ME44206 – Quantitative Methods for Logistics
GROUP ASSIGNMENT Q2
Due Date: December 19, 2025

Consider a vehicle routing problem where you have a number of locations in a region to be visited in order to pick up materials to recycle. You have a fleet of electric vehicles with a given battery range. Vehicles start and finish at the designated depot. A subset of the locations in the network is installed with charging facilities that vehicles can use during their trips. Note that, a vehicle can charge at a location only if this location is visited for a pickup. The vehicle capacity is limited in volume. Each location has a time window (between the earliest time and latest time) when they will be available for the pickup. As long as the service starts in the time window it is deemed feasible. Moreover, it is assumed that service time at the nodes and charging time can overlap.

The datasets for this problem consist of multiple rows; each row defines a pickup task with the following information:

- LOC_ID: ID number for a location; the first row represents the depot
- XCOORD: x coordinates of the location
- YCOORD: y coordinates of the location
- DEMAND: volume to be picked up at each location (for the depot: zero)
- READYTIME: earliest time for the start of pickup (for the depot: opening time)
- DUETIME: latest time for the start of pickup (for the depot: closing time)
- SERVICETIME: time needed for a pickup at the location
- CHARGING: 1 if there is a charging possibility at the location; 0 otherwise.

You are provided with several data files with different characteristics. Use the correct file for each question. You can assume Euclidean distances between nodes and 1 distance unit is traveled in 2 time units. The battery range is given in time units but with *different rates* of charge and discharge across different questions. If the rate of charge is 2, it means the battery level increases by 2 units every time unit it is charging. Similarly, if the rate of discharge is 2, it means every time unit of travel reduces the battery level by 2 units. For example, if charge and discharge rates are 1 and if the battery range is given as 60, it means that the vehicle can travel 60 time units and when its battery is empty it will need 60 time units of charging. The batteries start with full range at time 0.

For this problem multiple questions must be answered. Read each question carefully to identify the relevant characteristics for that question. In case a formulation is not clear, please post your question on Brightspace. For specific questions about your own work, please contact us (me44206@tudelft.nl) for clarification *mentioning your group number* and *adding your draft mathematical model (even if it is just a start)*.

In the initial part of the assignment, focus on a capacitated VRP with time windows. We have a fleet of electric vehicles that is homogenous regarding both capacity and battery range. All pickup tasks need to be completed respecting the time windows and each vehicle needs to return to the depot before closing time respecting the battery range. A subset of the locations is equipped with charging facilities (no limit on maximum charging time and no limit on grid capacity). Charging decision needs to be considered as part of the optimization model such that your model decides where, when and how much to charge.

a. **[30 points]** Formulate the mathematical model for this capacitated electric VRP with time windows with the objective of minimizing the total distance traveled. *Note that your formulation should work with any number of vehicles and nodes and with any speed of vehicles, as well as with different speeds of charging and discharging.*
b. **[15 points]** Implement the model in part a in python and solve with gurobi using the data file **data_small.txt**. Consider 4 vehicles of 120 capacity each and the battery range of each vehicle is 110 with the rates of charge and discharge being 1. Report your results including the total distance traveled, the locations visited by the vehicle(s) together with the sequence (i.e., route of the vehicles), the time of visit and the load of the vehicle at each location. Moreover, provide the battery level (remaining battery range) at each location. Create 2D plots of the solution for presenting the routes but also the battery level for each vehicle, demonstrating the battery charge moments clearly.
Tips: spend some time on formatting the outputs of your implementation, so that it shows not only the objective value but also gives insight in the decisions! You can also make use of "numpy" and "matplotlib.pyplot" in your implementation.
Note: The units are only relatively meaningful, but if it helps you to picture it easier you can consider that, in this part, you have one day of operations (need to be back at the depot at the end of the day, 1440 min), and battery range is 110 min.

Now consider that we have a charging cost and that differs across time periods (but same across different locations). You need to minimize the charging costs in addition to the total distance traveled. The additional information is provided in **data_periodsCharge.txt**. It consists of multiple rows; each row defines a time period with the following information:
- PER_ID: ID number for charging period
- STARTTIME: start time of the period
- ENDTIME: end time of the period
- COST: unit cost of charging in the period (euro/time unit)

c. **[15 points]** Update the formulation indicating any changes in the model (sets, parameters, variables, objective function, constraints etc.) compared to part a. Explain and justify any choice you make in the formulation. *Note that the model should be kept as a mixed integer linear programming problem avoiding nonlinearity. The formulation should work with any number of charging periods.*
d. **[10 points] Experiment** with different cases of this problem using the data file **data_small.txt**. Consider the following cases for your experiments:
    1. (Case 1) 4 vehicles of 120 capacity each with a battery range of 110, charge/discharge rate of 1, uniform charging cost of 2 euros across all periods
    2. (Case 2) 4 vehicles of 120 capacity each with a battery range of 110, charge/discharge rate of 1, charging costs in **data_periodsCharge.txt**
    3. (Case 3) 4 vehicles of 120 capacity each, battery range of 110, charge rate of 1.1 and discharge rate of 0.7, charging costs in **data_periodsCharge.txt**
    4. (Case 4) 4 vehicles of 120 capacity each, battery range of 90, charge rate of 1.1 and discharge rate of 0.7, charging costs in **data_periodsCharge.txt**
    5. (Case 5) 4 vehicles of 200 capacity each, battery range of 140, charge rate of 1.1 and discharge rate of 0.7, charging costs in **data_periodsCharge.txt**

    Discuss the changes in the decisions of the model across the 5 cases as well as compared to the solution you obtained in part b. Namely, compare the routes taken, the charging decisions, number of vehicles used together with the total distance and total cost. Also discuss the computational time needed with your insights behind it.

Now, consider that you have a fleet of heterogeneous vehicles: some diesel vehicles (DV) and some electric vehicles (EVs) which have different cost structures. Namely, they incur a fixed cost for each trip and a distance-based variable cost. Therefore, in addition to the time-dependent charging costs in part c you also have these costs for the vehicles.

e. **[10 points]** Update the formulation indicating any changes in the model (sets, parameters, variables, objective function, constraints etc.) compared to part d. *Note that the model should be kept as a mixed integer linear programming problem avoiding nonlinearity and it should work with any composition of the fleet.*

f. **[5 points]** Implement the model in part f using **data_small.txt** and **data_periodsCharge.txt**. Consider a fleet with 3 EVs and 3 DVs available, all with a capacity of 100. EVs have a battery range of 90 with a charge rate of 1.1 and discharge rate of 0.7. The speed of the vehicles is the same and stays as before. The variable and fixed cost for EVs and DVs are provided below:

	DV	EV
Fixed cost (euro)	100	120
Variable cost (euro/distance unit)	2	1.25

Run the model and evaluate the differences compared to your results in part d (you can do so with similar ones in terms of the parameter settings). You need to discuss the total distance traveled, change of the routes, usage of vehicles of each type, charging decisions as well as the computational time. Provide your insights justifying the differences with the reasons behind.

g. **[5 points]** Run the same model using **data_large.txt** and **data_periodsCharge.txt**. Consider a fleet with 3 EVs and 3 DVs all with a capacity of 300. EVs have a battery range of 120 with a charge rate of 1.1 and discharge rate of 0.7. The speed of the vehicles, the variable and fixed cost for EVs and DVs are the same as part f. Run the model and discuss the computational time and the decisions of the model (routes, charging, usage of vehicles etc.).

h. **[10 points]** In this problem, we have many assumptions about the vehicles, batteries, the grid etc. The behavior of the equipment and the systems involved is more complex in real-life. Now, think about an extension which would bring your model closer to reality in one of these aspects. This extension should not be only about changing the inputs but rather the way the model is formulated in the objective function or constraints, or both. First motivate the extension you are going to work on together with the purpose. Then formulate your mathematical model highlighting the extensions and then run the model and present your results. As the complexity of your model can grow, you can choose which size of the dataset you would use and the associated parameter settings. You can use **data_small.txt** or **data_large.txt** together with **data_periodsCharge.txt**. When you discuss the results, highlight the differences to the results you obtained with the model you formulated in part e. If your idea requires additional data, create a separate data section in your python file (do not create more input files).

Submission

Please follow submission guidelines in **ANS** for different parts of your report and your .py files (not others, .ipynb etc.). Indicate your group number and members' names in the files. Keep the reporting of your mathematical models compact; use short (but clear) definitions and avoid formula derivations or explaining text (if that is needed, report that in a separate section, not in the section with the mathematical model itself). You can refer to the template we provided for the TSP.

Please use the data files in the format they are provided (.txt) and do not convert them to other formats, e.g., excel files.

Notes

- Solve the problems to optimality if the computational time is within 60 min and report the computational time. When it goes **beyond 60 min** you can set a time limit of 60 min (=3600 s) in order to get solutions (by using "model.Params.timeLimit = 3600"). If you do that, report the **optimality gap** together with your results. If your group has issues with the computational time, if you cannot get a feasible solution within this time limit for any of the questions, you can let us know.
- In order to deal with the time dimension of these routing problems, you may define a variable for the start time of the service at each node. This variable then facilitates the definition of related constraints.
- Some common VRP formulations repeat the depot (node 0) as the last node (node n+1). Such modifications are not obligatory but can be helpful. In any case, **you MUST use the input file AS IS** and you can implement such things after reading the datafile in python within your python implementation!
- Include a **contribution statement** where for each of the group members you list down what was the contribution from this member, e.g., data handling, mathematical formulation for a specific part, python implementation, discussion and presentation of results, report writing etc. The idea is that you as a group are all aware and transparent about the share of the work. We may ask questions to verify this contribution statement as part of the grading.
- **Use of generative AI/chatbots**: The submission for this statement will be indicated in ANS. If you did not use a chatbot, a short statement is sufficient. In case you did use a chatbot for the assignment: write a clear statement, mentioning the name of the tool used. Per question, give the prompts used and how the answers helped you with that question. Note: in some cases, we will invite students for an interview about the delivered report as part of the assessment procedure.