Supply Chain Analytics (42380)

Project Assignment 2

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Contents

1 Introduction

1.1 Q1. Differences between TL and LTL and how they relate to distributions of goods from central distribution centers.

For truckload (TL) transportation it is common to assume direct shipping, a single vehicle delivers to a single node with typically full capacity. For less-than-truckload (LTL) transportation, on the other hand, it is more common that a vehicle visits multiple nodes and it is called routing.

Truckload transportation is more cost-effective for large shipments but less-than-truckload is more beneficial for smaller shipments as it allows for more flexibility and cost savings.

It is likely that truckload transportation would be the better option to distribute goods from the central distribution center to the service centers, as this method is more efficient at handling large shipments. Then Comma Computing could restock effectively at the service centers when the stock goes below re-order point. On the other hand, less-than-truckload transportation would be more suitable for distributing goods directly from the central distribution center to customers when shipments are smaller and destined for multiple locations.

2 Facility Location for Service Centers

2.1 Q2. The capacitated fixed-charge location problem - Optimal objective value and visualization

Please refer to the Julia file `Question_2.jl` for the full code solution to this problem.

To optimize the problem, we followed the steps outlined in the mathematical model presented during Week 7 of the Facility Location Models lecture (slide 15). However, the fixed cost differed slightly due to the opening and closing costs for new and existing facilities. Additionally, the formula used to calculate the great-circle distance between locations was Formula 8.1 from the textbook, as shown below:

$$2r \arcsin\left(\sqrt{\sin^2\left(\frac{\Delta\alpha}{2}\right) + \cos\alpha_1 \cos\alpha_2 \sin^2\left(\frac{\Delta\beta}{2}\right)}\right)$$

The optimization yielded an optimal objective value of approximately **433,376.61** Swiss francs.

The following facilities were identified to be opened in the optimal solution:

- Facility 1: Zurich West
- Facility 2: Geneva South
- Facility 3: Luzern North
- Facility 8: Montreux
- Facility 10: Thun

The usage of each open facility, in terms of the proportion of its capacity utilized, is as follows:

- Facility 1: 237 out of 480 units
- Facility 2: 185 out of 288 units
- Facility 3: 233 out of 270 units

- Facility 8: 140 out of 140 units
- Facility 10: 140 out of 140 units

Figure 1 illustrates the facilities and customer connections. The facilities that are represented in red are open, and as you can see, they show how they are connected to each customer.

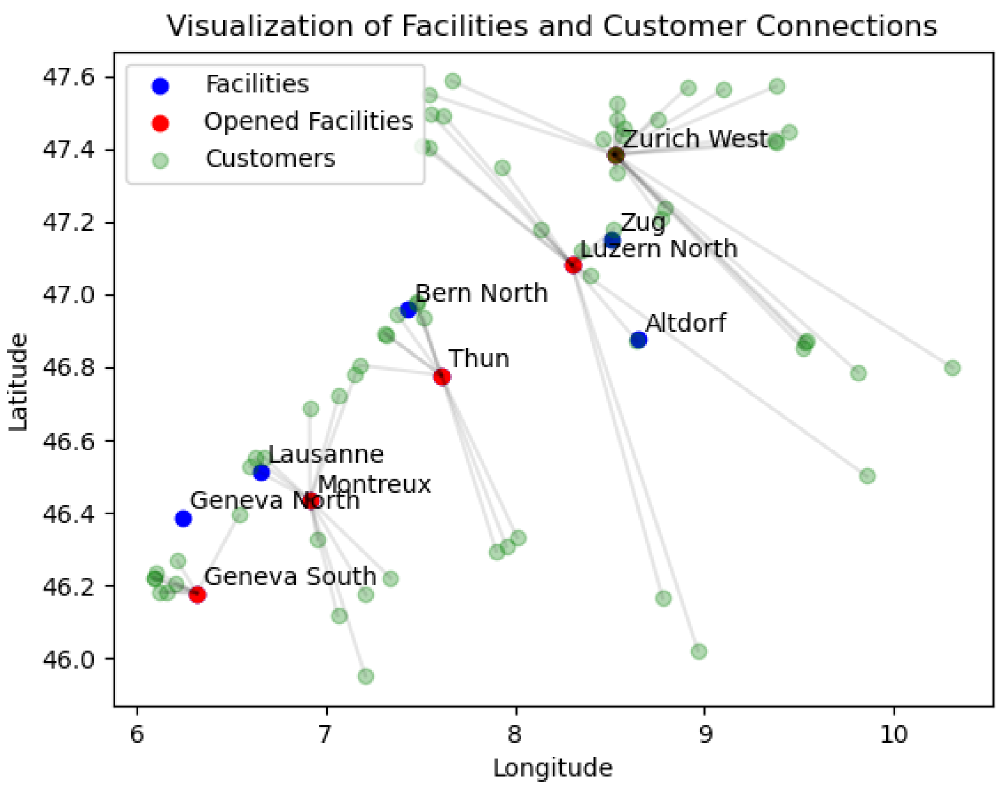

Figure 1: Visualization of the facilities and customer connections

2.2 Q3. The new set of facilities Vs. the original set of facilities used by Comma Computing

The original set of facilities used for distribution included Zurich West (1), Geneva South (2), and Luzern North (3). After solving the capacitated fixed-charge location problem, we determined that Comma Computing should keep the existing facilities open and open two additional facilities to minimize costs. The newly opened facilities are Montreux (8) and Thun (10). By opening them, Comma Computing is expected to achieve lower distribution costs compared to the original set of facilities. Please refer to the usage of each facility in Q2.

2.3 Q4. Mathematical formulation of the stochastic fixed-charge location problem

Comma Computing is exploring facility location plans for its service centers while considering uncertainty in customer demand and facility capacities. This formulation aims to minimize costs associated with facility opening and customer service under various scenarios.

Here below you can see the mathematical formulation of the stochastic fixed-charge location problem.
Parameters:

n : Number of facilities
m : Number of customers
S : Set of scenarios $(s = 1, 2, ..., S)$
h_{is} : Demand of customer i in scenario s
c_{ij} : Transportation cost per unit distance from customer i to facility j
f_open_facility_j : Fixed cost of opening facility j
$\text{f\_close\_facility}_j$: Fixed cost of closing facility j
Capacity_{js} : Capacity of facility j in scenario s
q_s : Probability of occurrence of scenario s

Variables:

x_j : Binary variable indicating whether facility j is opened
y_{ijs} : Fraction of demand of customer i served by facility j in scenario s

Objective Function:

$$\text{Minimize} \quad \sum_{j=1}^{n} \text{f\_open\_facility}_j \cdot x_j + \sum_{j=1}^{n} \text{f\_close\_facility}_j \cdot (1 - x_j) + \sum_{s=1}^{|S|} \sum_{i=1}^{m} \sum_{j=1}^{n} q_s \cdot h_{is} \cdot c_{ij} \cdot y_{ijs}$$

Constraints:

$$\text{Demand Constraint:} \quad \sum_{j=1}^{n} y_{ijs} = 1, \quad \forall i \in \{1, 2, ..., m\}, \forall s \in S$$

$$\text{Service Assignment Constraint:} \quad y_{ijs} \leq x_j, \quad \forall i \in \{1, 2, ..., m\}, \forall j \in \{1, 2, ..., n\}, \forall s \in S$$

$$\text{Capacity Constraint:} \quad \sum_{i=1}^{m} h_{is} \cdot y_{ijs} \leq \text{Capacity}_{js}, \quad \forall j \in \{1, 2, ..., n\}, \forall s \in S$$

2.4 Q5. Stochastic fixed-charge location problem solved using the provided set of scenarios

Please see Julia file `Question_5.jl` for the full code solution of this problem.

The optimization yielded an optimal objective value of approximately **446,877.24** Swiss francs.

The following facilities were identified to be open in the optimal solution:

- Facility 1: Zurich West
- Facility 2: Geneva South
- Facility 3: Luzern North

- Facility 4: Bern North
- Facility 8: Montreux

Figure 2 illustrates the locations of the opened facilities.

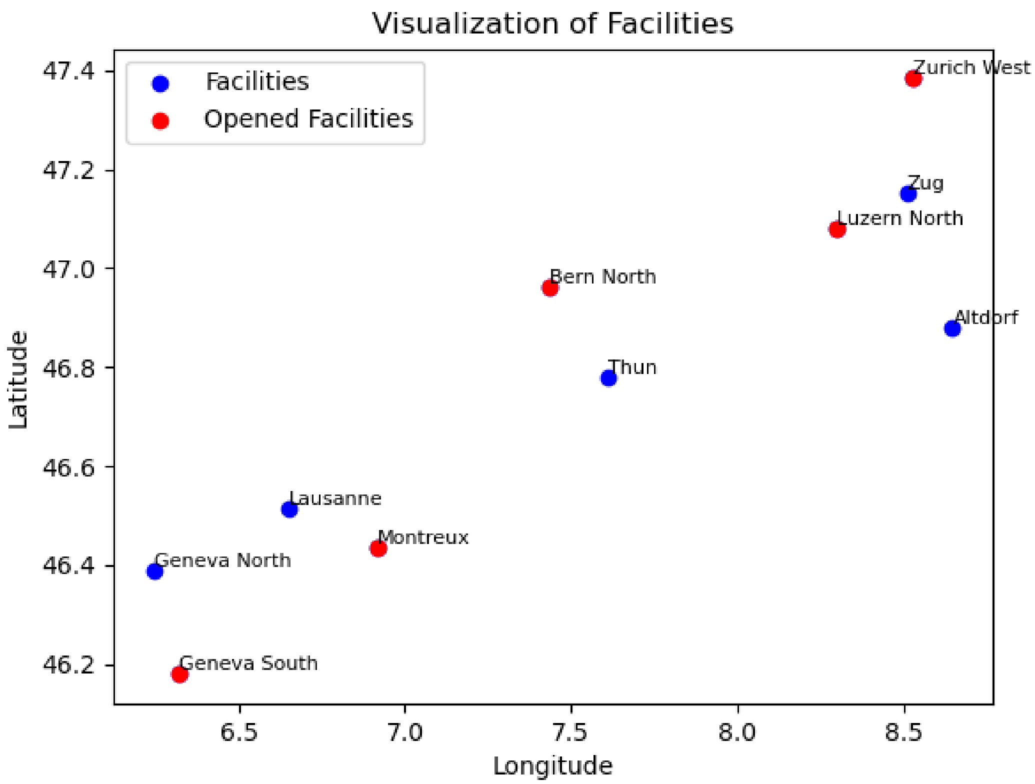

Figure 2: Visualization of the facilities

2.5 Q6. The chosen facilities from Q5 vs. the chosen facilities from Q2

The selected facilities identified in Question 5 were Facilities 1, 2, 3, 4, and 8. In contrast, the facilities chosen in Question 2 were Facilities 1, 2, 3, 8, and 10. Therefore, the sole distinction lies in the stochastic fixed-charge location problem, which includes Facility 4 instead of Facility 10.

In the stochastic fixed-charge location problem, we account for uncertainty in both customer demands and facility capacities across 30 different scenarios. This enables us to make decisions that are robust across various potential future conditions. Conversely, the deterministic facility location problem solely aims to minimize distribution costs without factoring in uncertainties.

Overall, the key difference lies in the approach to decision-making: the deterministic model prioritized cost efficiency in the present, while the stochastic model focused on building resilience and flexibility to address future uncertainties.

2.6 Q7. Advice to Comma Computing on how to improve their facility design for service centers

Based on the results from the deterministic and stochastic facility location models, we recommend the following managerial advice for improving Comma Computing's facility design for facilities:

1. **Consider Uncertainty:**
   You need to consider uncertainty when making your distribution plans. That it why we would recommend the use of stochastic models that can account for various possible outcomes and make more informed decisions based on different scenarios.

2. **Flexible Facility Design:**
   Design the facilities with flexibility in mind. Make them so that you can easily scale production up or down based on changing demand or capacity requirements. This could minimize the possibility of stockouts and holding costs.

3. **Technology Investment:**
   We recommend that Comma Computing invests in technology such as real-time data analytics and optimization algorithms. This will enhance decision making on daily basis for distribution, capacity allocation and routing strategies.

3 Routing Technicians within Zurich

3.1 8. Explain why the defined problem for this part of the assignment can be modeled as a (traditional) vehicle routing problem.

The problem defined in this part of the assignment involves technicians providing repair services to private customers in Zurich. Let's explore why this scenario can be modeled as a traditional vehicle routing problem (VRP):

1. Technicians act as vehicles (They each have a vehicle), starting and ending their routes at a central distribution center and customer locations serve as the points to be visited.
2. The objective is to allocate the technicians efficiently to minimize total travel time or distance while making sure that each customer gets service within the time frame needed.
3. Repair times at each customer location corresponds to service times in the VRP.
4. The constraints on the technicians working hours correspond to the time window constraint in the VRP.

As mentioned earlier, repair times at each customer location are treated as service times, influencing the duration of each visit. The maximum repair duration per technician is included as a constraint that limits the total duration of repairs assigned to each technician.

These factors are incorporated into the optimization algorithm to ensure efficient allocation of repair tasks while still ensuring compliance with technicians' work-hour regulations."

3.2 9. Results from the vehicle routing problem (VRP) using load constraint formulation.

Please see Julia file `question_09.jl` for the full code solution of this problem.

Here below you can see the objective value, optimality gap and the number of technicians with their routes with VRP using load constraint formulation. This result is based on a 30 second max run-time.

Please keep in mind that if the system would be allowed to run longer than a better solution might be found and it also depends on the computer that runs this.

- **Objective Value**: 192.12 (kilometers of distance)
- **Optimality Gap**: 36.31% (due to reaching the time limit of 30 seconds)
- **Technician 1 Route**: $0 \rightarrow 1 \rightarrow 3 \rightarrow 11 \rightarrow 25 \rightarrow 2 \rightarrow 12 \rightarrow 15 \rightarrow 0$
- **Technician 2 Route**: $0 \rightarrow 7 \rightarrow 20 \rightarrow 19 \rightarrow 24 \rightarrow 21 \rightarrow 5 \rightarrow 0$
- **Technician 3 Route**: $0 \rightarrow 6 \rightarrow 22 \rightarrow 23 \rightarrow 26 \rightarrow 18 \rightarrow 29 \rightarrow 4 \rightarrow 0$
- **Technician 4 Route**: $0 \rightarrow 13 \rightarrow 17 \rightarrow 14 \rightarrow 27 \rightarrow 9 \rightarrow 8 \rightarrow 10 \rightarrow 30 \rightarrow 0$
- **Technician 5 Route**: $0 \rightarrow 16 \rightarrow 28 \rightarrow 0$

3.3 10. Results from the vehicle routing problem (VRP) with location-based heuristic. Comparison of the routes to Q9.

3.3.1 Results from Q10:

Please see Julia file `Question_10.jl` for the full code solution of this problem.

Here below you can see the objective value, optimality gap and the number of technicians with their routes with VRP using location-based heuristic. This result is based on a 30 second max run-time.

This was run on the same computer to able to compare the two results (Q9 and Q10).

- **Objective Value**: 171.43 (kilometers of distance)
- **Optimality Gap**: 0% (Since the optimization problem has been solved to optimality before 30 seconds)
- **Technician 1 Route**: $0 \rightarrow 9 \rightarrow 10 \rightarrow 11 \rightarrow 28 \rightarrow 0$
- **Technician 2 Route**: $0 \rightarrow 3 \rightarrow 4 \rightarrow 12 \rightarrow 13 \rightarrow 15 \rightarrow 16 \rightarrow 18 \rightarrow 26 \rightarrow 0$
- **Technician 3 Route**: $0 \rightarrow 6 \rightarrow 8 \rightarrow 20 \rightarrow 21 \rightarrow 22 \rightarrow 25 \rightarrow 0$
- **Technician 4 Route**: $0 \rightarrow 7 \rightarrow 17 \rightarrow 19 \rightarrow 23 \rightarrow 24 \rightarrow 27 \rightarrow 29 \rightarrow 31 \rightarrow 0$
- **Technician 5 Route**: $0 \rightarrow 2 \rightarrow 5 \rightarrow 14 \rightarrow 30 \rightarrow 0$

3.3.2 Comparison of Q9 Vs. Q10:

In the table below, you can observe that technicians 1 and 3 serve more customers in Q9, whereas technicians 2 and 5 serve fewer customers, while technician 4 remains unchanged. The objective value is superior in Q10, and the program runs significantly faster than in Q9. Therefore, in this scenario, allocating more tasks to technicians 2 and 5 might be advantageous to achieve a better solution and distribute the workload more evenly.

	Number of customers visited in Q9	Number of customers visited in Q10
Technician 1	7	4
Technician 2	6	8
Technician 3	7	6
Technician 4	8	8
Technician 5	2	4

Table 1: Number of customers visited per technician for Q9 and Q10

3.4 11. Based on the results from Q9 and Q10, give managerial advice on which of these two methods seems most suitable for Comma Computing.

Based on the results from Q9 and Q10, we recommend that management prioritize the VRP with location-based heuristic as the primary method. The primary reason for recommending the location-based heuristic is the ability to find optimal routes within the time constraint of 30 seconds. In contrast, the load constraint method required significantly longer runtime, exceeding two minutes, and still yielded inferior results compared to the location-based approach.

This method offers several advantages:

1. **Efficiency and Speed:** The location-based method significantly expedites the process of finding optimal routes for technicians, enabling them to more effectively service customers.
2. **Workload Distribution:** With the location-based method, Comma Computing can evenly distribute tasks among technicians, as illustrated in Table 1. This ensures optimized workforce utilization and promotes technician satisfaction with their workload.
3. **Cost Savings:** The location-based method entails less distance traveled, resulting in reduced fuel and vehicle maintenance expenses. This translates to greater cost savings for Comma Computing.

It is important to note that both methods do have their strengths but the location-based method stands out for its simplicity and effectiveness in meeting the company's goals.

3.5 12. Adjustment of Clarke-Wright Savings Heuristic for Time Windows

To adjust the Clarke-Wright savings heuristic to respect customer time windows, we can follow these steps:

1. **Calculate Savings**: As in the original Clarke-Wright heuristic, calculate the savings for each pair of customers based on the distance between them and the depot.
2. **Sort Savings**: Sort the savings in descending order to prioritize the most significant savings.
3. **Iterate Over Savings**: Starting with the highest savings, consider each pair of customers and attempt to insert them into existing routes or create new routes while respecting their time windows.
4. **Check Feasibility**: Before inserting a customer into a route, check if adding the customer maintains the route's feasibility, i.e., if it respects the time windows of all customers already in the route and the capacity constraints.
5. **Update Routes**: Adjust the routes accordingly by either inserting the customer into an existing route or creating a new route if necessary.
6. **Repeat**: Continue this process until all customers have been assigned to routes.

By following these adjustments, the Clarke-Wright savings heuristic can provide solutions that respect the customer time windows while efficiently optimizing the vehicle routing problem.

3.6 13. Implement the algorithm that you described in question 12.

Please see Julia file `Question_13.jl` for the full code solution of this problem.

By following the steps outlined in Section 12, we determined the new objective for the updated time window of each customer. The total objective value was 1792 minutes, and the total distance was calculated considering a cost of 2.5 minutes per kilometer, resulting in a total distance of **716.8** kilometers. Below are the routes that each technician needs to follow:

- **Technician 1 Route**: $0 \to 9 \to 7 \to 8 \to 10 \to 27 \to 0$, with a total time of 298 minutes.
- **Technician 2 Route**: $0 \to 12 \to 2 \to 25 \to 1 \to 5 \to 0$, with a total time of 280 minutes.
- **Technician 3 Route**: $0 \to 13 \to 15 \to 3 \to 11 \to 14 \to 17 \to 0$, with a total time of 278 minutes.
- **Technician 4 Route**: $0 \to 16 \to 18 \to 23 \to 26 \to 0$, with a total time of 219 minutes.
- **Technician 5 Route**: $0 \to 19 \to 20 \to 24 \to 21 \to 0$, with a total time of 360 minutes.
- **Technician 6 Route**: $0 \to 28 \to 4 \to 29 \to 6 \to 22 \to 30 \to 0$, with a total time of 357 minutes.

Overall, this outcome isn't entirely surprising, considering the time window constraints each technician must fulfill for the customer. The necessity for more routes to accommodate each customer results in longer distances to cover.

4 Contribution:

4.1 Individual Contribution:

- **Brynjar Karl Ævarsson:** Brynjar focused mainly on problems 1, 3, 6, 7, 8 and 11 and assisted in solving problems 2, 4 and 5.
- **Sölvi Björnsson:** Sölvi focused mainly on problems 9, 10, and 13. He also assisted with solving problems 8, 11, and 12.
- **Þórir Lárusson:** Þórir focused mainly on problems 2, 4, and 5. He also assisted in solving problems 1, 3, 6, 7, 12, 13.

This is just a rough estimate of the distribution of the workload. We worked together on all parts of this project but our focus areas can be seen here above.

4.2 Generative AI Usage:

We used ChatGPT and Grammarly to assist with the grammar of our textual answers and also in some cases with enhancing the clarity and cleanliness of our code.