ISyE 3133 Team Project PART B Due: March 12

Submission Instructions

This project is to be completed in teams. For **Part B** of this project, each team should submit (a) a written report, and (b) two Python files (three if answering the bonus points question). Details of these are given below.

Written Report The written report should present the team's mathematical formulations of the LP and ILP models, answering Question B.1.1(c) and Question B.2.1 (and B.2.3, if answered). The report should discuss all aspects of the investigation you carried out. It should also summarize the findings obtained through the use of the Gurobi solver. It is important to note that in the written report, only the mathematical formulation should be provided, not the Python implementation of the model. However, a glossary page, showing the correspondence between the names of variables and parameters in your mathematical model and the names used in the Python code, should be appended to your report. The report should be written to be informative and helpful for Starfleet Command. It should explain your findings in terms a Starfleet office could understand and appreciate, while also providing details of your models and technical approach, so that these could be audited and duplicated by others if needed. The written report is not expected to be more than ten pages. **Fewer pages** and **handwritten reports are welcome**. The written report (printed or written on paper) should be given to Dr Boland at the start of her lecture on March 12. Electronic submission of the written report is permitted if agreed with your recitation class instructor.

Python Files Each team should submit two Python files, one in response to Question B.1.2(a) and one for Question B.2.1. If seeking bonus points, also submit a Python file for Question B.2.3. Your files should be named

"Name1Name2Name3PartB1–2a.py" and "Name1Name2Name3PartB2–1.py",

where "Name1", "Name2" and "Name3" are your team member names (either first, second or a short name are fine, as long as the end result is likely to uniquely identify your team and to make your identities apparent to your class instructor). For example, if your team members are Anh Do, Celia Pacquola and Mark bin Bakar, your first .py file could be "AnhCeliaBakarPartB1–2a.py". Submit your Python files by uploading them to Canvas under the assignment named "Team Project Part B". Please delegate only **one** of your team members to submit the files.

Shortly after the release of these project instructions, data sets for a small test problem, as well as the larger data set for which you should present results, will be released on Canvas. **Do not submit a Python code that does not run; any code file submitted must successfully compile and produce output, taking as input the data sets provided in .csv format.**

Below is **Part B** of the project. It is strongly encouraged for you to take the published LP model and Python code for Part A as a starting point.

Team Project: Problem Statement

You work for the Starfleet Corps of Engineers. Starfleet has just acquired a new space station, Deep Space Nine, from an alien race called the Cardassians, and you've been tasked with modifying the station's residential district so that it can house its new occupants. While the residential power grid was more than sufficient for the Cardassians, the people moving into the station have different energy requirements, and the grid can't serve all of them. Your job is to satisfy as much of the energy demand as possible.

Your field teams have provided you with the following information on Deep Space Nine's power grid.

Power flows from the main generator for the station through a series of conduits to demand nodes, where it is accessed by residents. Conduits run from one node to another (one, both, or neither end may be a demand node) and have limited capacity. The power can flow in either direction through the conduit, but whichever direction is used, the magnitude of the flow cannot exceed the given capacity. Fortunately, Cardassian conduits (while having a poor capacity) are extremely efficient; the power put into one end is exactly the power that will come out the other end. The chart in Figure 1 shows the conduits and demand nodes for the residential district.

A linear programming (LP) model, implemented in Gurobi Python, has been used to decide how power should be distributed so as to satisfy the most total demand. The solution obtained from this model revealed two key issues. First, the model confirmed there was not enough capacity in the network's conduits to enable power demand at every node to be satisfied. Only 103 units could be supplied, which is a shortfall of 59 units, or more than 36% of the total demand. This was a much higher shortfall than Starfleet had anticipated. Second the level of demand satisfied for each of the several groups of residents on the station – Bajorans, Ferengi, humans, Vulcans, Starfleet personnel, Starfleet officers, and visitors, with their concentrations shown by the color coding of the nodes in the network in Figure 1 – was found to be very uneven.

Part B.1: Linear Programming Models for Fairness

In the short term, Starfleet can see no remedy for the overall shortfall in demand met. Thus, Starfleet has asked you to use and adapt the existing LP model and Python code to decide how, in the short term, power should be distributed so as to address the issue of fairness with respect to the different groups of residents. Clearly, it wouldn't be fair if an optimal solution meant that the Bajorans got no power so that everyone else could get more power on average; and it also wouldn't be fair if an optimal solution sacrificed all of the humans' power so that all of the Ferengis' demand could be fulfilled.

1. Starfleet has asked you to develop a metric to measure how fair a solution is.

    (a) State your metric, and illustrate how it works by calculating the value it gives to

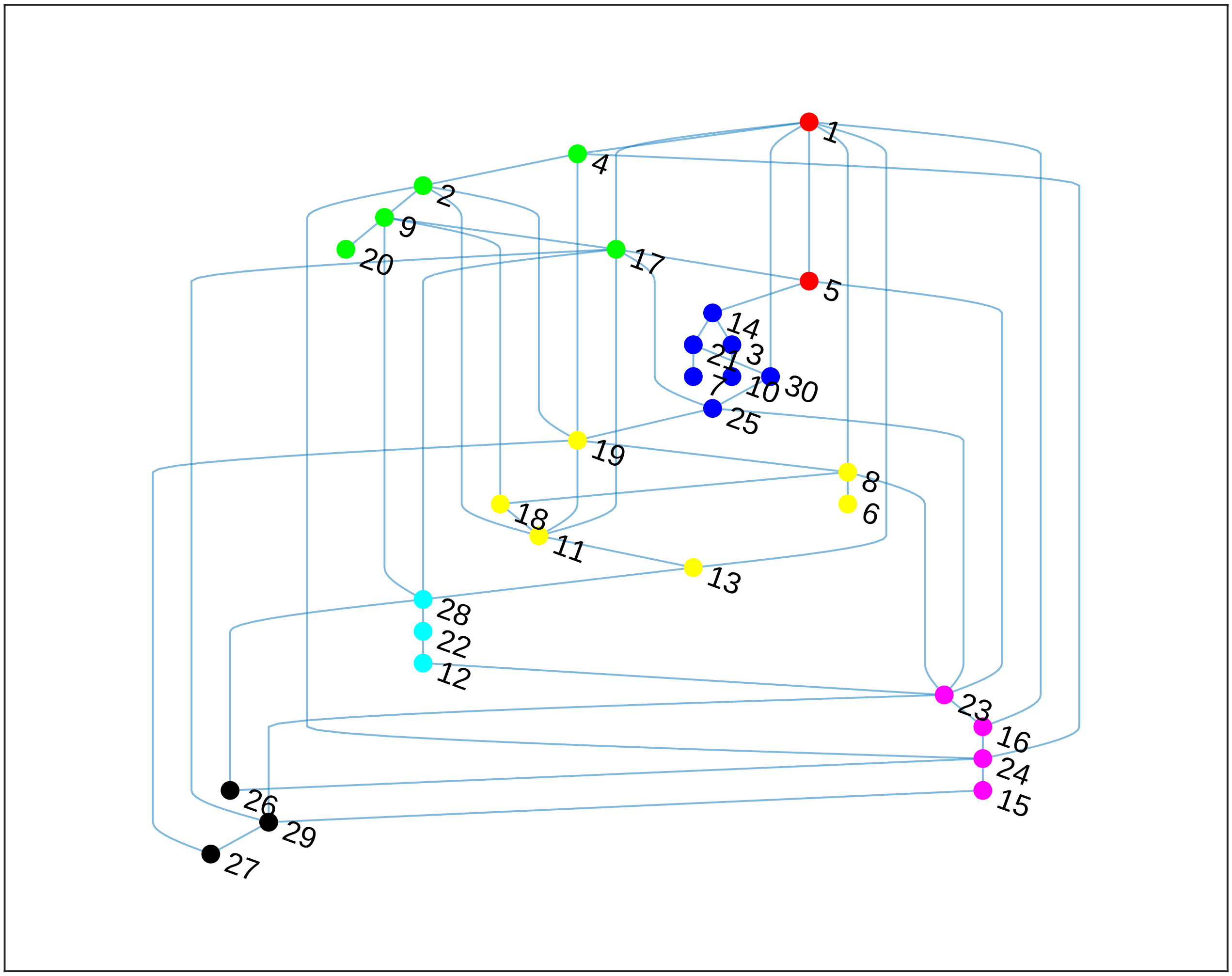

Figure 1: The station residential district power network. It has 30 demand nodes and 54 conduits between pairs of demand nodes. The main generator is located at node 1. There are 7 different groups of residents represented by a color coding of the nodes.

the solution given by the existing LP model, which maximizes the total demand satisfied.

(b) Discuss at least one possible shortcoming of your metric. Are there solutions that your metric would score highly (would deem to be very fair), but that some resident groups may reasonably complain is not fair? Might your metric score two different solutions as equally fair, when in fact there are ways in which one is clearly more fair than the other?

(c) Formulate an LP model for deciding how power should be distributed in order to maximize your fairness metric.

2. Starfleet has considered your solution and metric, and has decided that the current solution isn't fair enough.

   (a) Adapt the existing code to implement the LP model you developed in Question 1(c), and use it to find a solution that maximizes your fairness metric, while still ensuring that the total demand satisfied is at least 95% of the maximum possible, which is 103 units.

   (b) The Starfleet Power Engineering Team likes this new solution, but the Station Harmony Council still feels it isn't fair enough. Both groups want you to generate a complete trade-off curve, showing for wide range of achievable levels of total demand satisfied the greatest level of fairness that can be achieved. Once they see that curve, they can discuss how to compromise, to choose a solution that is fair enough, but still satisfies enough demand.

Part B.2: Integer Programming Models to Increase Network Capacity

To create a long-term solution to the power shortfall issue, DS9 is negotiating to purchase a large shipment of self-sealing stem bolts, which the engineers on the station can use to increase the capacities of conduits in the power grid. Using 1 bolt on a conduit will increase its capacity by 1 unit, and installing more bolts on it will increase its capacity proportionately. Each conduit has a maximum number of bolts that can be installed on it (data is available on this maximum for each conduit). It will take an engineer 3 hours to access and prepare a conduit for improvement, and 1 hour per bolt installed on that conduit. The team on the station can only spare a limited number of hours for power grid improvements.

Note: DS9 hopes that the long-term solution will mitigate any issues of fairness, so while it may be interested in how fairly power can be distributed in an improved network, you should here start from the original, existing, LP model, without any fairness-related variables, constraints or objective.

1. Write and implement an Integer Linear Programming (ILP) model that decides which improvements should be made to maximize the total demand fulfilled after improve-

ments. Your model should use a parameter for the number of hours required of an engineer to make the improvements. Use your code to determine the “theoretical maximum” total demand that could be satisfied by an improved power network, if the engineering team had unlimited hours to devote to it.

2. In order to prioritize its work, the team wants to understand how much the time it spares for power grid improvements impacts the amount of power that the network will be able to deliver, within the range of 40 to 80 hours. Use your model to create a trade-off curve, showing how the amount of power that can be delivered by the network, changes as a function of the engineer hours made available for the improvements.

3. (For bonus points) Adapt your ILP model and your code to determine the minimum number of hours needed by an engineer to achieve the theoretical maximum value of the total demand (which was calculated in Question 1). Your ILP model should do this in a single run; do not simply do bisection search on the number of hours parameter!