Project Report
Optimization of NYU Shanghai Shuttle Bus Schedule

Xue Bai & Yuhan Yao

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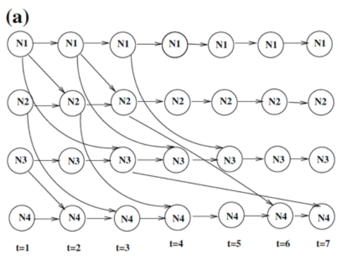
1 Introduction

The shuttle bus service is essential to the everyday life of NYU Shanghai students and faculty. Many students choose shuttle buses to commute between residential halls and Pudong campus. Maintaining the shuttle bus service is also a crucial part of the school budget. As convenient as the shuttle bus service may be, there still exist unsatisfactory incidents. Have you ever found yourself waiting in the line to get on the last shuttle in the morning just to be informed there are no more seats? Have you ever gone downstairs ten minutes earlier to go back to Jinqiao just to find the only shuttle bus has been long gone?

In this project, we are hoping to deal with the common pains of wasting time due to the unreasonable shuttle timetable. However, increasing bus frequency to shorten waiting time will cause the service cost to skyrocket. Therefore, we aim to construct a mathematical model to optimize NYU Shanghai shuttle bus timetable that balances the trade-off between total waiting time and commuting time for students and service costs for the school.

2 Methodology

We adopted the spatio-temporal networks model, or more specifically, time expanded networks (Betsy and Kim) for our project. The spatio-temporal networks model is a graphic model that captures changes across time and space. It is widely used in time series analysis in computer science and is gaining increasing popularity in transportation science as vehicle scheduling problems becomes more important. Time expanded graph in particular, “can be used to represent tim dependent graphs” (Betsy and Kim, pp. 14). As shown in Graph 1, a time expanded graph splits time into several intervals and duplicate the nodes of the network for every interval. The graph is connected by “holdover edges” (pp. 14), which connects the same node across different time period, and “transfer edges” (pp. 14), which connects different nodes across different time interval. This graph allows us to track the behavior of transportations (in our case shuttle buses) for each interval and see whether they are staying at the same place or commuting to another.



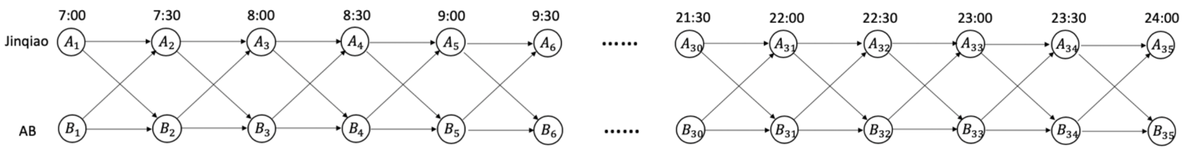
Graph 1. Example of Time Expanded Graph (Betsy and Kim)

3 Model Formulation

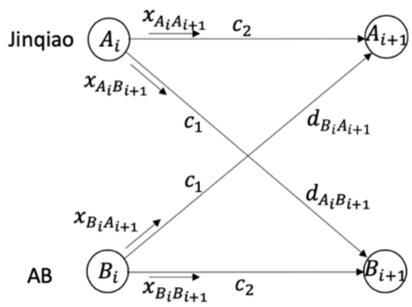
While NYU Shanghai has three residential halls and the bus schedule is may be different during midterms, finals and weekends, to simplify our model, we make the following assumptions:

- All shuttle buses commute only between Jinqiao and the academic building because the existing schedules are identical.
- All shuttle buses leave from Jinqiao or wait at Jinqiao for the first dispatch.
- Shuttle bus service starts from 7:00 in the morning and ends at 24:00 at night (17 hours per day) on weekdays with no schedule changes on special occasions.
- All shuttle buses can only travel from A to B or travel from B to A once in interval T.

We set the time interval T to be 30 minutes because it is a reasonable period of time that fits assumption 4 and is the shortest interval in the existing timetable (See Appendix A). Therefore, we will have 34 intervals in total. We denote A_i and B_i ($i \in \{1,2,3,\ldots,34\}$) as the node of Jinqiao and the academic building at the beginning of interval i respectively and A_{35} and B_{35} as the node of Jinqiao and the academic building at the end of interval 34. For example, as shown in Graph 2, A_1 and B_1 represent Jinqiao and AB at 7:00 am respectively, A_2 and B_2 represent Jinqiao and AB at 7:30 am respectively, etc. The changes in the number of buses at nodes A_{i+1} and B_{i+1} and nodes A_i and B_i indicates the number of buses waiting at the same place or traveling to the other place. For example, if at 7:00 am, there are 11 buses at A_1 and 0 bus at B_1. At 7:30 am, there are 6 buses at A_2 and 5 buses at B_2. Then, five buses leave from Jinqiao to AB during the first interval and 6 buses waits at Jinqiao and do not travel.



Graph 2. NYU Shanghai Bus Schedule Model



Graph 3. Details of One Interval

For decision variables (See Graph 3), we defined the following:

- $x_{A_iA_{i+1}}$: The number of buses waiting from node A_i to node A_{i+1}.

- $x_{A_iB_{i+1}}$: The number of buses commuting from node A_i to node B_{i+1}.
- $x_{B_iA_{i+1}}$: The number of buses commuting from node B_i to node A_{i+1}.
- $x_{B_iB_{i+1}}$: The number of buses waiting from node B_i to node B_{i+1}.
- a_i: The number of buses at node A_i for $\forall i = 2,3 \dots ,35$.
- b_i: The number of buses at node B_i for $\forall i = 2,3, \dots ,35$.

For parameters (See Graph 3), we define the following:

- N: Total number of shuttle buses.
- c_1: Cost of traveling per bus per interval.
- c_2: Cost of waiting per bus per interval.
- a_1: Initialize the number of buses at node A1, which will be equal to N according to our second assumption.
- b_1: Initialize the number of buses at node B1, which will be equal to 0.
- $d_{A_iB_{i+1}}$: The number of students travelling from node A_i to node B_{i+1}.
- $d_{B_iA_{i+1}}$: The number of students travelling from node B_i to node A_{i+1}.
- s: The number of seats on each shuttle bus.

The baseline formulation where we ensure each and every student must have seats on shuttle buses is as follows:

$$\min_{x} W = \sum_{i=1}^{34} (x_{A_iA_{i+1}}c_2 + x_{A_iB_{i+1}}c_1 + x_{B_iA_{i+1}}c_1 + x_{B_iB_{i+1}}c_2)$$

s.t.

$$sx_{A_iB_{i+1}} \geq d_{A_iB_{i+1}}, for\ \forall i = 1,2, \dots ,34$$
$$sx_{B_iA_{i+1}} \geq d_{B_iA_{i+1}}, for\ \forall i = 1,2, \dots ,34$$
$$a_i = x_{A_iA_{i+1}} + x_{A_iB_{i+1}}, for\ \forall i = 1,2, \dots ,34$$
$$b_i = x_{B_iA_{i+1}} + x_{B_iB_{i+1}}, for\ \forall i = 1,2, \dots ,34$$
$$x_{A_iA_{i+1}} + x_{B_iA_{i+1}} = a_{i+1}, for\ \forall i = 1,2, \dots ,34$$
$$x_{B_iB_{i+1}} + x_{A_iB_{i+1}} = b_{i+1}, for\ \forall i = 1,2, \dots ,34$$
$$x, a_i, b_i \in \mathbb{N}*$$

where the objective function is to minimize the total cost of running the shuttle bus service in one day; the first and second constraints specify that all students must be able to get on shuttle buses; the third, fourth, fifth and sixth constrains ensure the number of buses going into a node and coming out of a node are the same; the last constraint specifies that all x, ai and bi are integer variables.

On top of the baseline formulation, we also want to bring in variations so that our model can be as realistic and applicable as possible. Since our survey data is based on a small number of student body, one person's survey answer can result in a huge difference in the estimated data that we are using to build the time schedule. These variations can reduce the model's sensitivity to the estimated data so that the model is more flexible and tolerant to new data input. A few variations we tested out are:

- We would like to lower the total number of buses N to lower the total cost as long as we can still obtain feasible solutions from the baseline model. In other words, we now have 11 buses in total, but in reality, we may need less buses.
- We want to try adding tolerance k to our model, meaning we do not satisfy all the demand of all students. For example, if in a certain interval, there are fewer than k=5 people for one shuttle bus, we can recommend them to use other transportations so that the bus can wait at its node for this interval.

  Under this assumption, we formulated a slightly different model:

$$\min_{x} W = \sum_{i=1}^{34} (x_{A_iA_{i+1}}c_2 + x_{A_iB_{i+1}}c_1 + x_{B_iA_{i+1}}c_1 + x_{B_iB_{i+1}}c_2)$$

  s.t.

$$sx_{A_iB_{i+1}} \geq d_{A_iB_{i+1}} - k, for\ \forall i = 1,2,\dots,34$$
$$sx_{B_iA_{i+1}} \geq d_{B_iA_{i+1}} - k, for\ \forall i = 1,2,\dots,34$$
$$a_i = x_{A_iA_{i+1}} + x_{A_iB_{i+1}}, for\ \forall i = 1,2,\dots,34$$
$$b_i = x_{B_iA_{i+1}} + x_{B_iB_{i+1}}, for\ \forall i = 1,2,\dots,34$$
$$x_{A_iA_{i+1}} + x_{B_iA_{i+1}} = a_{i+1}, for\ \forall i = 1,2,\dots,34$$
$$x_{B_iB_{i+1}} + x_{A_iB_{i+1}} = b_{i+1}, for\ \forall i = 1,2,\dots,34$$
$$x, a_i, b_i \in \mathbb{N}$$

  where the objective function is still to minimize the total cost of running the shuttle bus service in one day; the first and second constraints specify that most students can get on shuttle buses but if one bus has fewer than 5 people, their demand will not be met; the third, fourth, fifth and sixth constrains ensure the number of buses going into a node and coming out of a node are the same; the last constraint specifies that all x, ai and bi are integer variables.

  By using the modified model above, we then lower the total number of buses N to see if we can lower total cost.
- We also want to try manually cancelling a few buses by tweaking the data of the number of students going to the school to see if you will have a better result. For example, we could cancel the 13:30pm buses and move the demand to 14:00pm to see if it makes a difference.

4 Data Source and Description

Since there are no public data for reference, we collected and estimated data on our own. Public safety provided us some basic information, which is the total number of shuttle buses N is 11, the average number of seats on each shuttle bus n is 50, the total number of drivers is 12 and in the Fall 2019 semester, the number of students taking shuttle bus each day is 1880 person-time. Public safety also informed us that as agreed by NYU Shanghai and Jinqiao Property Management, shuttle buses are not allowed to park at Jinqiao overnight, but buses would arrive at Jinqiao/Pusan half an hour before their first departure, which means all buses should start from Jinqiao/Pusan in the morning, confirming our second assumption above.

To estimate the cost of traveling and waiting per bus per hour, we searched online for information on bus driver wages, gas price and bus maintenance fee. According to sh.58.com, we set the monthly salary of one bus driver to be 6,000 RMB, which gives us an hourly salary at about 6,000RMB/(25days*16hour/day) =15 RMB/hour. Therefore, the cost of waiting per interval c_2 will be 15/2 = 7.5. Because of the drop in international gas prices, the price of #93 gas is 5.47 RMB/L, the price of #97 gas is 5.82 RMB/L and the price of diesel is 5.08RMB/L (by May 4, 2020). We will round up to 5.5 RMB/L for the simplicity of calculation. Big buses such as shuttle buses consume around 23L of gas after running 100km. The average distance between the campus and Jinqiao is about 7km. Then, we have the average cost of gas for one travel in one interval is around (23L*5.5RMB/L*7km)/100km = 8.855RMB. Monthly maintenance fee for one bus is about 4,000RMB/month. If we assume each bus will be operating for 10 hours a day, then we have the hourly maintenance fee at around 4,000RMB/(25days/month*10hours/day) = 16RMB/hour. Since maintenance fee is positively correlated with the miles a bus travel, we will add it to the cost of travel and the hourly cost of travel will be 15+8.855+16 ≈ 40 RMB/hour. Therefore, the cost of travel per interval c_1 will be 40/2 = 20RMB/interval.

As for the number of commuting students, it is hardly possible to obtain all the data from every student. Therefore, we conducted a survey and collected valid data and opinions from 56 NYU Shanghai students (See Appendix B). We augmented the number of students based on the data of 1880 person-time per day according to Public Safety and obtain an estimation, with 1882 students in total.

	7:00	7:30	8:00	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00
JinqiaotoAB	114	106	132	132	117	83	57	52	13	8	18	13	26	3	13	10	0
ABtoJinqiao	0	0	0	0	0	0	14	2	0	7	12	7	9	5	7	7	12
	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	19:30	20:00	20:30	21:00	21:30	22:00	22:30	23:00	23:30
JinqiaotoAB	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
ABtoJinqiao	9	32	39	53	35	30	18	60	44	60	53	90	58	78	71	35	55

Table 1. Estimation of the Number of Students travelling

To sum up, we have the following parameters:

$$N = 11$$
$$c_1 = 20$$
$$c_2 = 7.5$$

$$a_1 = N$$
$$b_1 = 0$$
$$s = 50$$

i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
dAiBi+1	114	106	132	132	117	83	57	52	13	8	18	13	26	3	13	10	0
dBiAi+1	0	0	0	0	0	0	14	2	0	7	12	7	9	5	7	7	12
i	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
dAiBi+1	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
dBiAi+1	9	32	39	53	35	30	18	60	44	60	53	90	58	78	71	35	55

Table 2. Parameters of waiting people

5 Implementation and Results

In our optimization model, all variables are integer variables and the objective function is linear, so we used CPLEX to solve our mixed integer programming problem (See Appendix C).

- For our baseline model, we yield the following result:

i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
xAiAi+1	8	5	2	5	2	3	1	0	0	0	0	0	0	0	0	0	1	2
xAiBi+1	3	3	3	3	3	2	2	2	1	1	1	1	1	1	1	1	0	0
xBiAi+1	0	0	6	0	3	0	1	1	1	1	1	1	1	1	1	1	1	1
xBiBi+1	0	3	0	3	3	6	7	8	9	9	9	9	9	9	9	9	9	8
a(i)	11	8	5	8	5	5	3	2	1	1	1	1	1	1	1	1	1	2
b(i)	0	3	6	3	6	6	8	9	10	10	10	10	10	10	10	10	10	9

i	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
xAiAi+1	3	4	5	6	7	8	8	8	7	7	7	7	7	8	8	9	
xAiBi+1	0	0	0	1	0	0	1	2	2	2	2	2	2	1	2	0	
xBiAi+1	1	1	2	1	1	1	2	1	2	2	2	2	2	2	1	2	
xBiBi+1	7	6	4	3	3	2	0	0	0	0	0	0	0	0	0	0	
a(i)	3	4	5	7	7	8	9	10	9	9	9	9	9	9	10	9	11
b(i)	8	7	6	4	4	3	2	1	2	2	2	2	2	2	1	2	0

```
----     60 VARIABLE W.L                 =     3955.000  total cost
```

Table 3. Baseline model result

- By lowering the value of N, we found that the total cost indeed drops when N is smaller. The smallest N that is feasible is 6.

N	z
11	3955
10	3725
9	3495
8	3265
7	3035
6	2805
5	infeasible

Table 4. Results with different N

- For our modified model, we have:

k	z
0	3955
1	3955
2	3930
3	3880
4	3880
5	3830
6	3805

When k=0, the modified model is the same as the baseline model

Table 5. Results with different k

The table shows us the tendency of the total cost decreasing as k increases. However, we only tried k=1,2,3,4,5,6 because we believe k=5 is a proper tolerance, meaning if there are more than 5 students on a bus, the shuttle bus should go to their destination.

- By lowering N on our modified model when k=5, we verify again that the total cost drops when N is smaller.

N	z
11	3830
10	3600
9	3370
8	3140
7	2910
6	2680
5	infeasible

Table 6. Results with different N with k = 5

We did not perform a grid search, but we expect the result of the grid search to be the same as the following:

i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
xAiAi+1	3	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	2
xAiBi+1	3	3	3	3	3	2	2	1	1	1	1	1	1	0	1	1	0	0
xBiAi+1	0	3	3	3	3	1	1	1	1	1	1	1	1	0	1	1	1	1
xBiBi+1	0	0	0	0	0	2	3	4	4	4	4	4	4	5	4	4	4	3
a(i)	11	3	3	3	3	3	2	1	1	1	1	1	1	1	1	1	1	2
b(i)	0	3	3	3	3	3	4	5	5	5	5	5	5	5	5	5	5	4

i	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
xAiAi+1	3	0	0	1	2	3	3	3	3	3	2	2	2	3	4	5	
xAiBi+1	0	4	1	0	0	0	1	2	1	2	2	2	2	1	1	0	
xBiAi+1	1	1	1	1	1	1	2	1	2	1	2	2	2	2	1	1	
xBiBi+1	2	1	4	4	3	2	0	0	0	0	0	0	0	0	0	0	
a(i)	3	4	1	1	2	3	4	5	4	5	4	4	4	4	5	5	6
b(i)	3	2	5	5	4	3	2	1	2	1	2	2	2	2	1	1	0

```
----     60 VARIABLE W.L                    =      2680.000  total cost
```

Table 7. Model result with N = 6 and k = 5

- By manually cancelling buses and adding the number of waiting people of cancelled buses to the previous or next interval, we have brand-new schedules. It is not possible to list every combination of buses that can be cancelled. Here, we picked a few based on observation of the data. Since fewer students travel between Jinqiao and AB at noon and in the afternoon, we decided to make such changes.
  First, we tried cancelling buses both from Jinqiao to AB and from AB to Jinqiao.

N	k	Cancel		z
		i	time	
11	5	8,9,11,12,14,15,17	10:30, 11:00, 12:00, 12:30, 13:30, 14:00, 15:00	3730
6	5	8,9,11,12,14,15,17	10:30, 11:00, 12:00, 12:30, 13:30, 14:00, 15:00	2580
11	5	8,9,11,12,14,15,17,18	10:30, 11:00, 12:00, 12:30, 13:30, 14:00, 15:00, 15:30	3705
6	5	8,9,11,12,14,15,17,18	10:30, 11:00, 12:00, 12:30, 13:30, 14:00, 15:00, 15:30	2555

Cancelling buses mimics the reality where we simply do not have buses at a certain time form either direction. It does yield a better result compared to the baseline model, but we would like to add more flexibility to the final bus schedule. Therefore, we tried another way that treats the two directions separately, meaning we can cancel buses from one direction but not the other. Here is our attempt:

N = 6	Direction	Cancel		z
		i	time	
k = 5	AB	9,12,14,15,17	11:00, 12:30, 13:30, 14:00, 15:00	2580
	BA	8,9,10,12,14,15,17	10:30, 11:00, 11:30, 12:30, 13:30, 14:00, 15:00	

	7:00	7:30	8:00	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00
JinqiaotoAB	114	106	132	132	117	83	57	52	0	21	31	0	26	0	0	26	0
ABtoJinqiao	0	0	0	0	0	0	14	0	0	0	21	0	16	0	0	19	0
	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	19:30	20:00	20:30	21:00	21:30	22:00	22:30	23:00	23:30
JinqiaotoAB	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
ABtoJinqiao	21	32	39	53	35	30	18	60	44	60	53	90	58	78	71	35	55

Table 8. Changes to waiting people number and cancellation of time

This schedule remains a very low cost and is comparatively more flexible than cancelling buses from both way. Therefore, we consider this schedule as the opitimal among all the ones we have tested.

6 Conclusion & Future Work

By testing different scenarios and tuning parameters, the optimal schedule with the least total cost of 2580RMB is with N=6, k=5 and cancelling buses from Jinqiao to AB at 11:00, 12:30, 13:30, 14:00, 15:00 and from AB to Jinqiao at 10:30, 11:00, 11:30, 12:30, 13:30, 14:00, 15:00. Compared with our baseline model which is highly dependent on the estimated data we acquired from our survey, we reduced the total cost by (3955-2580)/3955 = 34.77%.The values of variables are:

i	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	29	30	31	32	33	34	35
xAiAi+1	3	0	0	0	0	0	0	2	2	1	0	1	0	1	1	0	1	1	0	1	0	1	2	3	3	3	3	3	2	2	2	2	4	5	
xAiBi+1	3	3	3	3	3	2	2	1	0	1	1	0	1	0	0	1	0	0	2	0	2	0	0	0	1	2	1	2	2	2	2	2	0	0	
xBiAi+1	0	3	3	3	2	2	3	0	0	0	1	0	1	0	0	1	0	1	1	1	1	1	1	1	2	1	2	1	2	2	2	2	1	1	
xBiBi+1	0	0	0	0	1	2	1	3	4	4	4	5	4	5	5	4	5	4	3	4	3	4	3	2	0	0	0	0	0	0	0	0	1	0	
a(i)	11	3	3	3	3	2	2	3	2	2	1	1	1	1	1	1	1	1	2	1	2	1	2	3	4	5	4	5	4	4	4	4	4	5	6
b(i)	0	3	3	3	3	4	4	3	4	4	5	5	5	5	5	5	5	5	4	5	4	5	4	3	2	1	2	1	2	2	2	2	2	1	0

```
----      72 VARIABLE W.L                    =      2580.000  total cost
```

Table 9. Final result

The schedule is formulated accordingly as:

Monday to Friday			
Jinqiao to AB		AB to Jinqiao	
7:00	3		
7:30	3		
8:00	3		
8:30	3		
9:00	3		
9:30	2		
10:00	2	10:00	3
10:30	1		
11:30	1		
12:00	1	12:00	1
13:00	1	13:00	1
14:30	1	14:30	1
		15:30	1
16:00	2	16:00	1
		16:30	1
17:00	2	17:00	1
		17:30	1
		18:00	1
		18:30	1
19:00	1	19:00	2
		19:30	1
		20:00	2
		20:30	1
		21:00	2
		21:30	2
		22:00	2
		22:30	2
		23:00	1
		23:30	1

However, there are still ways to perfect our bus schedule. First, to have more accurate parameters, we need to work with Public Safety to gather more targeted data. During the period of COVID-19, some shuttle buses are newly equipped with card scanner so we can record the exact number of students on the bus (See Appendix D). If the school continue using imposing the card scanner in the future, we will be able to obtain the most authentic data from public safety so that we can know the real number of students traveling between AB and Jinqiao. Other than that, we can also obtain the actual student demand by using the data from the turnstile. Since some students may miss shuttle buses and have to come to AB by other transportation to attend classes, we can estimate the actual demand by learning from the turnstile data. By then, we can test out various combinations of the bus schedule so that we can find the bus schedule that is truly suitable to both the students and the school.

Appendix A: Existing Shuttle Bus Schedule

Bus Schedule for JINQIAO Residence Halls Fall 2019

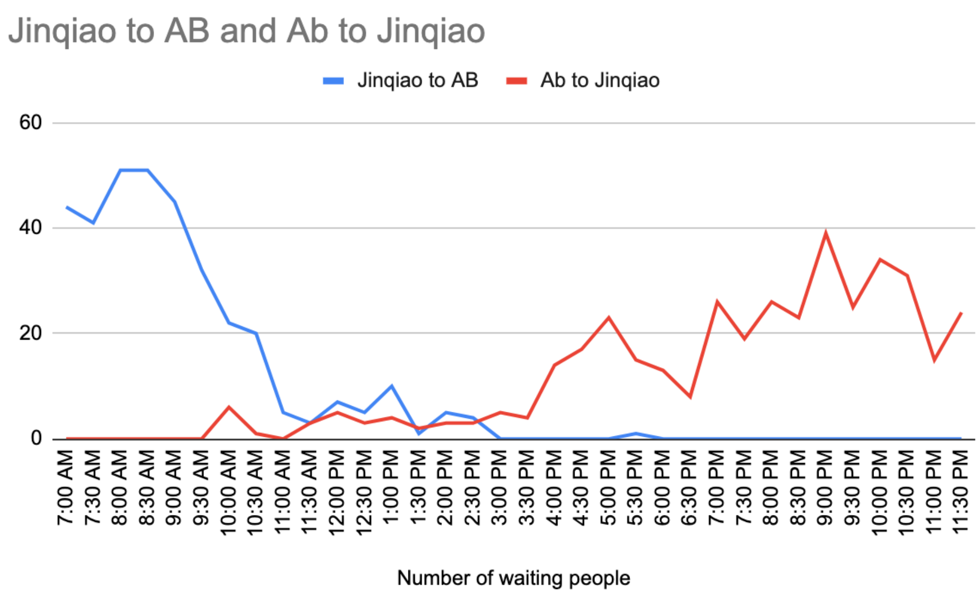
Monday to Friday/周一至周五	
JQ/JY Residence to Pudong Campus 宿舍至浦东校园	Pudong Campus to JQ/JY Residence 浦东校园至宿舍
7:15	-
8:45	-
-	9:45
10:30	-
11:45	11:45
12:45	12:45
-	13:45
14:15	14:45
15:15	15:15
16:15	16:15
-	16:45
-	17:15
-	17:45
-	18:15
-	18:45
-	19:15 *
19:30	-
-	19:45
-	20:15 *
-	20:45
-	21:15 *
-	21:45
-	22:15 *
-	22:45
	23:15 *
-	23:45 *

* For Monday to Thursday only. The last bus on Friday departs on 22:45, going from Campus to Dorm

Table 1. Existing Shuttle Schedule of Jinqiao in Fall 2019 Semester (Public Safety)

Appendix B: Survey Data on Students' Preference on Bus Schedule

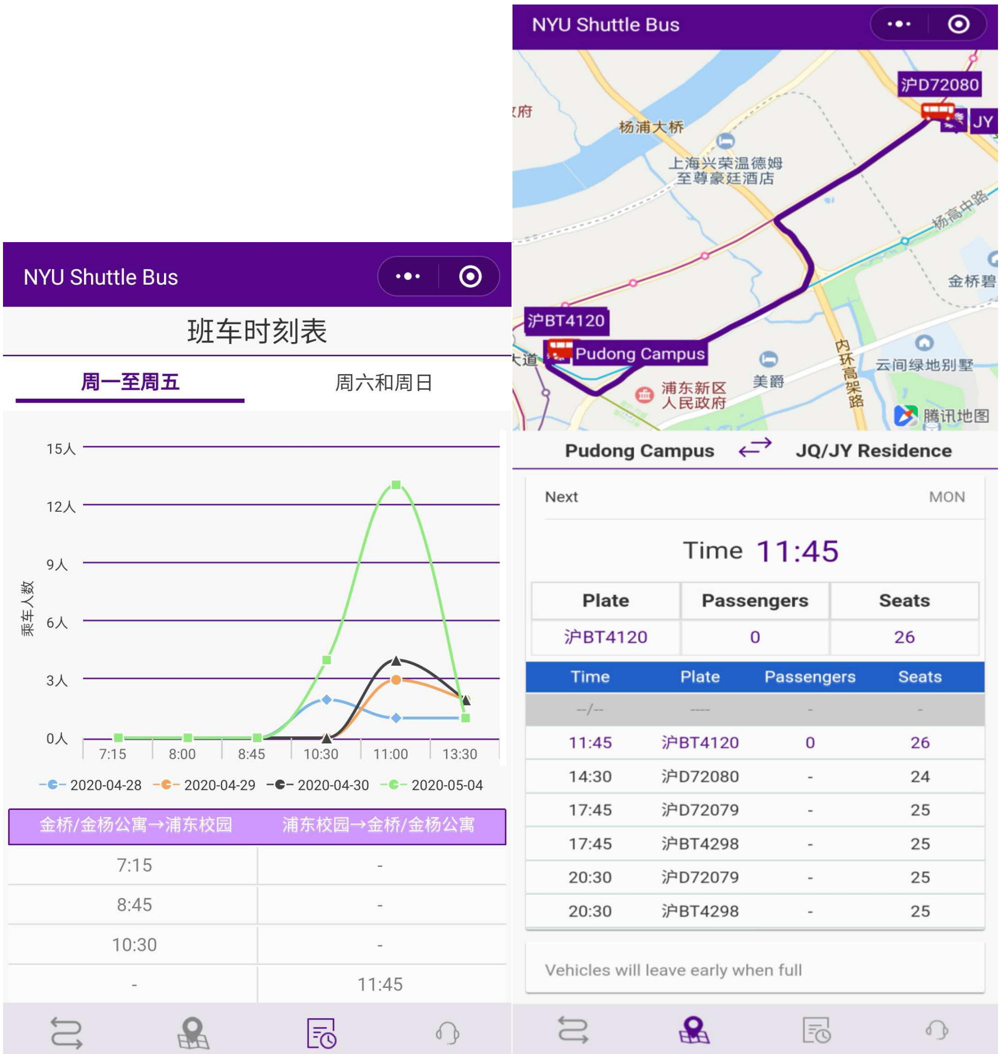
	7:00	7:30	8:00	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00
JinqiaotoAB	44	41	51	51	45	32	22	20	5	3	7	5	10	1	5	4	0
ABtoJinqiao	0	0	0	0	0	0	6	1	0	3	5	3	4	2	3	3	5
	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	19:30	20:00	20:30	21:00	21:30	22:00	22:30	23:00	23:30
JinqiaotoAB	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
ABtoJinqiao	4	14	17	23	15	13	8	26	19	26	23	39	25	34	31	15	24



Appendix C: GAMS Code

```
Sets
   i time interval /1*34/
   j '1:jinqiao to ab, 2:ab to jiqiao' /1,2/ ;

integer Variable
   AA(i) bus from A to A
   BB(i) bus from B to B
   AB(i) bus from A to B
   BA(i) bus from B to A
   a(i) bus at A
   b(i) bus at B;

Variable
   W total cost  ;

parameter
         d(j,i) waiting people at A
$CALL GDXXRW.EXE student.xlsx par=d rng=A5:AI7
$GDXIN student.gdx
$LOAD d
$GDXIN
display d;

Scalar
     s number of seats /50/
     N max number of bus /6/
     c1 cost of traveling /20/
     c2 cost of waiting /7.5/
     k tolerance /5/;

Equations
     cost objective function
     Anumber(i) satisfy students demand at ai
     Bnumber(i) satisfy students demand at bi
     AAbus(i) bus number at node ai
     BBbus(i) bus number at node bi
     ABbus(i) bus number at node a(i+1)
     BAbus(i) bus number at node b(i+1)
     starta
     startb;

cost .. W =e= sum(i, c2*AA(i)+c2*BB(i)+c1*AB(i)+c1*BA(i))    ;
Anumber(i) ..  s*AB(i) =g= d('1',i) -k ;
Bnumber(i) ..  s*BA(i) =g= d('2',i) -k ;
AAbus(i) ..    a(i) =e= AA(i)+ AB(i) ;
BBbus(i) ..    b(i) =e= BB(i)+ BA(i) ;
ABbus(i)$(ord(i)<34) ..  a(i+1) =e= AA(i)+ BA(i) ;
BAbus(i)$(ord(i)<34) ..  b(i+1) =e= BB(i)+AB(i)  ;
starta .. a('1') =e= N  ;
startb .. b('1') =e= 0  ;


Model schedule /all/;
option mip = Cplex;
Solve schedule using mip minimizing W ;

Display  a.l, b.l, AA.l, AB.l, BA.l, BB.l, W.l;
```

Appendix D: NYU Shuttle Bus Information on WeChat



References

Betsy, George, and Sangho Kim. *Spatio-Temporal Networks Modeling and Algorithms*. Springer New York, 2013.

NYU Shanghai department of Public Safety, Bus Schedule for Jinqiao Residential Halls Fall 2019.