Optimal Planning Of Charging Facilities For The Electrification Of Bus Fleets In Public Transit Systems

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Joint work with professor Andy Sun (ISyE-GaTech)

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Introduction

The issue: global warming.

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2. The average terrestrial temperature already increased by 1 Celsius degree.
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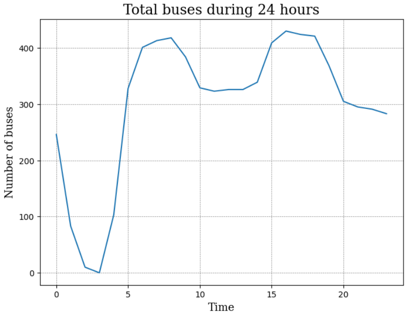
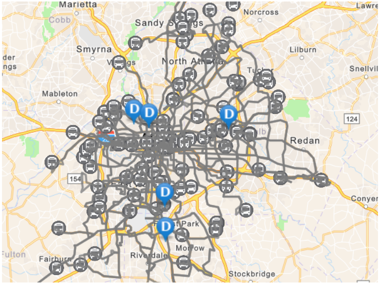
The challenge: the travel range and the fuel supply technology.

1. Infra-structure choice such as type of BEB, charger technology and location.
2. Efficient management of the bus schedule and charging times.

Case-study: MARTA

Bellow we have the bus demand and bus routes for the city of Atlanta.





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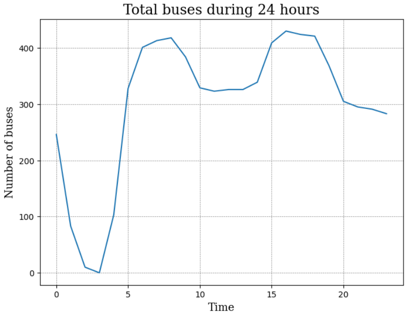

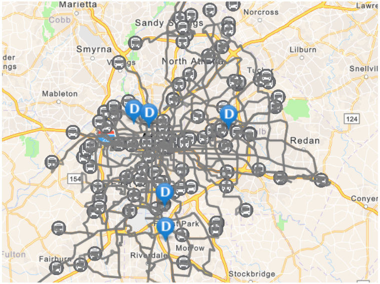

Data and parameters

Our data about bus schedules, routes and bus stops is obtained from the GTFS. The BEB parameters and cost are obtained from technical reports.

Problem formulation

$$
\begin{aligned}
& F_\theta(\boldsymbol{x}^{\theta-1}, \boldsymbol{\chi}^{\theta-1}, \boldsymbol{y}^{\theta-1}, \boldsymbol{\eta}^{\theta-1}, \tilde{\boldsymbol{\eta}}^{\theta-1}, \boldsymbol{\lambda}^{\theta-1}) = \\
= \min \quad & \sum_{i\in I} f_i \cdot [x_i - x_i^{\theta-1}] + \sum_{r\in R} \tilde{f}_r \cdot [\chi_r - \chi_r^{\theta-1}] + \sum_{(i,k)\in I\times K} c_{ik} \cdot [y_{ik} - y_{ik}^{\theta-1}] \\
& + \sum_{b\in B_{depot}} c_{b,beb} \cdot [\eta_b - \eta_b^{\theta-1}] + \sum_{b\in B_{route}} \tilde{c}_{b,beb} \cdot [\tilde{\eta}_b - \tilde{\eta}_b^{\theta-1}] + c_{cnv} \cdot [\lambda - \lambda^{\theta-1}] \\
& + G_\theta(\boldsymbol{x}, \boldsymbol{\chi}, \boldsymbol{y}, \boldsymbol{\eta}, \tilde{\boldsymbol{\eta}}, \boldsymbol{\lambda}) + \gamma \cdot F_{\theta+1}(\boldsymbol{x}, \boldsymbol{\chi}, \boldsymbol{y}, \boldsymbol{\eta}, \tilde{\boldsymbol{\eta}}, \boldsymbol{\lambda})
\end{aligned}
$$

s.t. $\underline{Q}_{ik} \cdot x_i \leqslant y_{ik} \leqslant \overline{Q}_{ik} \cdot x_i, \quad \forall i \in I,\ k \in K,$ (1)

$0 \leqslant \chi_r \leqslant CP_r, \quad \forall r \in R,$ (2)

(Investment budget constraint) (3)

(Initial facility constraints) (4)

$\boldsymbol{x} \in \{0,1\}^{|I|}, \quad (\boldsymbol{\chi}, \boldsymbol{y}, \boldsymbol{\eta}, \tilde{\boldsymbol{\eta}}, \boldsymbol{\lambda}) \in \mathbb{Z}_+^M.$ (5)

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Theorem: The Electrical Bus Fleet (EBF) problem is NP-hard

The Uncapacitated Facility Location problem can be polynomially reduced to the EBF problem.

Problem formulation: the operational part

$$
\begin{aligned}
G_\theta(\boldsymbol{x}, \boldsymbol{\chi}, \boldsymbol{y}, \boldsymbol{\eta}, \tilde{\boldsymbol{\eta}}, \boldsymbol{\lambda}) = \min \quad & \text{(charging costs)} + \text{(bus operating costs)} + \text{(penalties)} && (6)\\
\text{s.t.} \quad & \text{(Bus demand constraint)} && (7)\\
& \text{(Depot charging capacity)} && (8)\\
& \text{(On-route charging capacity)} && (9)\\
& \text{(Number of Depot BEB)} && (10)\\
& \text{(Number of On-route BEB)} && (11)\\
& \text{(Number of Conventional buses)} && (12)\\
& \text{(Depot state transition eq.)} && (13)\\
& \text{(On-route state transition eq.)} && (14)\\
& \text{(Conventional buses state transition eq.)} && (15)\\
& \text{(Policy constraints)} && (16)
\end{aligned}
$$

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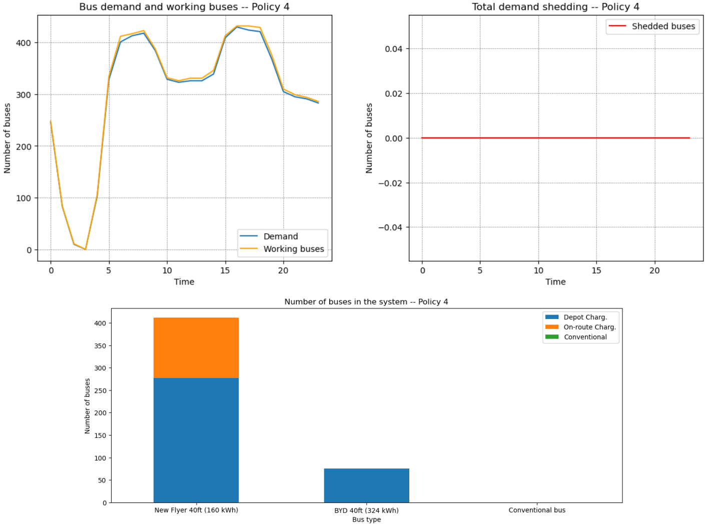
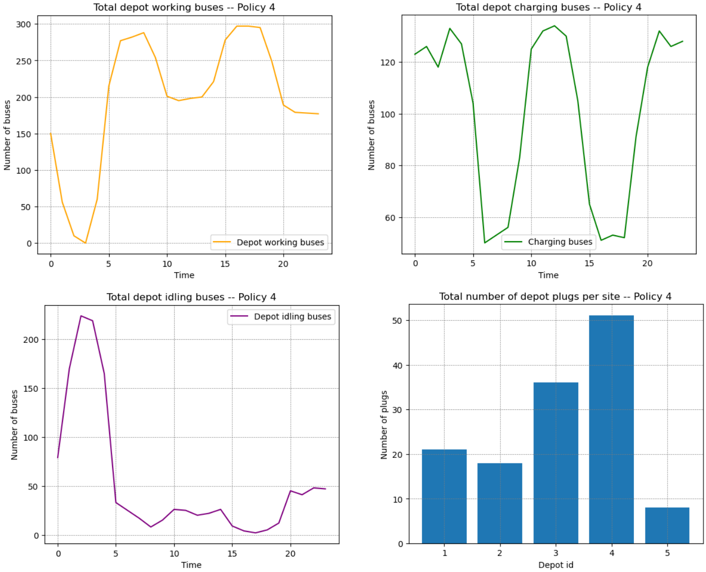
Single-period instance.

Computational time is 10 minutes with an optimality gap of 2.67%.

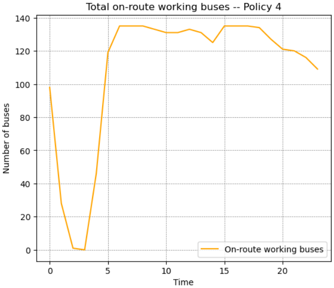
General features

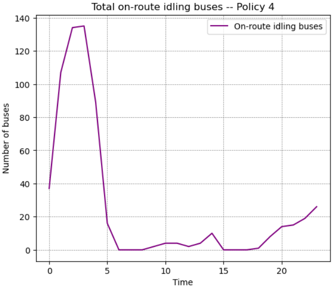


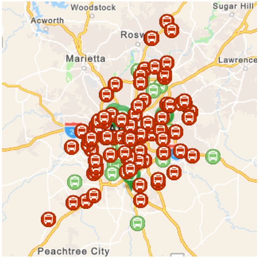
Depot dynamics

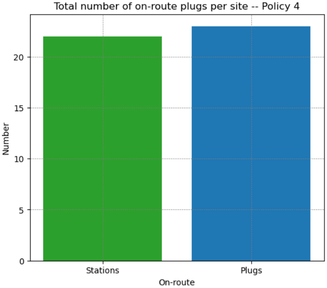


On-route dynamics

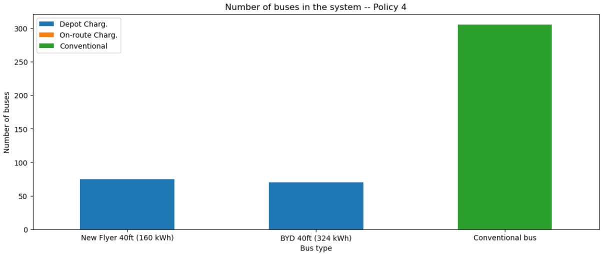




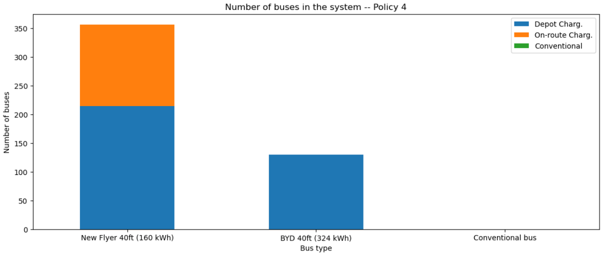




Multi-periodic case



(a) Investment period 1.



(b) Investment period 3.

Greedy heuristic

Result for 6 investment periods:

	Opt. gap (%)	time (min)
Atlanta	6.23	67
Detroit	7.11	25
LasVegas	9.83	29

Table: Greedy algorithm run time and optimality gap.

Thank you!

Questions?