School of Mathematics
Dr Jörg Kalcsics

THE UNIVERSITY *of* EDINBURGH

Risk and Logistics

Homework Assignment 2

March 1, 2024

Instructions

1. For this assignment, you will have to write a report and produce some code using Xpress or python.
2. You should attempt all questions.
3. The total marks for this assignment are: 35.
4. Explain in your report what you have been doing in a concise and reproducible way. Write full sentences, not just the final results. The style in which you present your answers is part of the marking.
5. Structure your code, include comments, and avoid unnecessary loops, conditions, and calculations. The style in which you write your code is also part of the marking.
6. **Use your imagination!** You don't have to do everything by the book. Moreover, it is okay to use simplifications and approximations, provided they are reasonable and well justified.

   If you have an idea for a new method or one that helps you to improve the efficiency or effectiveness (or both!) of an existing method, without deteriorating the other too much, then please go ahead. The questions are kept deliberately vague to allow you that freedom (it would be boring – both for you and me – if I'd tell you exactly what to do and what not).

   I am happy with any method that is reasonable and does the job, but I expect you to properly explain and motivate why you think this is a good idea - and, ideally, back it up with some empirical results.

   Marks will be awarded for creativity and clever ideas (to some extent, independent of whether or not they work), and the overall efficiency, i.e. runtime, and effectiveness, i.e. solution quality, of your heuristics.
7. The strict deadline for handing-in your assignment is **12:00 on Friday, 29 March 2024**.

   Please upload exactly two files on Learn: a PDF with your report and a zip file containing all your codes and, if applicable, your data files. If you use jupyter, please also convert your code into a pdf and add it to the zip file.

Setting the Scene

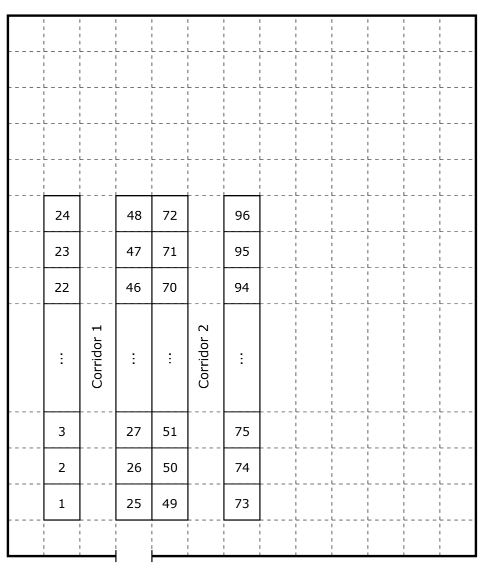
With your help, *Tartan Trade* has set up their supply chain and the first year was a big success for them, both financially and in the number of customers they attracted. However, they are struggling to meet their "next day" delivery goal. In the last two months they have invested a lot of time and effort into improving and fine-tuning their inventory policies. While this has helped, they are, unfortunately, still shy of achieving their goal. Just recently, they have turned their attention to *order picking*, which is the most labour intensive activity inside a warehouse. Order picking is the process of an employee, the so-called picker, walking with a trolley into the storage area, picking all the individual items of a customer order from their respective storage shelves, and bringing them to the packaging area, where another employee puts them into an adequately sized cardboard box. The packaging area is outside the main storage area and close to the docking bays for the lorries.

Speaking to the pickers, one of the founders, Bogi, has observed that they often have to walk long distances in the warehouse to pick all items for a given order, often resulting in significant processing delays. This made her think about the allocation of products to storage shelves, which has gradually evolved over the last year in line with their growing product portfolio. It seems that whenever new products where added to the portfolio, the first available shelf was assigned to a product. What seemed to be natural at that time, now appears to be exceedingly inefficient.

Starting with their warehouse near Inverness, she has extracted all orders from the last three months that were processed by that warehouse, around 2,000 in total. Using that data, she now wants to optimize the allocation of products to storage shelves and she has asked for your help. The goal is to find a new allocation that minimizes the total walking distance for picking all orders.

Further Information and Simplifying Assumptions

- *Tartan Trade's* assortment of items exceeds 1,000, but for storage purposes they have been grouped into 90 product groups, numbered from 1 to 90.
- In the last year, each customer orders consisted of items from **at most five different product groups**, i.e., a picker had to visit up to five shelves on their tour. You can assume that this will not change in the foreseeable future.
- The warehouse is partitioned into 96 storage places or shelves, numbered 1 to 96. The floor plan of the storage area is sketched below.



The storage area is 39 meters wide (horizontal distance) and 90 meters high (vertical distance). As you can see, the shelves are arranged into four columns, with corridors separating the first two and the last two columns, labelled "Corridor 1" and "Corridor 2". Shelves can only be accessed from these two corridors. The rest of the storage area is currently empty. Each shelf has a width and depth of 3 meters, and the corridor has a width of 3 meters. The only entrance to the warehouse is at the bottom left. The floor plan also shows dashed lines superimposing a grid on the storage area. All grid lines are 3 meters apart.

To compute the walking distance between two shelves, we simply count the number of squares a picker has to enter to get from the current shelf to the target shelf, multiplied by 3 meters. A picker always takes the shortest path and the square where they start does not count. For example, to get from Shelf 3 to Shelf 50, the picker has to enter 8 squares, resulting in a walking distance of 24 meters. To get from Shelf 3 to Shelf 25, the distance is 6 meters, and to get from Shelf 3 to Shelf 94, the picker has to enter 28 squares, resulting in a distance of 84 meters.

To compute the walking distance from the packaging area to a shelf, or vice versa, we use the square next to the entrance as the reference square. For example, to get to Shelf 3 from the entrance, the picker has to enter 4 squares, resulting in a distance of 12 meters. To get to Shelf 25, the distance is 6 meters, and to get to Shelf 94, the picker has to enter 24 squares, resulting in a walking distance of 72 meters.

- Each shelf can hold products from at most one product group, i.e. we are not allowed to mix items from different groups in the same shelf, and each shelf is big enough to store all units of every item of that group.

  Each product group must be stored in at least one of the shelves and at the moment each group is assigned to exactly one shelf. But this is not a strict requirement. A product group could be spread out over two different shelves, but not more. In that case, the shelves do not have to be adjacent, they do not even have to be in the same corridor. Moreover, we can assume that sufficiently many units of each product of the group are stored in both shelves. That is, a picker can go to either shelf to collect items from that group.

  For example, considering the first order given in *OrderMatrix.csv* (see below for details), if product group 50 is stored in Shelves 1 and 51, then the picker can either go to Shelf 1 or Shelf 51 to pick the products of the group.

  Bogi is happy for you to use all available shelves, i.e. also the currently empty ones.

- A picker can collect products for only one order at a time, i.e., once all products for one order have been picked, the picker first needs to walk to the packaging area and drop the products before they can start picking the next order.

Data

I have uploaded on Learn

- *OrderList.xlsx*: A spreadsheet that contains a list of 2,000 customer orders. The orders are numbered from 1 to 2,000 (Column 1) and contain the indices of the product groups of the order (Columns 2-6). If the order comprises less than five product groups, the row is filled up with zeros.

- *DistanceMatrix.xlsx*: A spreadsheet containing the pairwise distances between pairs of shelves and between shelves and the entrance of the storage area. The first row and column contains the shelf number. The last row and column contain the walking distance between a shelf to entrance to the storage area.

- *CurrentAllocation.xlsx*: A spreadsheet containing the current allocation of product groups to shelves. The first row of the table is the shelf number and the second row the number of the product group stored in that shelf. The last six shelves, numbered 91 to 96, are empty and have 0's in the product group column.
- *Data_Xpress.txt*: A file that contains all of the above data in Xpress format.
- *Template.mos*: A Mosel template file that reads in all the data.
- *FloorPlan.pdf*: The floor plan.

Questions

1. For the given allocation of product groups to shelves, implement a function that computes the total walking distance of the pickers for the given set of orders.

   Describe the function in your report.

   Run your function on the given set of orders for the current allocation given in *CurrentAllocation.xlsx*. Include the total walking distance in your report as well as the runtime of your function. **[10 marks]**

2. Develop and implement a construction heuristic that creates a new shelf allocation from scratch. I leave the choice of heuristic to you.

   Describe your construction heuristic in the report.

   Run your heuristic for given set of orders and include in your report the total walking distance of this allocation as well as the runtime of your heuristic. **[5 marks]**

3. Develop and implement a local search heuristic that tries to improve a given shelf allocation.

   I leave it up to you how you define your neighbourhood(s), how you explore them, and how you check whether or not you found a better solution.

   Describe your improvement heuristic in the report.

   Run your heuristic for the given set of orders on

   - the shelf allocation given in *CurrentAllocation.xlsx* and
   - the shelf allocation provided by your construction heuristic.

   Include in your report the total walking distance of this allocation as well as the runtime of your heuristic.

   Compare the final solutions with the starting solutions. **[12 marks]**

4. The current layout of the shelves may well not be optimal. Try to come up with an improved floor plan for the shelves. You have full freedom to rearrange all 96 shelves within the confines of the storage area, except for stacking them on top of each other.

   Create the new distance matrix and run your construction and improvement heuristic for the given set of orders with the new floor plan.

   Explain in your report why you chose this floor plan and include the total walking distance of this new allocation as well as the runtime of your heuristics. **[8 marks]**