Bus Routing Optimization Helps Boston Public Schools Design Better Policies

Team 21

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Contents

Background

1. History

   Remain of segregation

   Lack of good schools

   Meandering topography

2. BPS Transportation

   Coverage area

   Disability students' request

   Excessive expenditure

   Variance in school hours

3. The Need For Analysis

   Generous School bus traffic distance

   Inefficient school bus routes

   Balance of school start time

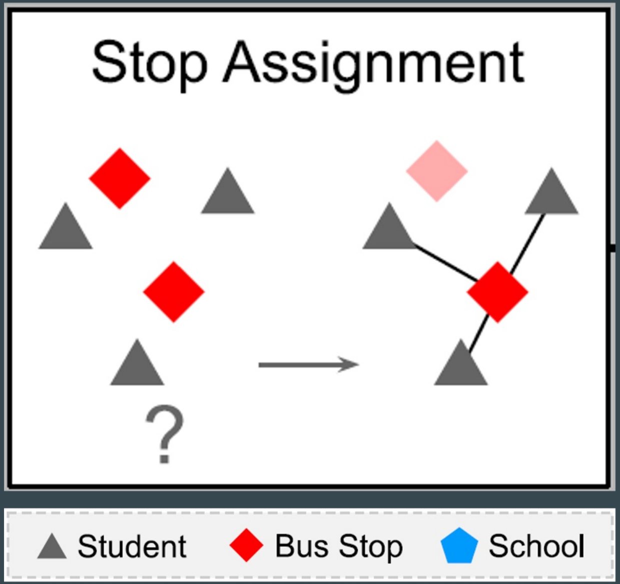
Data Consideration and Modeling

- Crowdsourcing
- MIT research team
- Bi-Objective Routing Decomposition (BiRD)

  -Be able to generalize many settings

  -Consisted with several stages

Single School Optimization - Assignment with Integer Optimization



Input Data: Student Homes, Bus Stop Locations, Walking Limitations

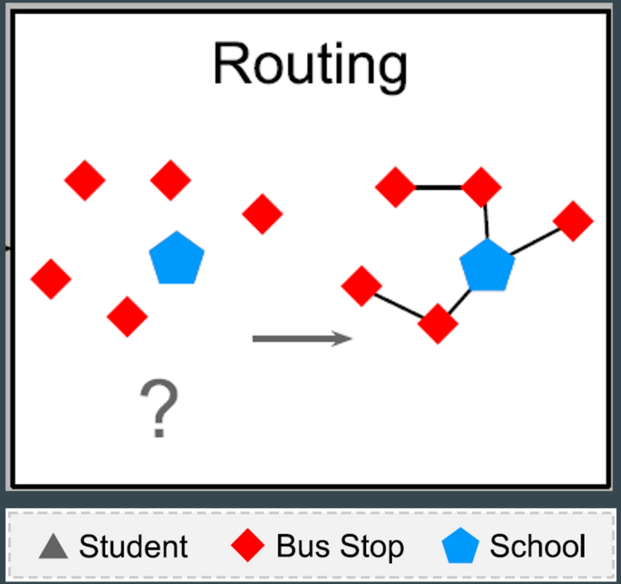
Objective Function : MIN number of stops

Constraints: Subject to MIN Walking Distance

Output Data: Bus stops for each school,

Assigned stop for each Student

Single School Optimization - Scheduling with Integer Optimization



Input Data:

School locations, Travel time estimates, Bus capacities, Maximum Riding time

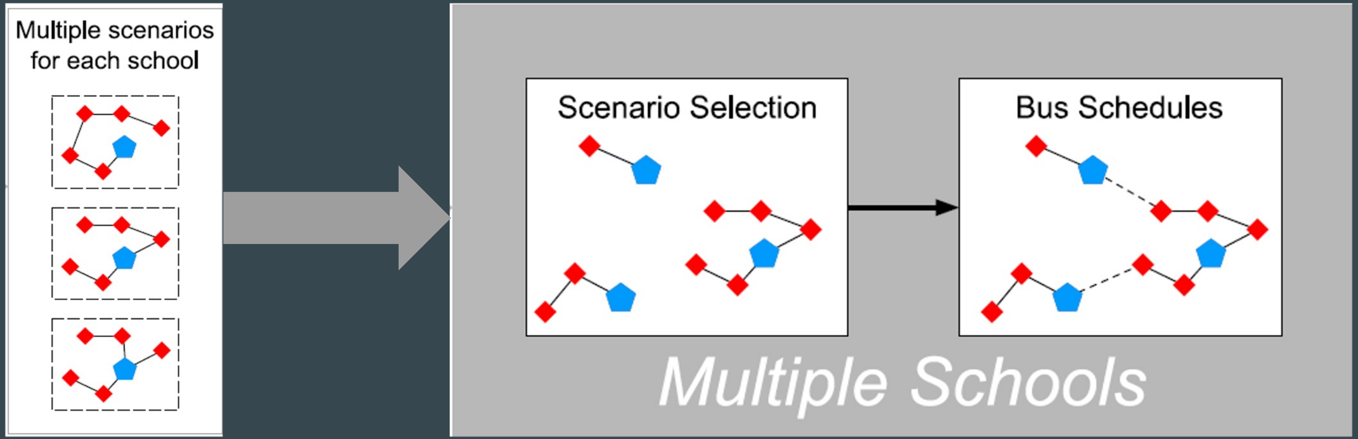
Objective Function :

Combine trips with MIN number of buses

Output Data:

Bus routes for each school with several potential solutions

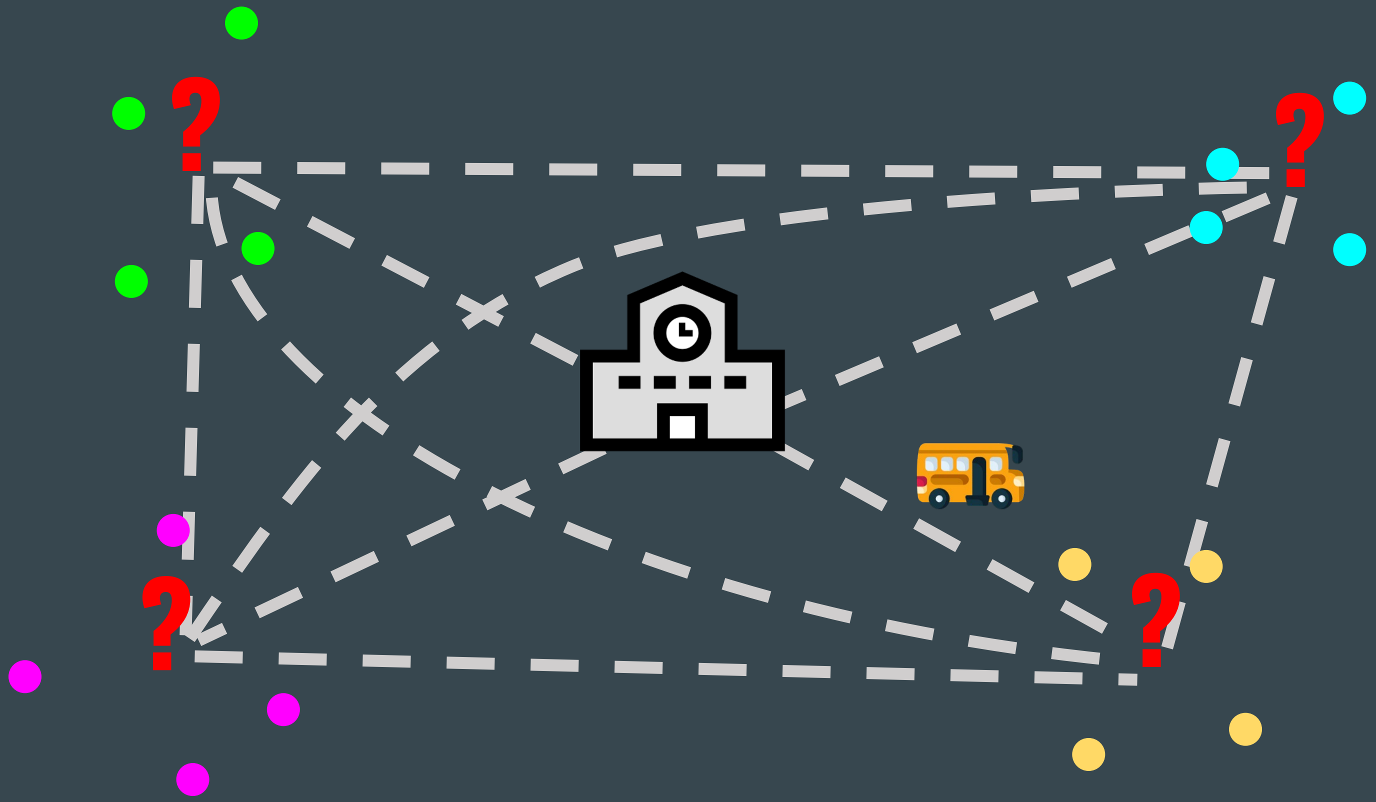
Multiple School Routing



- Using Pareto Frontier on several optimized routing scenarios
- Network Flow with integer optimization -> MIN number of buses for each district
- Optimize number of buses in both morning and afternoon

->School Bus Routing uses Modules of Optimization models

Teaching Example - Single School, Single Bus



Excel Model

Decision Variables

Location	X	Y					
Bus Stop 4	386.8441	1212.858					
	X	Y	Distance		Residents(students)	Distance * Students	
Residence A	225	845	401.8868296	=SQRT((B6-B4)^2+(C6-C4)^2)	5	2009.434	=D6*I6
Residence B	90	1375	338.2402178	=SQRT((B7-B4)^2+(C7-C4)^2)	10	3382.402	=D7*I7
Residence C	550	1345	209.9556031	=SQRT((B8-B4)^2+(C8-C4)^2)	9	1889.6	=D8*I8
Residence D	450	1115	116.4682666	=SQRT((B9-B4)^2+(C9-C4)^2)	7	815.2779	=D9*I9
				Objective Function min	Total distance	8096.715	=SUM(K6:K9)

Constraint

X	>=	0
Y	>=	800
X	<=	600
Y	<=	1400

Location Optimization

Routing Assignment

Parameter

	School	Bus Stop 1	Bus Stop 2	Bus Stop 3	Bus Stop 4
School	0	423.1415	672.092815	825.645858	513.02672
Bus Stop 1	423.1415	0	756.834799	1140.42751	926.30693
Bus Stop 2	672.0928	756.8348	0	588.833576	989.75866
Bus Stop 3	825.6459	1140.4275	588.833576	0	789.69054
Bus Stop 4	513.0267	926.30693	989.758662	789.690544	0

Decisions

	School	Bus Stop 1	Bus Stop 2	Bus Stop 3	Bus Stop 4	assignment
School	0	0	1	0	0	1
Bus Stop 1	0	0	0	1	0	1
Bus Stop 2	0	0	0	0	1	1
Bus Stop 3	1	0	0	0	0	1
Bus Stop 4	0	1	0	0	0	1
assignment	1	1	1	1	1	

Constraints

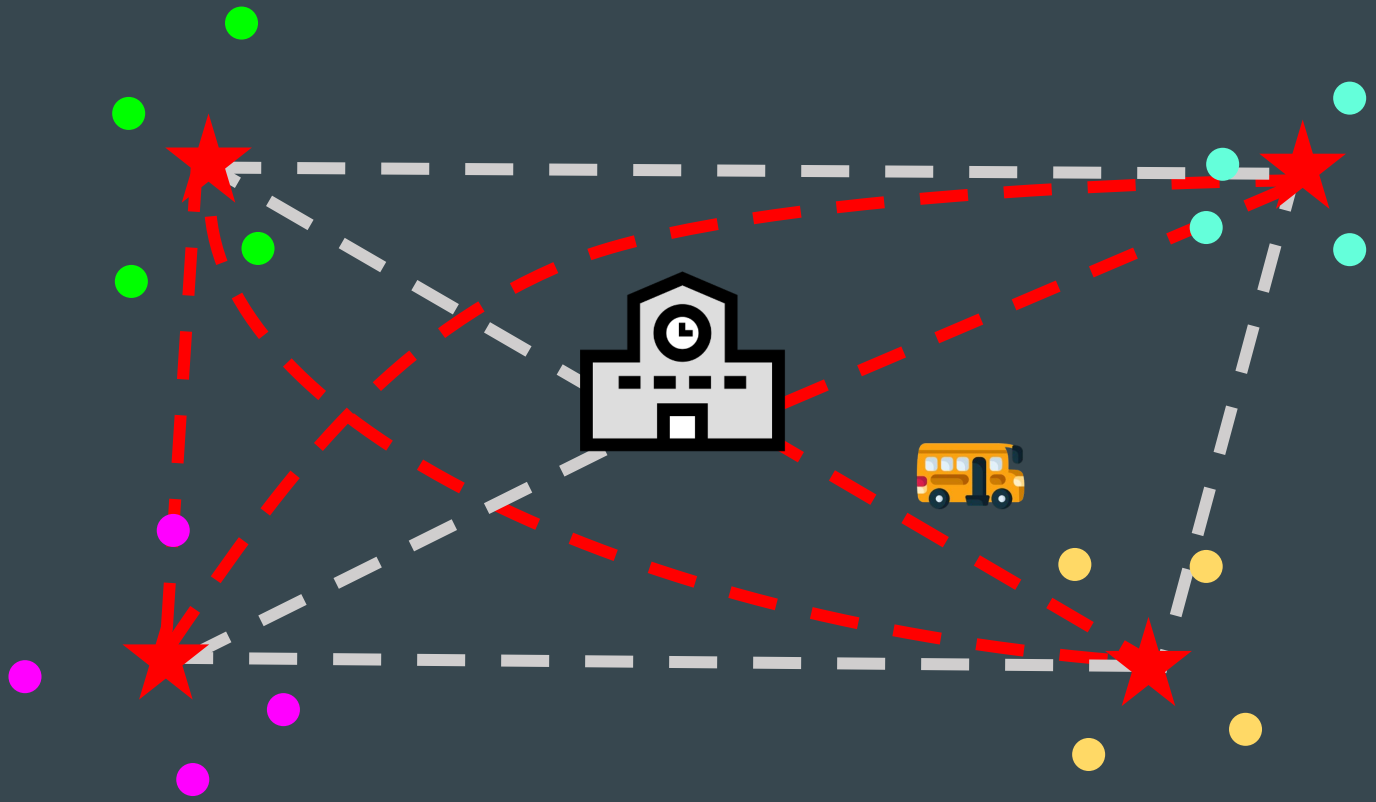
1	=	1	=SUM(C13:G13)
1	=	1	=SUM(C14:G14)
1	=	1	=SUM(C15:G15)
1	=	1	=SUM(C16:G16)
1	=	1	=SUM(C17:G17)
1	=	1	=SUM(C13:C17)
1	=	1	=SUM(D13:D17)
1	=	1	=SUM(E13:E17)
1	=	1	=SUM(F13:F17)
1	=	1	=SUM(G13:G17)

A -> A is impossible(School -> School)

Objective

Total distance	4554.2318	=SUMPRODUCT(C5:G9,C13:G17)

Optimal Routing Tour



Result and Benefits

- Reduced the bus fleet by 12% with no negative change in the quality
- Contributed a growing national conversation about school start times
- Helped visualizing the policy trade-offs of different bell time scenarios
- Communicated with the public about the trade-offs
- Boston school committee approved a new policy to seek to optimize

- **Analytics can be used to solve difficult problems in public sectors and help government implement better policies.**

Limitation

- Younger students or students from less safe neighbors

  -> because they tend to walk shorter than others

- Many family could not accommodate the changes in schedule

- Could not get enough approval from the community

External Reference and Current Relevance

Table 5
Example of converting calculating results into bus operation schedule.

	Scheduled arrival time at stop 8	Scheduled arrival time at stop 13	Scheduled arrival time at southern terminal (stop 19)
[Case-1]	16:57:28	17:10:01	17:26:09
[Case-2]	16:56:41	17:08:47	17:24:42
[Case-3]	16:58:13	17:11:13	17:27:38

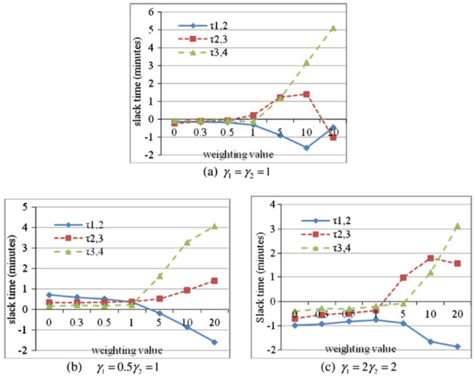


Fig. 3. Results of sensitivity analysis of the weighting value λ.

Robust Optimization Model of Schedule Design for a Fixed Bus Route

Relevance: both model used and implemented the optimization model to schedule fixed bus route

Yan, Yadan, et al. “Robust Optimization Model of Schedule Design for a Fixed Bus Route.” *Transportation Research Part C: Emerging Technologies*, vol. 25, 2012, pp. 113–121., https://doi.org/10.1016/j.trc.2012.05.006.

References

Bertsimas, Dimitris, et al. “Bus Routing Optimization Helps Boston Public Schools Design Better Policies.” INFORMS Journal on Applied Analytics, vol. 50, no. 1, 2020, pp. 37–49., https://doi.org/10.1287/inte.2019.1015.

Yan, Yadan, et al. “Robust Optimization Model of Schedule Design for a Fixed Bus Route.” *Transportation Research Part C: Emerging Technologies*, vol. 25, 2012, pp. 113–121., https://doi.org/10.1016/j.trc.2012.05.006.