variances 5, 15 and 25, respectively. The facility policy is to adopt a uniform vehicle type for its collection operations. We used the cost data of the light commercial vehicle Fiat Fiorino Cargo inquired in August 2013. The purchasing price is at most the wholesale price of virgin vegetable oil, which is around 3.50 TL per liter. The cost of storing one liter of WVO, namely inventory holding cost $h$ is equal to the daily interest rate times $p$. This results in $h = 0.02$ TL/day.

Results and discussion

In our first paper using the cost data of 2010, we found that vehicle operating costs have the biggest share in the objective function, and using the vehicle type with the higher capacity (Fiat Doblo Cargo maxi) decreases the objective function significantly. In our second paper we developed an adaptive large neighborhood search (ALNS) algorithm for SPIRIP. Overall 54 test instances have been generated of size 20 to 100 source nodes. We can summarize our findings as follows:

(i) When there are less than 30 source nodes, ALNS cannot perform as well as MILP.

(ii) For instances with 40 source nodes, ALNS improves the MILP solutions by 15.4% on average. In these instances, the maximum CPU time spent by ALNS is six minutes, while the Cplex solution of the MILP model cannot match the respective ALNS solution even at the end of four hours.

(iii) For larger instances which have 50 to 100 source nodes, we evaluate the performance of ALNS on the basis of the lower bounds obtained from three models, namely MILP, PLR (Partial Linear Relaxation of the MILP model) and RR (Relaxation without Routing). Among the three, RR yields the highest, hence the best lower bounds in all 24 large size instances.

(iv) Our proposed heuristic ALNS achieves an average gap of 7.14% (4.15%) between the best lower bounds, and an average solution time of 484 seconds (40 seconds) for large size (small size) instances. The longest solution time remains under 1 hour.

For future research, we wish to look into a location routing version of the SPIRIP. The extended problem will address the question of where to open one or more additional depots as WVO collection increases to much higher levels than today.

References