Optimization of NYU Shanghai Shuttle Bus Schedule

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Xue Bai & Yuhan Yao

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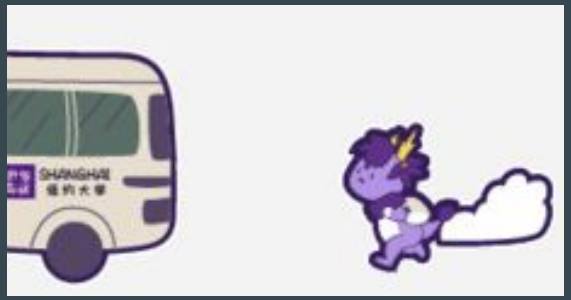
Background & Motivation

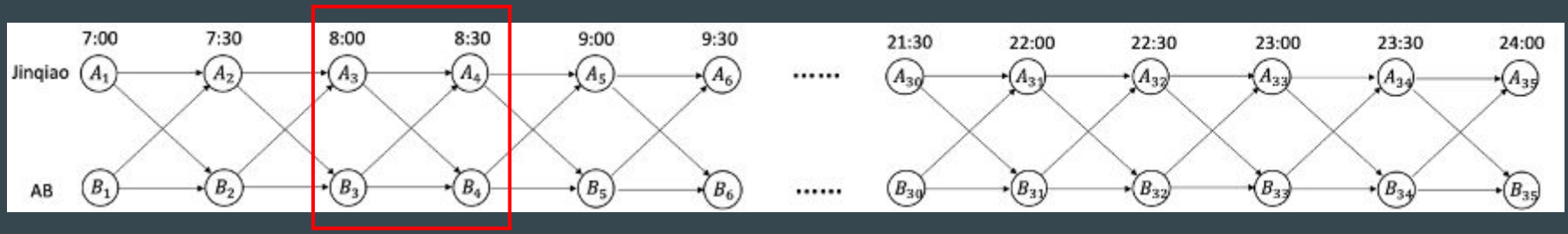
NYU Shanghai shuttle bus



WeChat meme named “late for school”

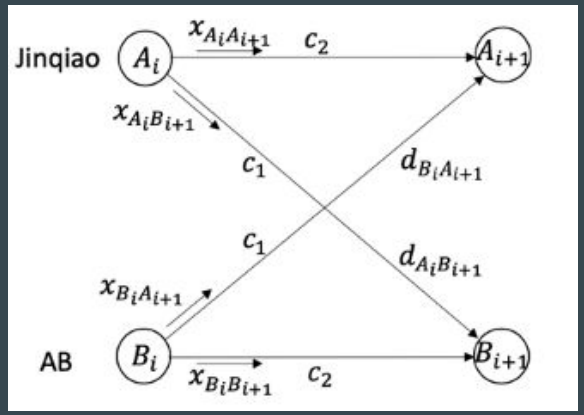
Methodology & Assumptions

- Spatio-Temporal Networks
- Holdover Edges & Transfer Edges (Betsy and Kim, pp. 14)



Graph 1. NYU Shanghai Bus Schedule Model

Variables & Parameters



For decision variables, 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, 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.

Baseline Model Formulation

- ensure each and every student must have seats on shuttle buses

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

s.t.

$$sx_{A_iB_{i+1}} \geq d_{A_iB_{i+1}}, for\ \forall i = 1,2,\dots,34$$

$$sx_{B_iA_{i+1}} \geq d_{B_iA_{i+1}}, for\ \forall i = 1,2,\dots,34$$

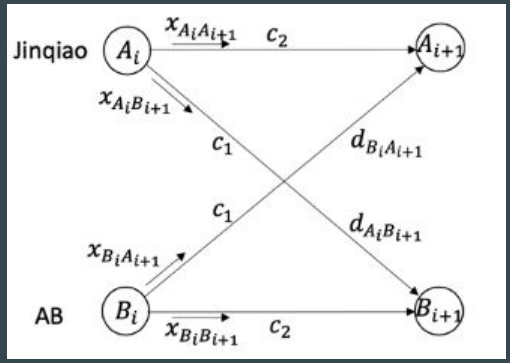
$$a_i = x_{A_iA_{i+1}} + x_{A_iB_{i+1}}, for\ \forall i = 1,2,\dots,34$$

$$b_i = x_{B_iA_{i+1}} + x_{B_iB_{i+1}}, for\ \forall i = 1,2,\dots,34$$

$$x_{A_iA_{i+1}} + x_{B_iA_{i+1}} = a_{i+1}, for\ \forall i = 1,2,\dots,34$$

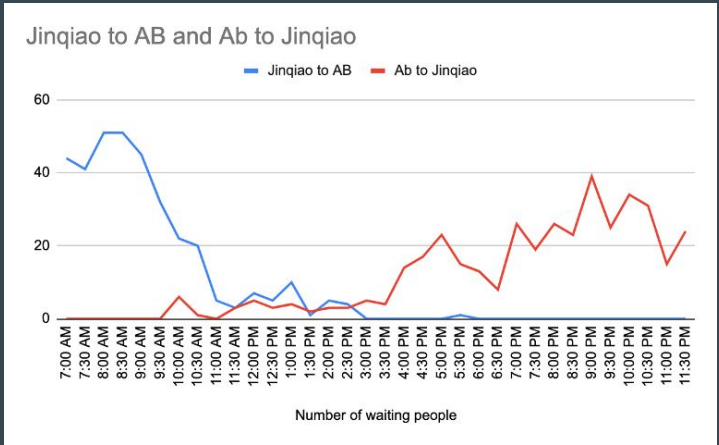
$$x_{B_iB_{i+1}} + x_{A_iB_{i+1}} = b_{i+1}, for\ \forall i = 1,2,\dots,34$$

$$x, a_i, b_i \in \mathbb{N}$$



Data Source & Description

- Survey & Public Safety



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

- Public Safety

N = 11

s = 50

a1 = N

b1 = 0

- Online Research

(cost of gas, driver salary, maintenance fee)

c1 = 20

c2 = 7.5

Baseline Result

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	8	5	2	5	2	3	1	0	0	0	0	0	0	0	0	0	1	2	3	4	5	6	7	8	8	8	7	7	7	7	7	8	8	9	
xAiBi+1	3	3	3	3	3	2	2	2	1	1	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1	2	2	2	2	2	2	1	2	0	
xBiAi+1	0	0	6	0	3	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	2	1	2	2	2	2	2	2	1	2	
xBiBi+1	0	3	0	3	3	6	7	8	9	9	9	9	9	9	9	9	9	8	7	6	4	3	3	2	0	0	0	0	0	0	0	0	0	0	
a(i)	11	8	5	8	5	5	3	2	1	1	1	1	1	1	1	1	1	2	3	4	5	7	7	8	9	10	9	9	9	9	9	9	10	9	11
b(i)	0	3	6	3	6	6	8	9	10	10	10	10	10	10	10	10	10	9	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
```

Variations of Models

Variation 1: Lower the total number of buses N

Variation 2: Add tolerance k (do not satisfy all demands)

Variation 3

Variation 4: Cancel time slots manually

Variation 1: Change N

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

Table 4. Results with different N

The smallest N that is feasible is 6.

Variation 2: Change k

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

s.t.

$$sx_{A_iB_{i+1}} \geq d_{A_iB_{i+1}} - k, for\ \forall i = 1,2,\dots,34$$

$$sx_{B_iA_{i+1}} \geq d_{B_iA_{i+1}} - k, for\ \forall i = 1,2,\dots,34$$

$$a_i = x_{A_iA_{i+1}} + x_{A_iB_{i+1}}, for\ \forall i = 1,2,\dots,34$$

$$b_i = x_{B_iA_{i+1}} + x_{B_iB_{i+1}}, for\ \forall i = 1,2,\dots,34$$

$$x_{A_iA_{i+1}} + x_{B_iA_{i+1}} = a_{i+1}, for\ \forall i = 1,2,\dots,34$$

$$x_{B_iB_{i+1}} + x_{A_iB_{i+1}} = b_{i+1}, for\ \forall i = 1,2,\dots,34$$

$$x, a_i, b_i \in \mathbb{N}$$

k: The least number of students for a shuttle bus to commute

Variation 2 Result

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

Table 5. Results with different k

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

Variation 3: Change N&k

Variation 1: k=0

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

Table 4. Results with different N

+ Variation 2

Variation 3: k=5

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

Comparison to the baseline model

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	1	0	0	0	0	0	0	0	1	0	0	1	2	3	0	0	1	2	3	3	3	3	3	2	2	2	3	4	5	
xAiBi+1	3	3	3	3	3	2	2	1	1	1	1	1	1	0	1	1	0	0	0	4	1	0	0	0	1	2	1	2	2	2	2	1	1	0	
xBiAi+1	0	3	3	3	3	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	2	1	2	1	2	2	2	2	1	1	
xBiBi+1	0	0	0	0	0	2	3	4	4	4	4	4	4	5	4	4	4	3	2	1	4	4	3	2	0	0	0	0	0	0	0	0	0	0	
a(i)	11	3	3	3	3	3	2	1	1	1	1	1	1	1	1	1	1	2	3	4	1	1	2	3	4	5	4	5	4	4	4	4	5	5	6
b(i)	0	3	3	3	3	3	4	5	5	5	5	5	5	5	5	5	5	4	3	2	5	5	4	3	2	1	2	1	2	2	2	2	1	1	0

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

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

Variation 4: Manually Cancelling Buses

4.1 : same for both directions

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

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

Variation 4

4.2 : different for each direction

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

Optimal Solution

(3955-2580)/3955 = 34.77%.

N=6; k=5

Canceling buses: from Jinqiao to AB at 11:00, 12:30, 13:30, 14:00, 15:00

from AB to Jinqiao at 10:30, 11:00, 11:30, 12:30, 13:30, 14:00, 15:00

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

Conclusion & Future Work

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)

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

Conclusion & Future Work

Improvements that can be made:

- More accurate demands (card scanner at the entrance of AB & on shuttle buses)
- Length of interval T based on traffic condition
- Data of actual daily budget from Public Safety
- Cost of students whose demand is not satisfied

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.

Thank you for listening!

Q&A