ME44206 – Quantitative Methods for Logistics
GROUP ASSIGNMENT Q2
Due Date: December 20, 2024

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. Vehicles start and finish at the designated depot. The vehicle capacity is limited in volume. Each location has a time window (between the earliest time and latest time) where they will be available for the pickup.

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

- LOC_ID: identification number for a location; the first row (with DEMAND = 0) represent 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)
- SERVICETIME: time needed for a pickup at the location
- READYTIME: earliest time for pickup (for the depot: opening time)
- DUETIME: latest time for pickup (for the depot: closing time)

You are provided with several data files, each with different characteristics. Use the correct file for each question. You can assume Euclidean distances between nodes and 1 distance unit corresponds to 1 time unit.

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 vehicles with homogenous capacity, each location needs to be visited by one vehicle during their time windows and the vehicle(s) need to return at the depot before closing time.

a. **[20 points]** Formulate the mathematical model for this capacitated 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.*
b. **[20 points]** Implement the model in part a in python and solve with gurobi using the data file "**data_small.txt**". Consider 2 vehicles of 130 capacity each. 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. Also draw a 2D plot of the solution.
Tip: spent 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! This is very useful for debugging during implementation, verification and reporting of results. You can also make use of “numpy” and “matplotlib.pyplot” in your implementation.
c. **[5 points]** Discuss the need and use of subtour elimination constraints in this capacitated VRP with time windows and compare it to the TSP case.

Now consider the case that we have **multiple time windows** available during the day in order to pick up the materials based on the availability of the personnel. Each location needs to be visited once during one of its time window options.

d. **[10 points]** Update the formulation indicating any changes in the model (sets, parameters, variables, objective function, constraints etc.) compared to part a. *Note that the model should be kept as a mixed integer linear programming problem avoiding nonlinearity. The formulation should be flexible in terms of number of time window options.*
e. **[15 points] Experiment** with different cases of this problem using "**data_small_multiTW.txt**".
Note the changes in the data file. Up until and including the SERVICETIME the rows are in the same structure. As of SERVICETIME it looks like as follows:
- SERVICETIME: time needed for a pickup at the location
- NUM_TW: number of options for time windows
- READYTIME: earliest time for pickup (for the depot: opening time)
- DUETIME: latest time for pickup (for the depot: closing time)

READYTIME and DUETIME are repeated as many times as the number of time window options. In this part, there are 3 time window options for all locations.

Consider the following cases for your experiments:
1. (Case 1) 2 vehicles with a capacity of 130 each & no time windows
2. (Case 2) 2 vehicles with a capacity of 130 & with the original time windows (reference case in part b – data_small.txt).
3. (Case 3) 2 vehicles with a capacity of 130 & with multiple time windows as you formulated in part d.
4. (Case 4) 3 vehicles with a capacity of 70 each & with original time windows (reference case in part b – data_small.txt).
5. (Case 5) 3 vehicles with a capacity of 70 each & with multiple time windows as you formulated in part d.

Evaluate the results of these cases in comparison to each other. Present the resulting routes, usage of vehicles, total distance traveled, the decisions on the time of pickup and computational time. Provide your insights for the differences between them across the different cases.

Now, consider that you can serve the locations by visiting them more than once with different vehicles and possibly at different time windows (known as "split delivery" – although our case is pickup). Assume that, if a location is visited multiple times, it is done by different vehicles, i.e., each vehicle has a single trip. It can be at a different time windows but not necessarily.

f. **[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.*
g. **[5 points]** Implement the model in part f using "**data_small_multiTW.txt**". Consider 3 vehicles with a capacity of 65 each. Run the model in comparison to your model in part d and evaluate the differences. You need to discuss the total distance traveled, change of the routes, usage of vehicles, usage of the split option, the usage of the

time window options as well as the computational time. Provide your insights justifying the differences with the reasons behind.

h. **[5 points]** Can you suggest better time windows, by changing at least one of the time window options for at least one of the locations, which would result in reduced total distance? Provide your suggested time window option and the improvement you get in the total distance traveled in comparison to your results in part g. Also present the routes, usage of the split option as well as the usage of the time window options.

Now, we would like to work with a larger size instance where also the number of time window options are flexible. In other words, different locations can have different number of options. This version represents the real-life problem better with its flexibility.

i. **[10 points]** Implement the model using "**data_large_multiTW_diff.txt**". Consider 3 vehicles with a capacity of 200 each. Run the model and discuss your results. You need to discuss the total distance traveled, the resulting routes, usage of vehicles, usage of the split option, usage of the time window options as well as the computational time.

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.

Notes

- Solve the problems to optimality if the computational time is within 30 min and report the computational time. When it goes **beyond 30 min** set a time limit of 30 min (=1800 s) in order to get solutions (by using "model.Params.timeLimit = 1800"). If you do that, report the **optimality gap** together with your results.
- 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.