Multi-stage, Multi-school Electric Bus Routing and Scheduling Optimization using Hybrid Metaheuristics

[1]Megh KC (meghbaha@buffalo.edu), [2]Ziqi Song, PhD (zqsong@buffalo.edu)
Department of Civil, Structural and Environmental Engineering , University at Buffalo, NY

University at Buffalo
The State University of New York

ASPIRE
NSF Engineering Research Center

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Introduction

Scenarios

- US school bus system: largest form od public transportation by feet size
- <1% of fleets are electrified
- Responsible for 5 Mn tons of emission annually
- Multiple schools in a single school district
- Transitioning diesel buses to electric buses is hindered due to high capital investment, range anxiety, and an efficient operational system

Fig: Diesel bus emission

Motivation

- Accelerated electrification through capital & operational cost optimization under practical constraints
- Innovative solution algorithm for NP-hard network optimization problems
- High priority but less explored research area

Objectives

- **Integrated solution for dynamic bus route optimization, timetabling and scheduling for multiple schools**
- **Novel integrated hybrid metaheuristics algorithm design for NP-hard network modeling problems**
- **Decision making process for school district on student transport electrification**

Constraints

⇒ **Routing Constraints**
- Bus stop visit
- Charging station visit

⇒**Schedule Constraints**
- Staggered school bell times
- Bus re-use and charging at school
- Student stop time window

ELECTRIFY SCHOOL BUSES

⇒ **Range Constraints**
- Battery state of charge (SoC)
- Upper & lower battery bound

⇒ **Bus capacity Constraint**

⇒ **Deadhead travel**

⇒ **Fast Charging Constraints**
- Location & charging time

Problem Setting

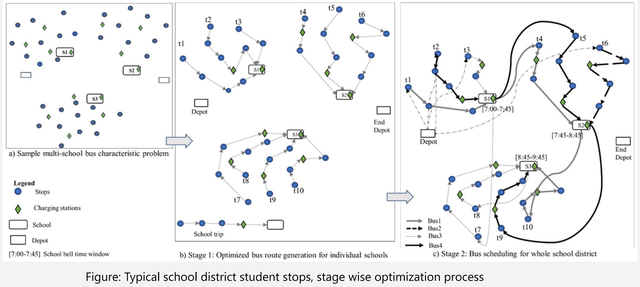


Figure: Typical school district student stops, stage wise optimization process

Mathematical Model Formulation

Stage-1: Route generation model formulation

Min

$$\sum_{i\in V_0^l, j\in V_{0,E}^l} t_{ij}x_{ij}^k + \sum_{k\in K}(c_r + g\,c_t^k)\sum_{i\in F, j\in V_E^l}(B^k - v_i^k)\,z_i^k$$

Subject to,

- *Student stop visit constraints*
- *Route start and end at depot constraints*
- *Fleet conservation constraints*
- *Travel time and stop time windows constraints*
- *Bus capacity constraints*
- *Battery consumption and battery bounds constraints*
- *Optimal charging location selection constraints*

Stage- 2: Multiple school bus scheduling MIP model formulation

$$Min\ Ob_1 + Ob_2 + Ob_3$$

$$Ob_1 = \sum_{k\in K} f^k \sum_{j\in\Delta^+\setminus E} x_{0j}^k$$ [Fleet cost component for multi-school bus service]

$$Ob_2 = \sum_{k\in K} c_t^k \sum_{i\in S, j\in ST} d_{ij}x_{ij}^k$$ [Deadhead distances for buses in transition]

$$Ob_3 = \sum_{k\in K}(c_r + g\,c_t^k)\sum_{i\in S, j\in\Delta^+} \varphi_i^k Y_i^k$$ [Charging and dwelling time cost in between services]

Subject to,

- *Staggered school bell times*
- *Bus charging at schools and bus re-use constraints*
- *Charging and travel time constraints*

Hybrid Metaheuristics Approach

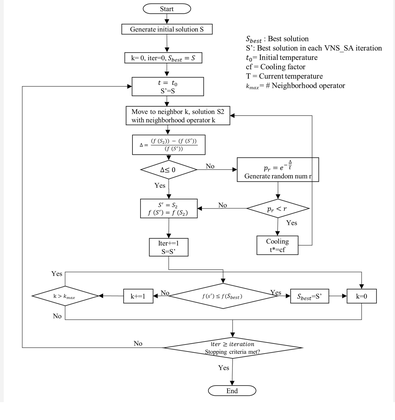
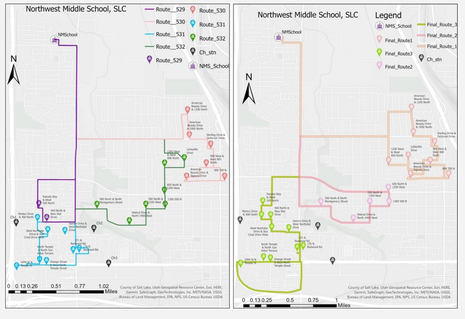


Figure: Metaheuristics implementation flowchart

Test Case Results for Stage1 and Stage 2



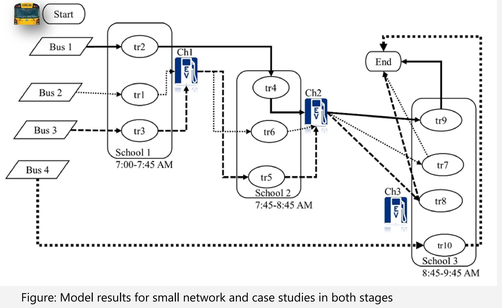


Figure: Model results for small network and case studies in both stages

Real World Case Study Result

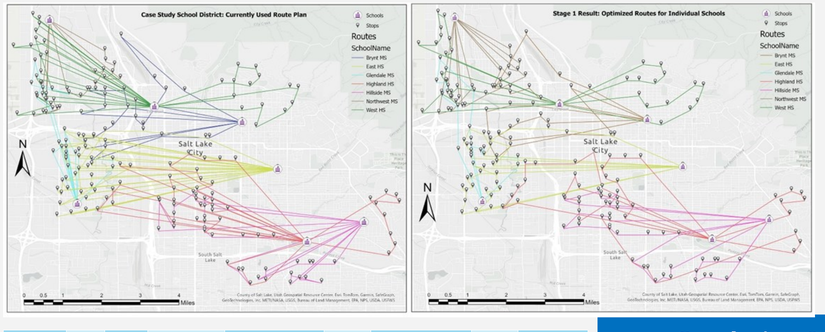


Figure: Salt Lake City school district case study and result improvement

Type	School (#)	Current trips (#)	Trips from the routing stage (#)	Total optimized trips to put into stage2	Scheduling result	Bus savings in individual schools (%)	Total savings	Remarks
Middle schools	1	5.00	5.00	35.00	22.00	0.00	37%	58% fleet savings compared to the current scenario
	2	5.00	3.00			40.00		
	3	5.00	4.00			20.00		
	4	6.00	6.00			0.00		
High schools	1	13.00	5.00			62.00		
	2	9.00	5.00			44.00		
	3	9.00	7.00			22.00		

Conclusion & Way Forward

- A new shift toward school bus electrification ESBRP was solved through simultaneous routing, scheduling, and charging operation
- Novel hybrid VNS-SA metaheuristics designed for large scale networks
- Multi stage multi school algorithm successfully solved more than 10,000 nodes problem outperforming the existing NP hard algorithms
- Real world case study showed the school district can save up to 37% of fleets for fully electrify their existing fleets

⇒ Inclusion of non-linear charging functions, candidate charging station installation and charger types could be the next step advancing research

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