Feed the Children: Transforming Hunger into Hope[1]

21-393 Operations Research II

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[1] Title borrowed from the Feed the Children campaign

Introduction

Dining on campus is meant to be a convenience that allows students and faculty to eat full meals while saving time. However, dining on campus at lunch-time can be very slow, especially with long lines spread out across various locations. Because there is no coordination among students, there are some locations with very long lines and others where there is no wait at all. This results in a very slow and inefficient lunch-time service, which reduces the quality of the dining experience for everyone involved. For many students, dining off campus at lunch is not a realistic solution to this problem. Freshmen are required to be on a meal plan, and thus have a lot of on-campus dining money to spend. Others simply do not have the time to wait in long lines for food, due to their lunch time being between classes or work. For our project, we will be assigning students to on-campus dining locations based on their personal preferences, travel time, and wait time. Our goal is to maximize the average satisfaction of students while reducing time spent at lunch in order to create faster lunch service and a better overall dining experience for everyone.

Problem

Given a sample of students, we want to assign students to dining locations so that we maximize their lunch satisfaction while drastically reducing the time students spend at lunch. We want to construct an efficient on-campus dining system, but we also want students to be relatively satisfied with their dining experience. The students in our sample provided us with the time it would take them to travel to each of the five on-campus dining locations we selected, as well as their ideal wait time at each location and their ranking of each location by preference. We will use this information to construct constraints on where students can be assigned, and assign students accordingly.

Assumptions

First, we define the time it takes to get lunch as the time it takes to travel to the dining location, wait in line to order, receive your food, eat, and travel back to your original location. As such, the total time to get lunch varies for each person depending on where they are leaving from and the amount of people in line at their assigned dining location.

In order to solve this problem, we have made several assumptions:

1. Students will be satisfied eating at one of these five on-campus dining locations.
2. Maximum wait time at each location is a linear function of the amount of people in line. This upper bound is used in our calculations as the wait time for each student assigned to that location.
3. The students in our sample are the only people eating lunch at these locations during each of the three lunch blocks.
4. Travel time is constant for students – that is, students are leaving for lunch from the same location every single day, and will be returning to this location after they have eaten lunch. We also assumed that students will be eating in the same time-block each day.

5. There is no spillover between time blocks − that is, no one from the 11 AM-12 PM time block will still be waiting in line when people from the 12 PM-1 PM time block arrive for lunch.

6. Each student spends 15 minutes eating lunch.

Constraints

Initially, we aimed to minimize wait time rather than maximize satisfaction. This was not a linear program, as wait time depended on the number of people assigned to each location. We tried to iterate on the number of people assigned to each location, but our results did not converge to a single solution. After we changed the problem to maximize satisfaction with certain time constraints, we ended up with results that either converged, or alternated between two solutions. Our final constraints are the following:

1. Each person will be assigned to exactly one dining location in their preferred time block.

2. No student will spend more than an hour (including travel time) at lunch. (In our solution, a student rarely ended up taking a full hour for lunch).

Methods

To obtain a sample of students' lunch preferences, we wrote and distributed a survey to students on the Carnegie Mellon University Facebook groups. We received 49 responses. The survey consisted of the following questions:

1. What time do you normally eat lunch during the week?
    a. 11AM - 12PM
    b. 12PM - 1PM
    c. 1PM - 2PM
2. Please rank your preferences for the following dining locations:
    a. The Exchange
    b. Resnik Cafe
    c. La Prima
    d. Au Bon Pain (ABP)
    e. Chipotle
3. How long does it take you to travel to Location X? (Each location substituted separately for X)
4. How long would you be willing to wait for food from Location X for lunch? (This time is known from here on out as the "ideal wait time")

We received 49 responses to our survey, with 10 students eating lunch between 11 AM and 12 PM, 29 students eating between 12 PM and 1 PM, and 10 students eating between 1 PM and 2 PM.

We used the rankings the students provided in the survey to assign the following default satisfaction levels to each location:

Ranking	Satisfaction Level
1st Choice	100%
2nd Choice	90%
3rd Choice	70%
4th Choice	40%
5th Choice	0%

Our initial intention was to set a constraint where no one waited longer than their indicated ideal wait time. Upon inspection of the data, we realized that this would result in an infeasible problem. Instead, we adjusted individual satisfaction levels based on the difference between the ideal wait time and the actual wait time for each student. If a student receives their food faster than their indicated ideal wait time, their satisfaction increased by 1% for every minute saved. If their food takes longer than their ideal wait time, their satisfaction decreased by 1% for each extra minute. For example, if a student is assigned to their second choice dining location, their ideal wait time at that location is 15 minutes, and they wait 13 minutes, their satisfaction level will be 92%.

We used PuLP, a Python package to solve our LPs and assign students to dining locations. See the appendix for our code.

Results

See the appendix for graphs illustrating the optimal assignments, their associated satisfaction levels, and their wait times.

In the first group, the average satisfaction was 119.9, and the maximum lunch time was 57 minutes. All students except for one got their first preference. The algorithm did not converge for the second group and rotated between two solutions. The average satisfaction levels were 90.4 and 82.9, and the wait times when the solutions were evaluated independently were 71 and 78 minutes. In the third group, all students were assigned their first choice dining location. The average satisfaction was 123.6, and the maximum lunch time was 48 minutes.

The algorithm tended to assign students to their first preference in small group sizes. This is caused by our estimation of wait time at each dining location, which is service time multiplied by the number of students assigned to that location. With a small group and the assumption that there are no outside students eating, dining location wait times will be extremely low, so it will not be very costly (in terms of docking satisfaction points for waiting) to send everyone to their first choice dining location. This resulted in the average satisfaction exceeding 100 in the first and third groups because most students were assigned their first choice and waited for a shorter period of time than expected (as indicated on the survey).

In the first group, there was an extremely unhappy student with satisfaction level of 41 after the assignment. After reviewing the survey data, they can be considered an outlier because they put extremely high travel times (>30 minutes) for all but their fourth choice, which they were assigned to. These travel times would not work with our current assumption of a lunch break being one hour long. We can see that in the rare case students have longer travel times than average, the algorithm struggles to satisfy them, preferring to place all the other students in better spots.

In our second lunch block, we didn't get a solution that converged. Rather, we ended up with two solutions which depended on each other, and together satisfied the constraints. Our first solution uses the wait times from the second solution and vice versa to assign people to food locations. Together, the two solutions satisfy our wait-time constraints, but separately they would be infeasible due to overly long lunch times. Furthermore, starting with an average of the two solutions will still result in the same scenario.

Discussion

Moving forward, we could make improvements to our wait time formula. Our current wait time formula assumes a linear relationship between the number of people in the line and the wait time. This can be unrealistic for a few reasons. First, one's wait time is only dependent on the number of people before them in line, not the total number of people in line. Also, considering the dining location might realistically make food in batches, thus accelerating the serving time, the wait time may not be linear in practice. Additionally, we assumed that everyone in the line would have the worst case scenario wait time. That is, all of the people in line would receive their food at the same time, after the last person's food has been made. With that said, because everyone arrives at a different time, each person's wait time should be different.

We could also make changes to our satisfaction function. Currently, our satisfaction function assumes that each ranking is evaluated the same way by each person. In reality, everyone views the rating of the dining locations differently. To eliminate this downside, we could require more data on how people truly value their preferences. Furthermore, our satisfaction function is set up to reflect a linear relationship between excess wait time and satisfaction level. However, people's satisfaction might decrease more dramatically the longer they wait. Therefore, we could develop a higher order function to better represent our population's satisfaction levels.

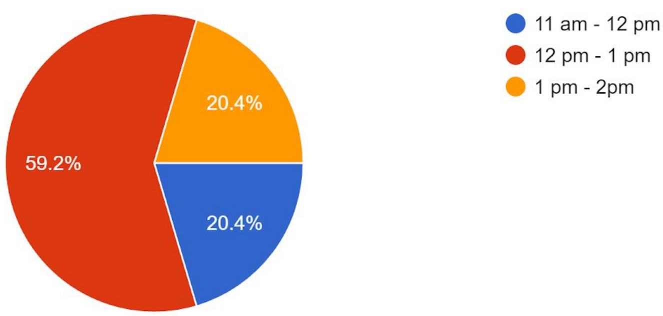
Last but not least, we could make revisions to our survey, so that people can interpret it in a clearer way. Instead of asking students to rank dining locations, we could ask how satisfied each person is with each location. This way, the satisfaction function would be more aligned with the specific preferences of each individual in the sample. The survey and problem could also be expanded to include all on-campus dining locations, to more accurately reflect the choices available to students in reality. In addition, we would prefer to have a bigger sample size, so that we can have a more realistic estimation of wait time.

Appendix

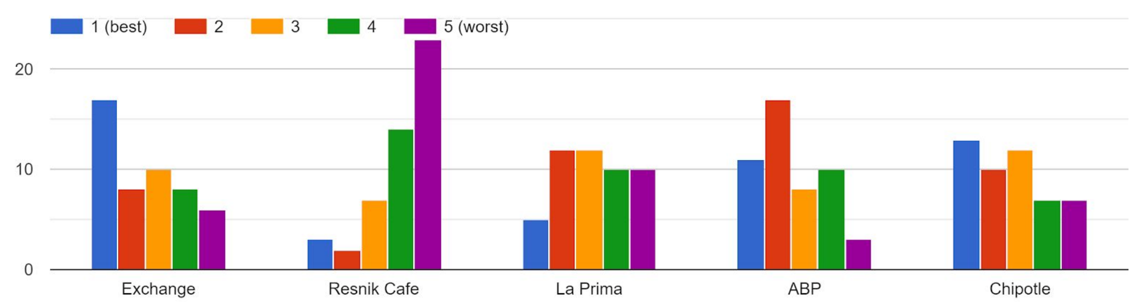
Survey Data

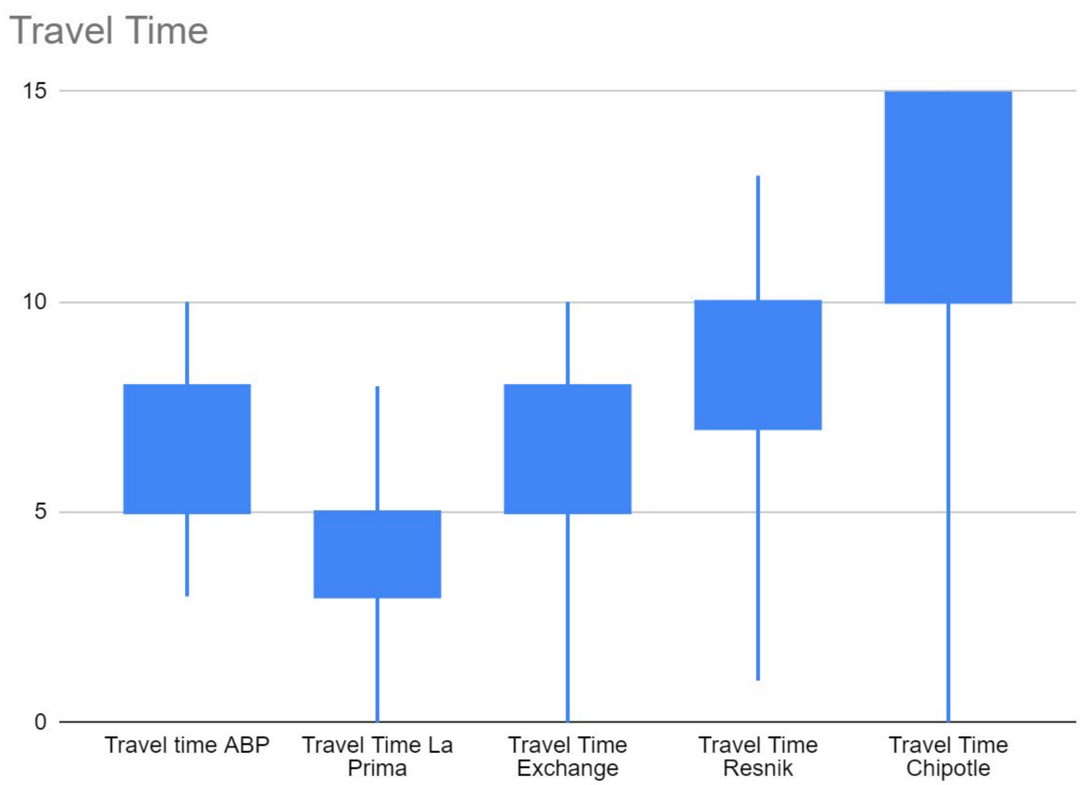
What time do you normally eat lunch during the week?

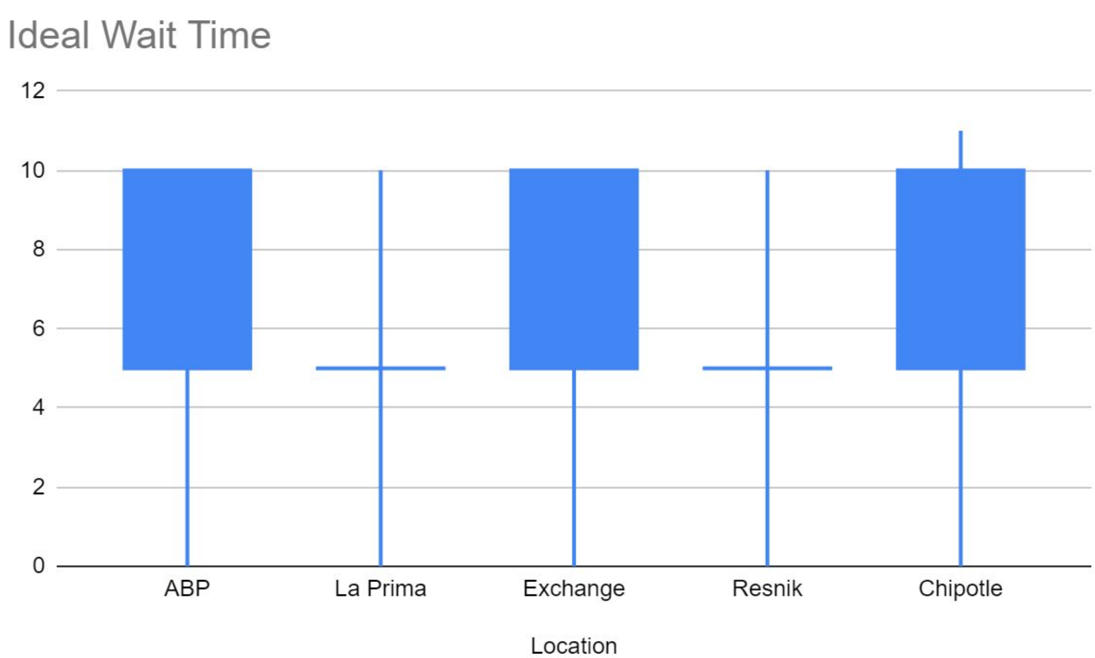
49 responses



Please Rank your preferences for the following restaurants




Travel Time
15
10
5
0
Travel time ABP
Travel Time La Prima
Travel Time Exchange
Travel Time Resnik
Travel Time Chipotle


Ideal Wait Time
12
10
8
6
4
2
0
ABP
La Prima
Exchange
Resnik
Chipotle
Location

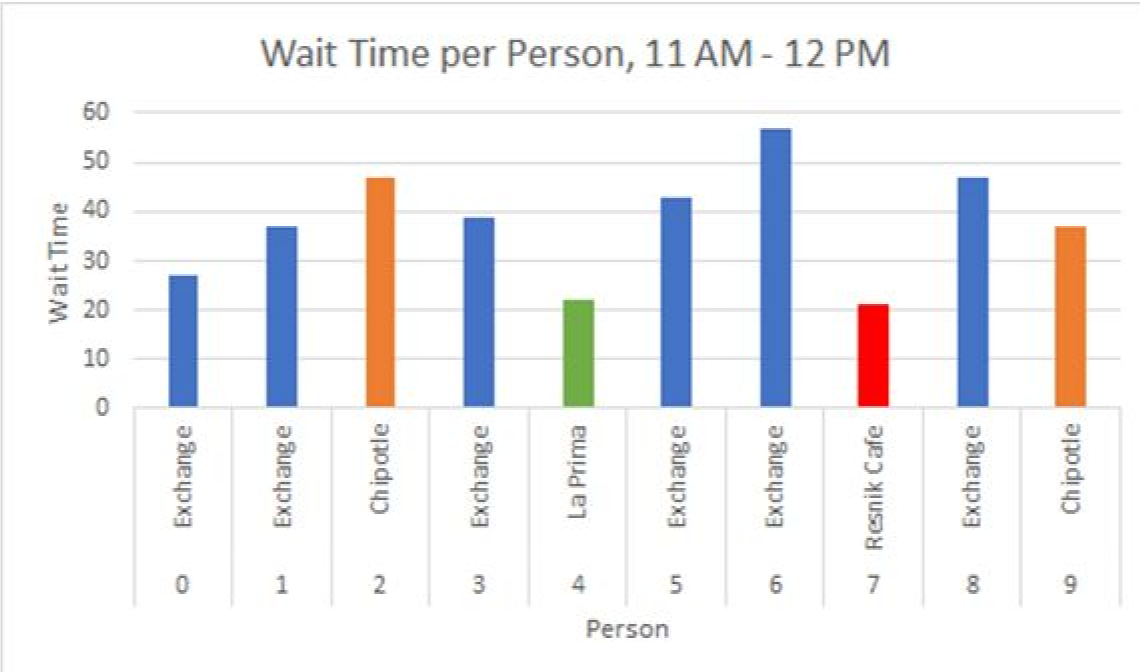
Code

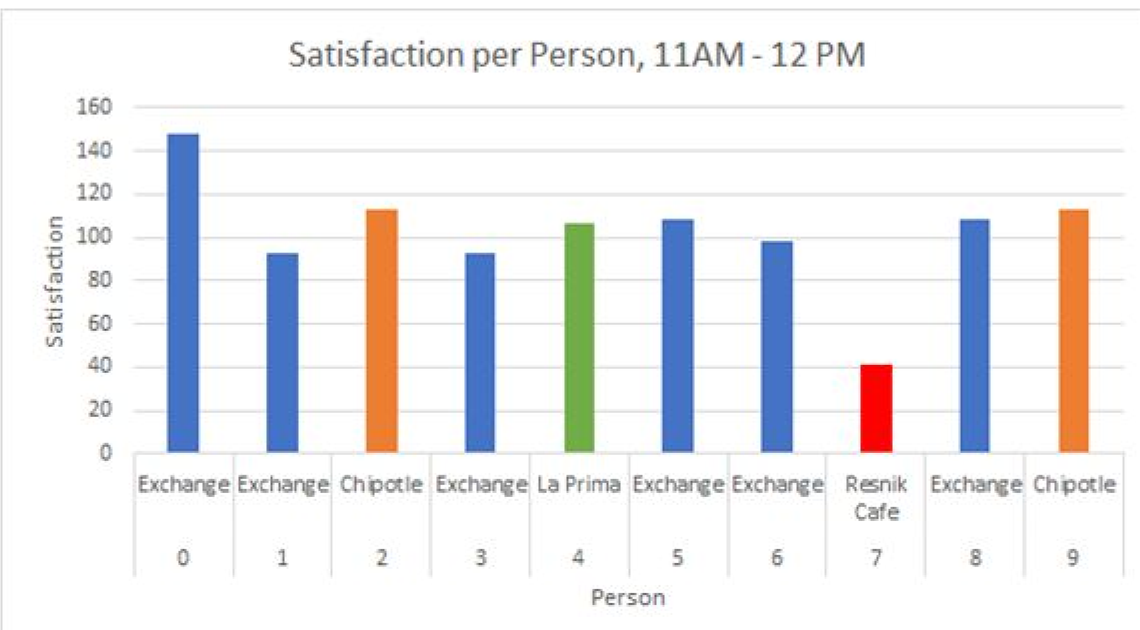
```
import sys
import pulp
import pandas as pd

# load data and LP settings

group = sys.argv[1]
path = None
if group == "a":
    path = '11-12-data.csv'
elif group == "b":
    path = '12-1-data.csv'
else:
    path = '1-2-data.csv'

dataset = pd.read_csv(path)

people = range(len(dataset))

names = ["The Exchange","Resnik Cafe","La Prima","ABP","Chipotle"]
serviceTime = [2,4,3,4,1] # wait time per person, estimated by group members
places = range(len(names))

preferences = dataset.loc[:, 'pref Exchange':'pref Chipotle']
travelTime = dataset.loc[:, 'travel Exchange':'travel Chipotle']
willingnessToWait = dataset.loc[:, 'wait Exchange':'wait Chipotle']
```

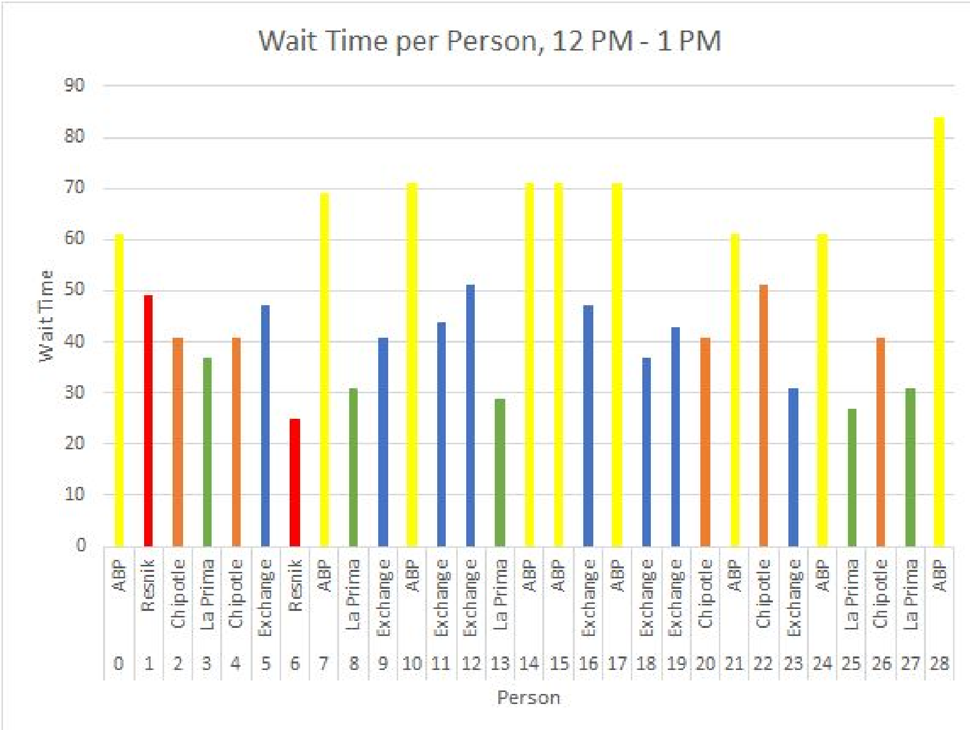
```
# starting number of people assigned to restaurants
# solution will iterate on this list
oldN = None
N = [0]*len(names)

iterations = 0

while (oldN != N) and iterations < 5:

    iterations += 1

    # start problem
    problem = pulp.LpProblem("cafe lunch problem", sense=pulp.LpMaximize)

    # variables
    assignments = pulp.LpVariable.dicts("A", ((person, place) for person in people for place in places), cat="Binary")
```

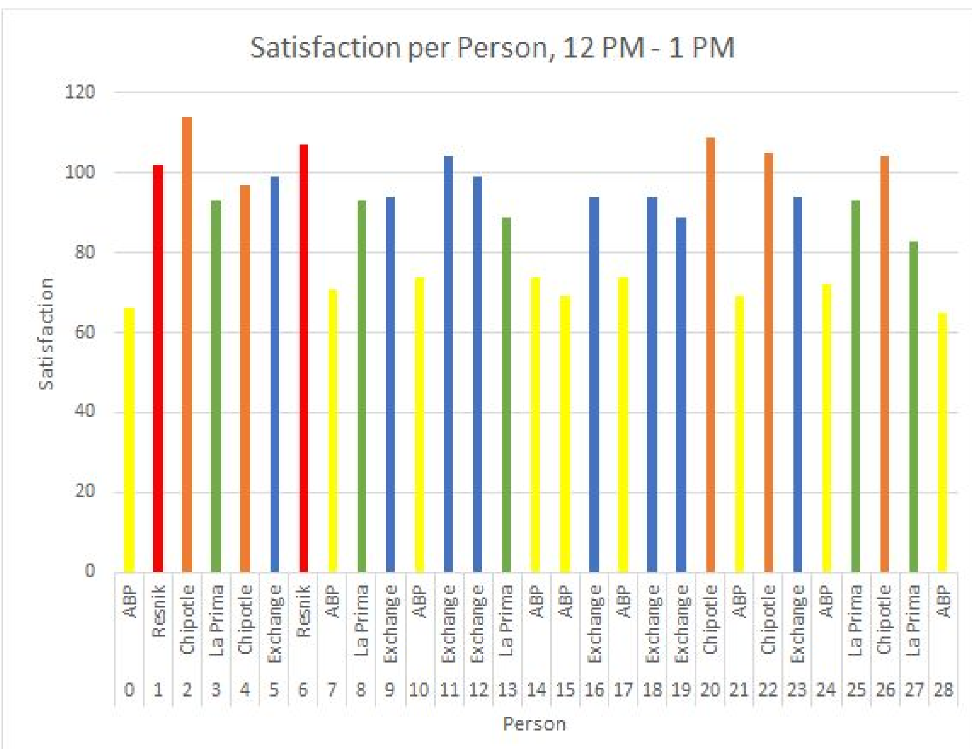
```
    # assignment constraint
    for person in people:
        problem += pulp.lpSum(assignments[person, place] for place in places) == 1

    # time limit constraint
    for person in people:
        problem += pulp.lpSum(assignments[person, place]*(N[place] * serviceTime[place]
                    + 2*travelTime.iloc[person][place] + 15)
                    for place in places) <= 60

    # objective
    problem += pulp.lpSum(assignments[person, place]*preferences.iloc[person][place]
                    + (willingnessToWait.iloc[person][place] - (N[place] * serviceTime[place]))
                    for person in people for place in places)

    # solution
    problem.solve()
```

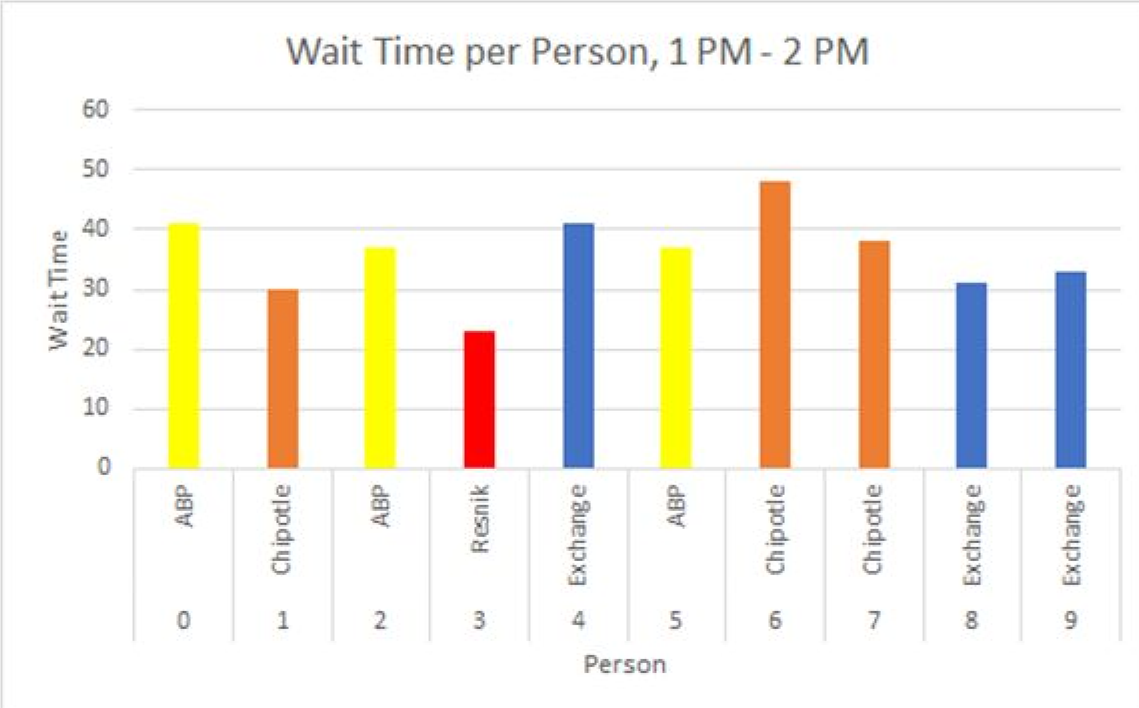
Results- Graphs

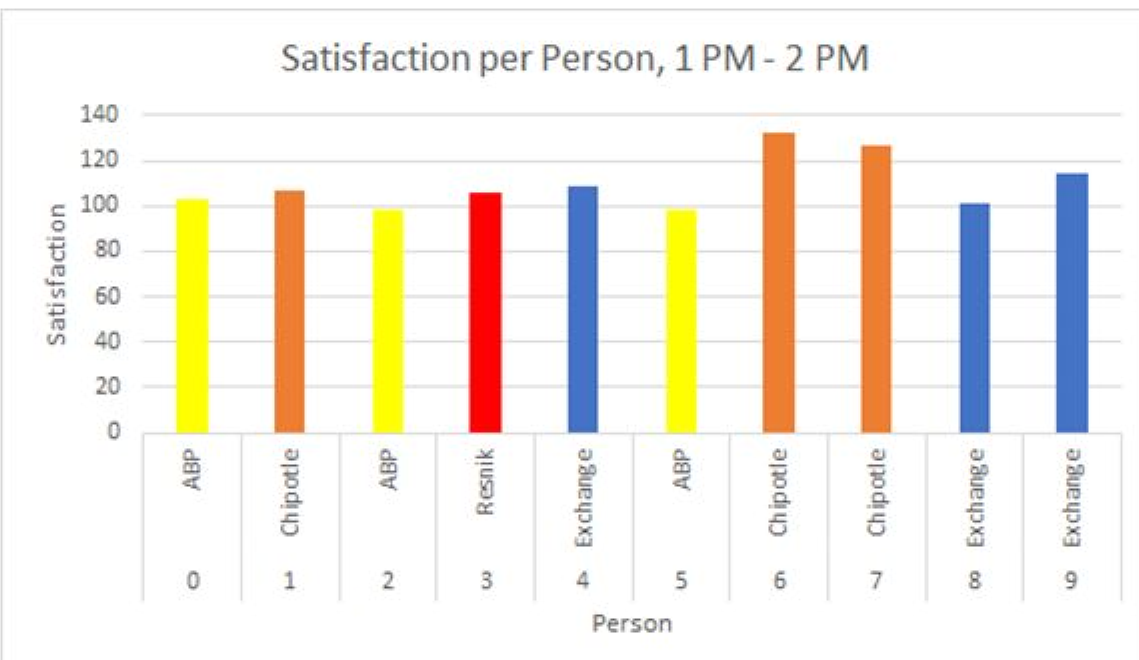





Wait Time per Person, 12 PM - 1 PM
Wait Time
90
80
70
60
50
40
30
20
10
0
ABP
Resnik
Chipotle
La Prima
Chipotle
Exchange
Resnik
ABP
La Prima
Exchange
ABP
Exchange
Exchange
La Prima
ABP
ABP
Exchange
ABP
Exchange
Exchange
Chipotle
ABP
Chipotle
Exchange
ABP
La Prima
Chipotle
La Prima
ABP
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Person


Satisfaction per Person, 12 PM - 1 PM
Satisfaction
120
100
80
60
40
20
0
ABP
Resnik
Chipotle
La Prima
Chipotle
Exchange
Resnik
ABP
La Prima
Exchange
ABP
Exchange
Exchange
La Prima
ABP
ABP
Exchange
ABP
Exchange
Exchange
Chipotle
ABP
Chipotle
Exchange
ABP
La Prima
Chipotle
La Prima
ABP
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Person


Wait Time per Person, 1 PM - 2 PM
Wait Time
0
10
20
30
40
50
60
ABP
Chipotle
ABP
Resnik
Exchange
ABP
Chipotle
Chipotle
Exchange
Exchange
0
1
2
3
4
5
6
7
8
9
Person


Satisfaction per Person, 1 PM - 2 PM
Satisfaction
0
20
40
60
80
100
120
140
ABP
Chipotle
ABP
Resnik
Exchange
ABP
Chipotle
Chipotle
Exchange
Exchange
0
1
2
3
4
5
6
7
8
9
Person

Code Output

Block 1:

Person 0 goes to The Exchange (100), total lunch time: 27, satisfaction: 148
Person 1 goes to The Exchange (100), total lunch time: 37, satisfaction: 93
Person 2 goes to Chipotle (100), total lunch time: 47, satisfaction: 113
Person 3 goes to The Exchange (100), total lunch time: 39, satisfaction: 93
Person 4 goes to La Prima (100), total lunch time: 22, satisfaction: 107
Person 5 goes to The Exchange (100), total lunch time: 43, satisfaction: 108
Person 6 goes to The Exchange (100), total lunch time: 57, satisfaction: 98
Person 7 goes to Resnik Cafe (40), total lunch time: 21, satisfaction: 41
Person 8 goes to The Exchange (100), total lunch time: 47, satisfaction: 108
Person 9 goes to Chipotle (100), total lunch time: 37, satisfaction: 113

Average Satisfaction: 119.9
Max Lunch Time: 57

Block 2:

Solution 1:
Person 0 goes to ABP (100), total lunch time: 61, satisfaction: 66
Person 1 goes to Resnik Cafe (100), total lunch time: 49, satisfaction: 102
Person 2 goes to Chipotle (100), total lunch time: 41, satisfaction: 114
Person 3 goes to La Prima (100), total lunch time: 37, satisfaction: 93
Person 4 goes to Chipotle (100), total lunch time: 41, satisfaction: 97
Person 5 goes to The Exchange (100), total lunch time: 47, satisfaction: 99
Person 6 goes to Resnik Cafe (100), total lunch time: 25, satisfaction: 107
Person 7 goes to ABP (90), total lunch time: 71, satisfaction: 69
Person 8 goes to La Prima (100), total lunch time: 31, satisfaction: 93
Person 9 goes to The Exchange (100), total lunch time: 41, satisfaction: 94
Person 10 goes to ABP (100), total lunch time: 71, satisfaction: 74
Person 11 goes to The Exchange (100), total lunch time: 44, satisfaction: 104
Person 12 goes to The Exchange (100), total lunch time: 51, satisfaction: 99
Person 13 goes to La Prima (100), total lunch time: 29, satisfaction: 89
Person 14 goes to ABP (100), total lunch time: 71, satisfaction: 74
Person 15 goes to ABP (100), total lunch time: 71, satisfaction: 69
Person 16 goes to The Exchange (100), total lunch time: 47, satisfaction: 94
Person 17 goes to ABP (100), total lunch time: 71, satisfaction: 74
Person 18 goes to The Exchange (100), total lunch time: 37, satisfaction: 94
Person 19 goes to The Exchange (100), total lunch time: 43, satisfaction: 89
Person 20 goes to Chipotle (100), total lunch time: 41, satisfaction: 109
Person 21 goes to ABP (100), total lunch time: 61, satisfaction: 69
Person 22 goes to Chipotle (100), total lunch time: 51, satisfaction: 105

Person 23 goes to The Exchange (100), total lunch time: 31, satisfaction: 94
Person 24 goes to ABP (100), total lunch time: 61, satisfaction: 72
Person 25 goes to La Prima (100), total lunch time: 27, satisfaction: 93
Person 26 goes to Chipotle (100), total lunch time: 41, satisfaction: 104
Person 27 goes to ABP (100), total lunch time: 65, satisfaction: 84
Person 28 goes to Chipotle (100), total lunch time: 51, satisfaction: 97

Average Satisfaction : 90.37931034482759
Max Lunch Time: 71.0
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Solution 2:
Person 0 goes to Chipotle (90), total lunch time: 32, satisfaction: 85
Person 1 goes to Resnik Cafe (100), total lunch time: 49, satisfaction: 102
Person 2 goes to Chipotle (100), total lunch time: 42, satisfaction: 113
Person 3 goes to La Prima (100), total lunch time: 58, satisfaction: 72
Person 4 goes to Chipotle (100), total lunch time: 42, satisfaction: 96
Person 5 goes to The Exchange (100), total lunch time: 49, satisfaction: 97
Person 6 goes to Resnik Cafe (100), total lunch time: 25, satisfaction: 107
Person 7 goes to La Prima (40), total lunch time: 68, satisfaction: 12
Person 8 goes to La Prima (100), total lunch time: 52, satisfaction: 72
Person 9 goes to The Exchange (100), total lunch time: 43, satisfaction: 92
Person 10 goes to La Prima (70), total lunch time: 78, satisfaction: 47
Person 11 goes to The Exchange (100), total lunch time: 46, satisfaction: 102
Person 12 goes to The Exchange (100), total lunch time: 53, satisfaction: 97
Person 13 goes to La Prima (100), total lunch time: 50, satisfaction: 68
Person 14 goes to La Prima (90), total lunch time: 58, satisfaction: 67
Person 15 goes to La Prima (90), total lunch time: 58, satisfaction: 62
Person 16 goes to The Exchange (100), total lunch time: 49, satisfaction: 92
Person 17 goes to La Prima (90), total lunch time: 56, satisfaction: 67
Person 18 goes to The Exchange (100), total lunch time: 39, satisfaction: 92
Person 19 goes to The Exchange (100), total lunch time: 45, satisfaction: 87
Person 20 goes to Chipotle (100), total lunch time: 42, satisfaction: 108
Person 21 goes to The Exchange (90), total lunch time: 35, satisfaction: 77
Person 22 goes to Chipotle (100), total lunch time: 52, satisfaction: 104
Person 23 goes to The Exchange (100), total lunch time: 33, satisfaction: 92
Person 24 goes to La Prima (90), total lunch time: 52, satisfaction: 62
Person 25 goes to La Prima (100), total lunch time: 48, satisfaction: 72
Person 26 goes to Chipotle (100), total lunch time: 42, satisfaction: 103
Person 27 goes to La Prima (90), total lunch time: 52, satisfaction: 62
Person 28 goes to Chipotle (100), total lunch time: 52, satisfaction: 96

Average Satisfaction : 82.93103448275862
Max Lunch Time: 78.0

Block 3:

Person 0 goes to ABP (100), total lunch time: 41, satisfaction: 103
Person 1 goes to Chipotle (100), total lunch time: 30, satisfaction: 107
Person 2 goes to ABP (100), total lunch time: 37, satisfaction: 98
Person 3 goes to Resnik Cafe (100), total lunch time: 23, satisfaction: 106
Person 4 goes to The Exchange (100), total lunch time: 41, satisfaction: 109
Person 5 goes to ABP (100), total lunch time: 37, satisfaction: 98
Person 6 goes to Chipotle (100), total lunch time: 48, satisfaction: 132
Person 7 goes to Chipotle (100), total lunch time: 38, satisfaction: 127
Person 8 goes to The Exchange (100), total lunch time: 31, satisfaction: 101
Person 9 goes to The Exchange (100), total lunch time: 33, satisfaction: 114

Average Satisfaction: 123.6
Max Lunch Time: 48