The depot and charging facility location problem for electrifying urban bus services

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Background

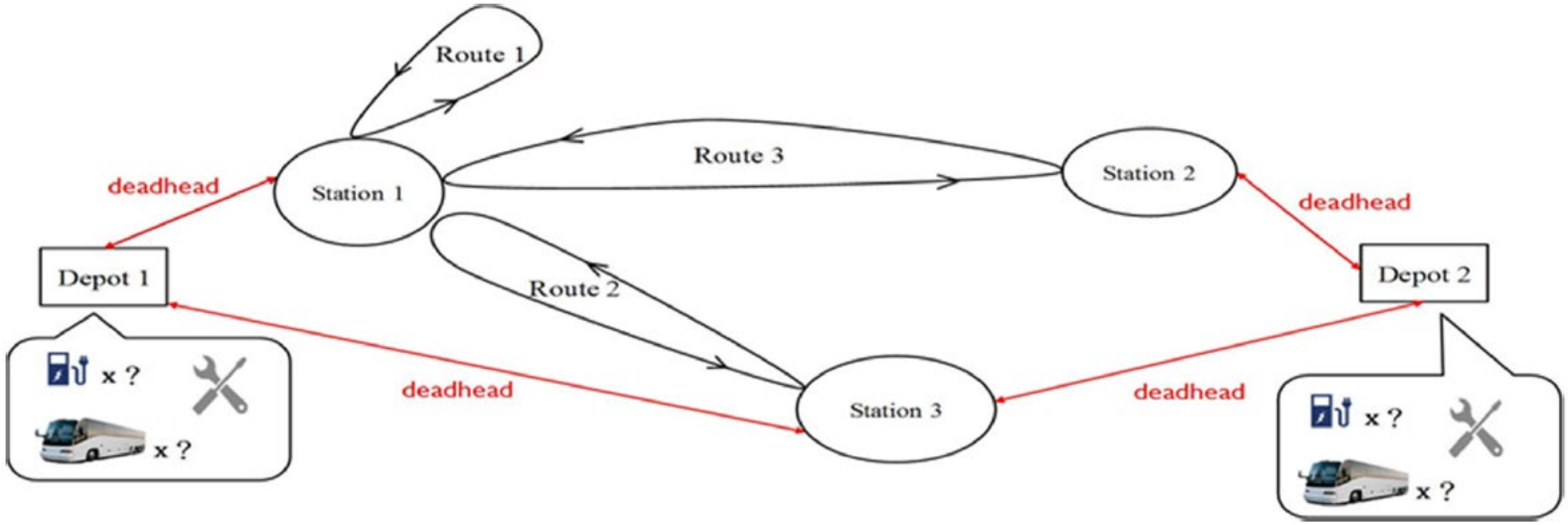
To transition from diesel-consuming buses to electric ones

- Fostering sustainable development with environment-friendlier public transport
- Targeting zero emissions
- Containing air pollutants (particularly PM 2.5)
- Advances in electricity storage and battery technologies

Location problem of deploying diesel-consuming bus services

Basic concerns in practice

- **Perspective of bus operators: operating cost and efficiency**
  - **Bus operation (fleet size, route assignment, deadhead mileage…)**
  - **Infrastructure construction and maintenance (depot capacity and land acquisition…)**



Location problem of deploying diesel-consuming bus services

Basic concerns in practice

- **Perspective of social welfare**
  - **- Service level**
  - **- Alleviating traffic congestion**
  - **- Environmental impact**
  - **- Accessibility and equity**

Transition to electric bus services

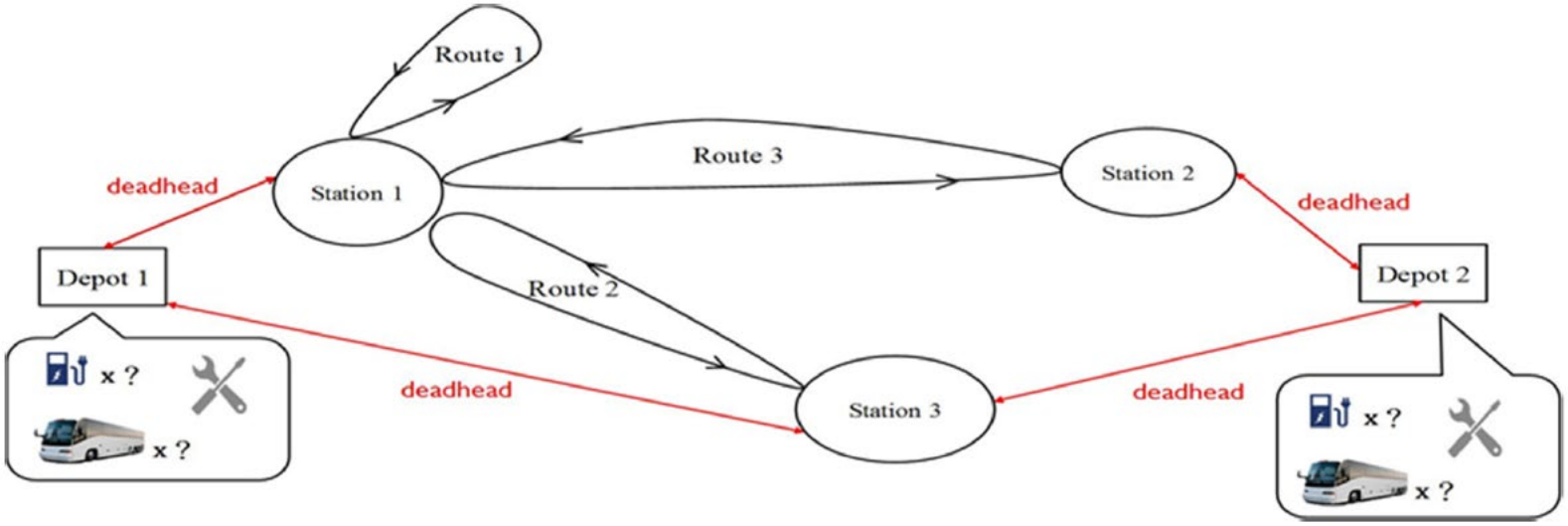
Additional issues

- **Fleet size and mixture of diesel-consuming and electric buses**
- **Deployment of charging stations**
  - **slow-recharging, fast-recharging, and battery exchange stations**
  - **power tracks**
- **Single charge range / range anxiety**

Fundamental considerations: cost-benefit analysis over the life cycle

Strategic planning

Considering both planning and operational perspectives (where system deployment cost over the planning horizon is converted into net present value)



To determine deployment strategies that minimize life-cycle operating cost

Formulation

Objective function:

Deadhead mileage

Establishing and operating depots

$$\text{MinZ} = w_d \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{m\in M}\sum_{f\in F} r^k_{ijmf} x^k_{ijmf} + w_c \sum_{i\in I_n}\sum_{m\in M}\sum_{f\in F} c_{im} a_{imf}$$

$$+ w_p \sum_{i\in I_n} cm^* p_i + w_e \sum_{i\in I}\sum_{m\in M} ce_m a_{im2} + \sum_{m\in M}\sum_{f\in F} bc_{mf} z_{mf} - \sum_{i\in I_o} s_i{}^* o_i$$

Establishing maintenance stations

Establishing chargers

Renting external buses

Selling off existing depots

Decision variables:

- Whether to establish depots, maintenance stations, chargers, and the associated capacities
- Route assignments (over multi-size and multiple fuel types)
- Whether to rent external buses
- Whether to close and sell off the land of existing depots

Formulation

Constraints:

Required number of buses for route assignments

$$\sum_{i\in I}\sum_{f\in F}\sum_{k\in K} x_{ijmf}^{k} \geq d_{jm} \forall j \in \mathrm{J}, m \in \mathrm{M}$$

$$a_{imf} - 1 \leq (1+\propto)\sum_{j\in J}\sum_{k\in K} x_{ijmf}^{k} \leq a_{imf} \forall i \in \mathrm{I}, m \in \mathrm{M}, f \in \mathrm{F}$$

Capacities of depots, maintenance stations, and chargers

$$\sum_{m\in M}\sum_{f\in F} r_m a_{imf} \leq m_i(1-o_i) \forall i \in \mathrm{I_o}$$

$$\sum_{m\in M}\sum_{f\in F} r_m a_{imf} \geq n_i(1-o_i) \forall i \in \mathrm{I_o}$$

$$\sum_{m\in M}\sum_{f\in F} r_m a_{imf} \leq m_i y_i \forall i \in \mathrm{I_n}$$

$$\sum_{m\in M}\sum_{f\in F} r_m a_{imf} \geq n_i y_i \forall i \in \mathrm{I_n}$$

$$\sum_{m\in M} r_m a_{im2} \leq m_i q_i \forall i \in \mathrm{I}$$

$$\sum_{j\in J}\sum_{k\in K}\sum_{m\in M}\sum_{f\in F} x_{ijmf}^{k} \leq m_i p_i \forall i \in \mathrm{I_n}$$

$$\sum_{j\in J}\sum_{k\in K}\sum_{m\in M} x_{ijm2}^{k} \leq m_i q_i \forall i \in \mathrm{I}$$

$$\sum_{j\in J}\sum_{k\in K}\sum_{m\in M} x_{ijm2}^{k} \geq q_i \forall i \in \mathrm{I}$$

Formulation

Constraints:

Requirement on the number of electric buses and associated route assignments

$$b_{km} - 1 \leq \sum_{i \in I} \sum_{j \in J} \sum_{f \in F} x_{ijmf}^{k} \leq b_{km} \forall k \in \mathrm{K}, m \in \mathrm{M}$$

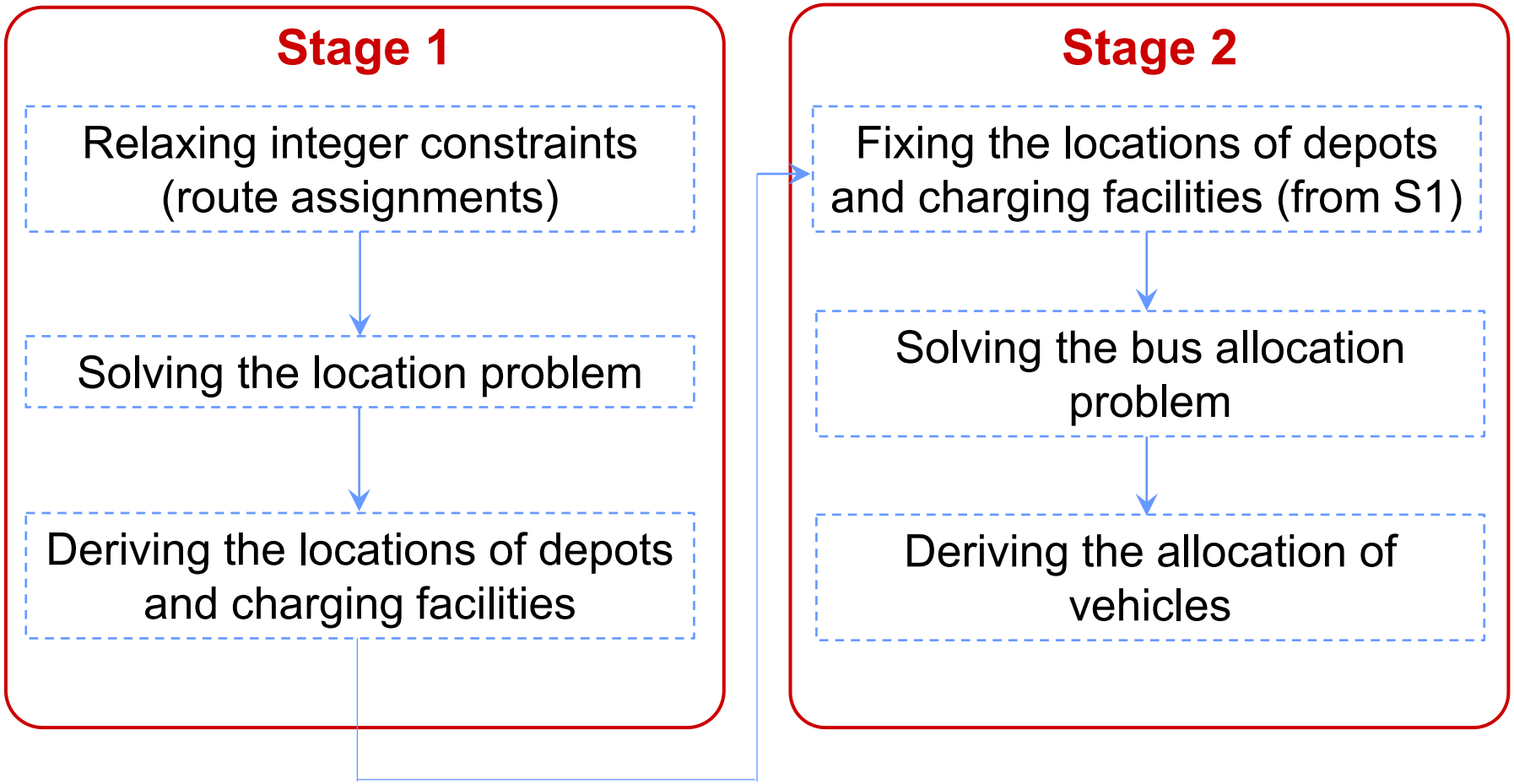
$$\sum_{i \in I} \sum_{j \in J} \sum_{m \in M} x_{ijm2}^{k} \geq u_k \left(\sum_{i \in I} \sum_{j \in J} \sum_{m \in M} \sum_{f \in F} x_{ijmf}^{k} \right) \forall k \in \mathrm{K}$$

$$\sum_{i \in I} \sum_{j \in J} \sum_{k \in K} x_{ijmf}^{k} \leq f_{mf} + z_{mf} \forall m \in \mathrm{M}, f \in \mathrm{F}$$

Binary and non-negative integer values of decision variables

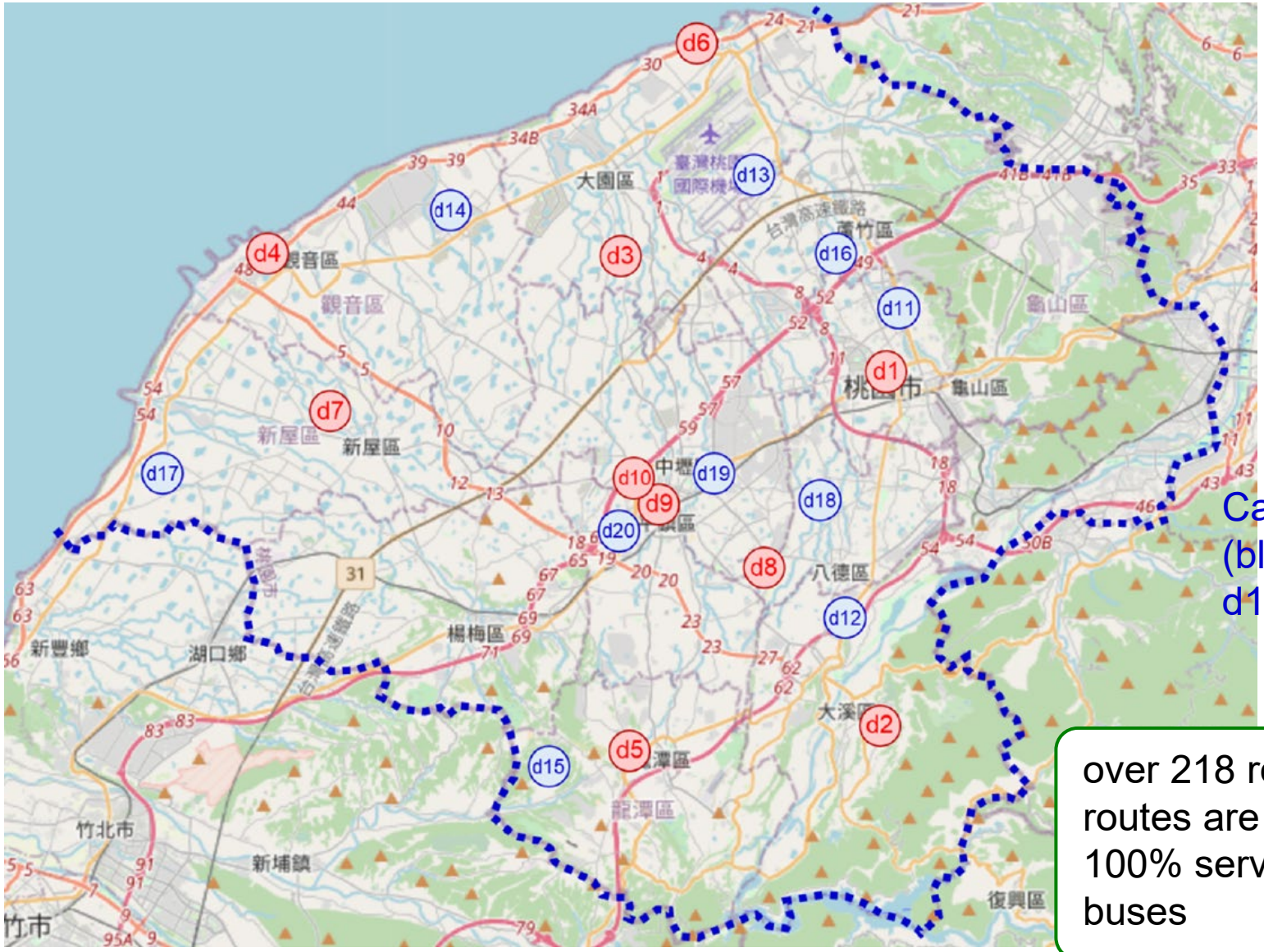
Solution algorithm (for the NP-hard problem)

Two-stage heuristic



Hsu, Y. T., Yan, S., & Huang, P. (2021). The depot and charging facility location problem for electrifying urban bus services. *Transportation Research Part D: Transport and Environment*, *100*, 103053.

Case study in Taoyuan, Taiwan

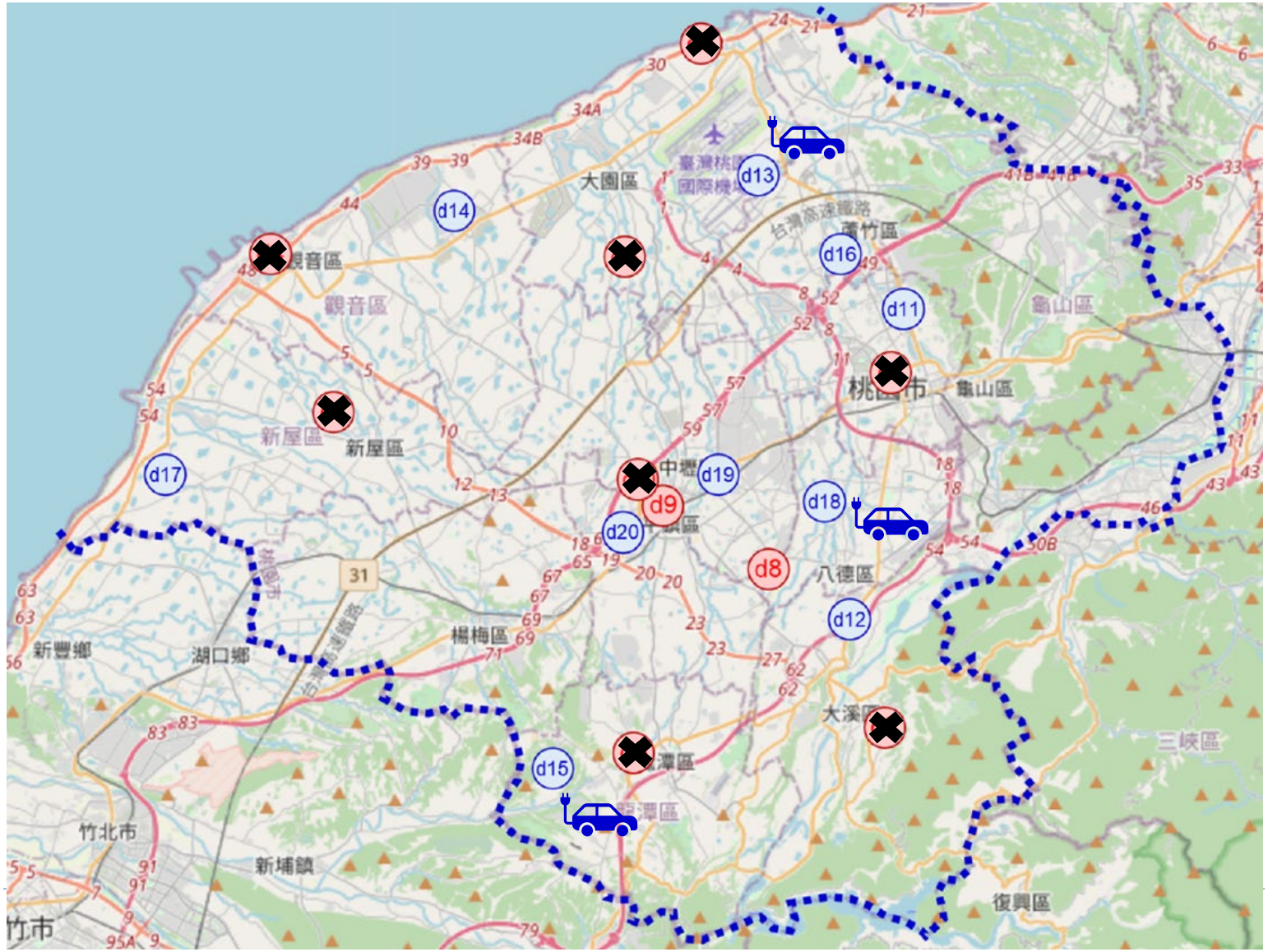


Existing depots (red circles, d1-d10)

Candidate depots (blue circles, d11-d20)

over 218 routes where 10 routes are required to be 100% served by electric buses

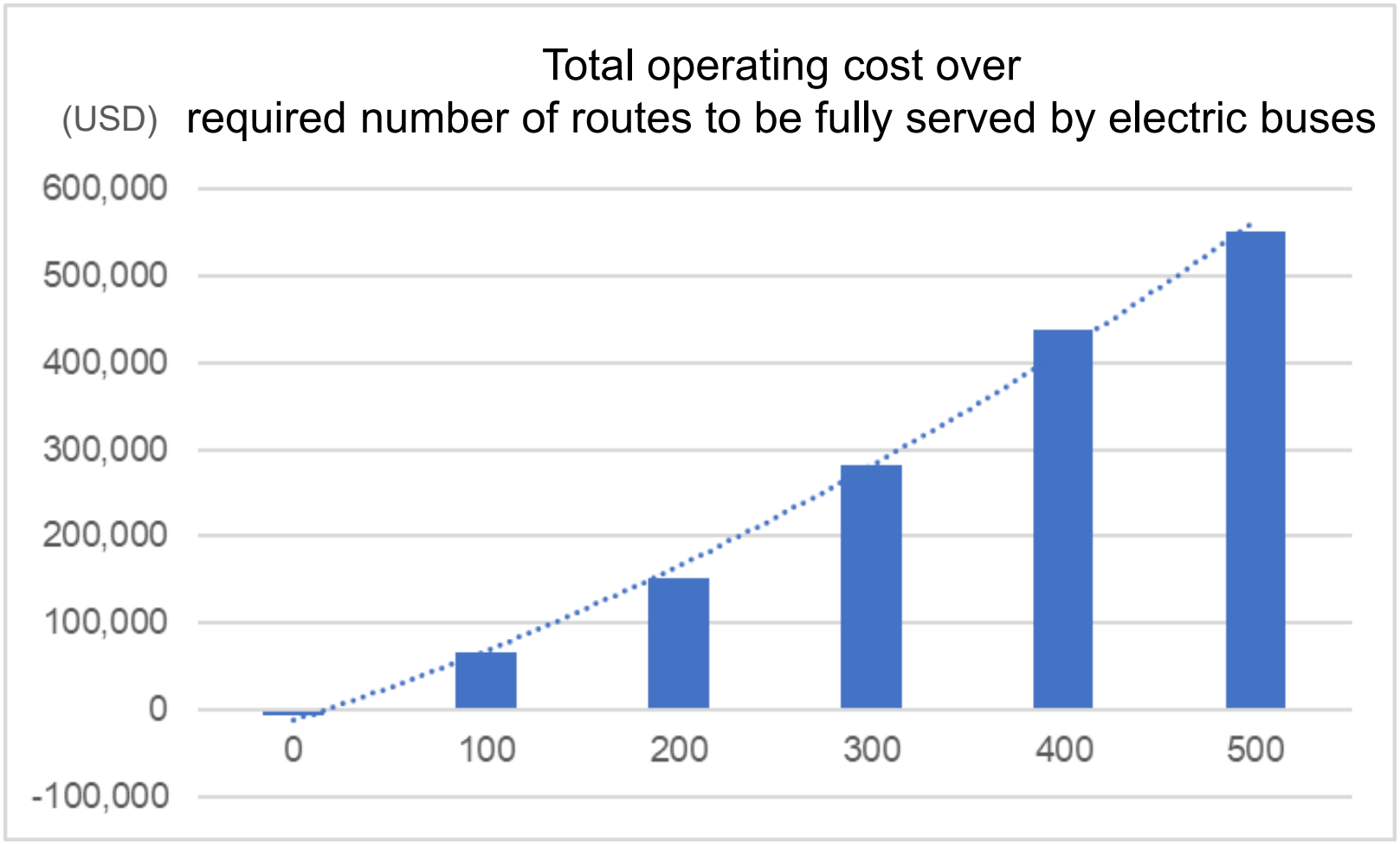
Case study in Taoyuan, Taiwan



Findings

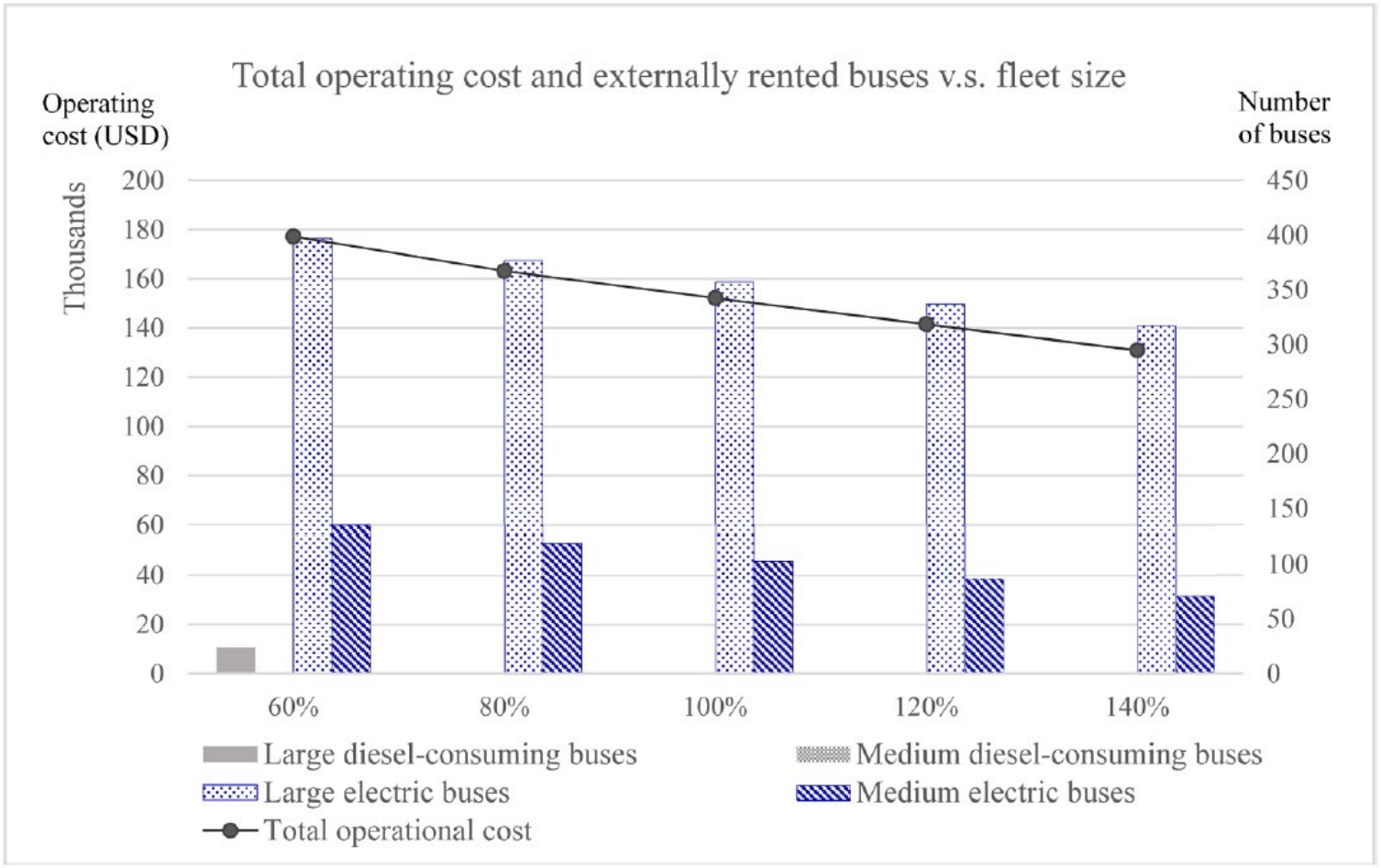
Operating cost (USD/km)	Large-sized	Medium-sized
Diesel-consuming buses	0.756	0.529
Electric buses	1.404	0.907

Approximate linear increase in total operating cost with the required level of electrification



Findings

A larger fleet size enables more robust and flexible operation (and lower needs for external buses)



Findings

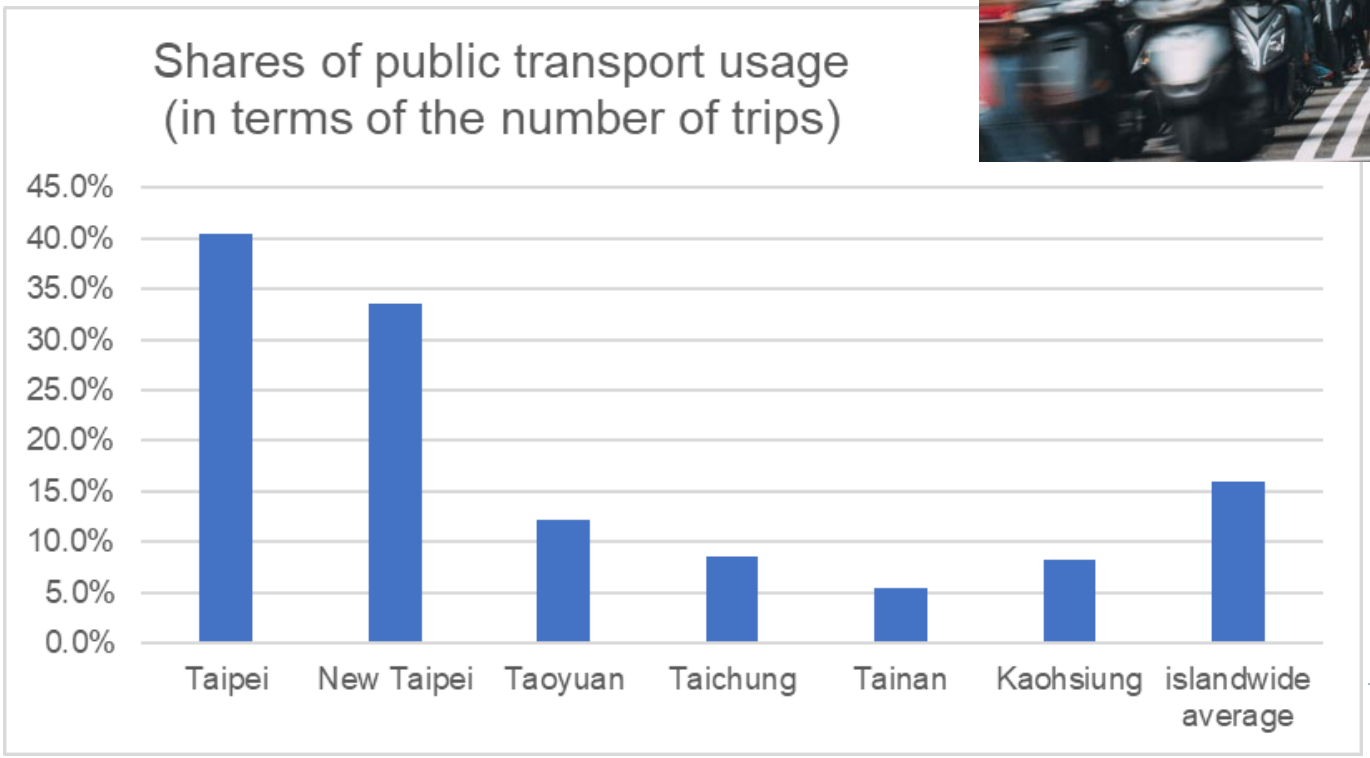
- **Sensitivity analysis on VMT cost**
  - **Decreasing VMT cost**
    - ⇨ **longer deadhead mileage (deploying depots in suburban areas)**
- **Sensitivity analysis on capacities of new depots**
  - **Improved operational efficiency by replacing larger-sized depots with smaller ones**
- **Sensitivity analysis on costs of establishing and operating new depots**
  - **Moving depots from downtowns to suburban areas to attain better urban development**

Issues to be further explored

- Demand and land-use pattern modeling
- Subsidy and financial analysis
- Mixed fleet with hybrid vehicles
- Scheduling of bus operation and charging
- Integrated model of electric bus system deployment and power grid design
- Comprehensive analysis of economic benefits

Into the real world: some facts about Taiwan

- **Population: 23.4 million**
- **No. passenger cars: 8.6 million**
- **No. motorcycles: 14.5 million**



Into the real world

Progress in Taipei: 2018 ⇨ 2023 (650 electric buses, 19%)
⇨ 2030 (100% electric buses)

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聽新聞 0:00 / 0:00

充電瓶頸 恐卡推電動公車速度

2024-01-22 00:20 聯合報／記者林麗玉／台北報導

2050淨零碳排、2030公車全電動化。
使用執照，但盲點是台電仍「不敢保證
史以來最嚴重的癱瘓時期。首都集團總
上路，但2030年所有4千輛要全電動恐
減緩推電動公車速度」。交通局表示，

因應東區用電需求，北市松湖臨時變電
質疑，儘管松湖將取得使照，但現況台
能供電無虞，北市既有公車調度站，就

要電動公車跑又不給電，北市近 50 輛電動公車閒置無法充電

作者 Chen Kobe | 發布日期 2022 年 07 月 22 日 12:14 | 分類 交通運輸，充電站，能源科技 分享 分享 Follow 分享

Into the real world

Electric bus: 11 million TWD (~370 thousand USD)

Diesel-consuming bus: 4.5 million TWD (~150 thousand USD)

Subsidy up to 120+100 thousand USD over 8 year

即時 要聞 娛樂 運動 全球 社會 地方 產經 股市 房市

符合補助電動公車選擇少 業界觀望

2024-03-06 01:05 聯合報／記者邱書昱／台北報導

+ 公車

分享 4 Share

中央目標2030年達到公車全面電動化，不過現行公車業者申請汰換補助，僅有2間車輛製造業者符合資格，選擇少，業者多觀望，影響電動化進程，

Into the real world

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年花90億預算 TPASS月票未成長

2024-04-25 02:20 聯合報／ 記者周湘芸、林佳彣／連線報導

+ 票價

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udn / 生活 / 生活新聞

聽新聞 0:00 / 0:00

TPASS上路 桃園通勤族怨：公車更難搭

2023-07-06 01:27 聯合報／ 記者朱冠諭／桃園報導

Into the real world

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分享 24 Share

TPASS基北北桃1200元月票1日正式上路，許多民眾改搭大眾交通工具，桃園市公車卻仍持續脫班，蘆竹、八德通勤族反映「公車更難搭了」。市府交通局坦言，主因還是駕駛人力不足，導致公車班次不穩定，將持續推動客運駕駛徵才和留才方案，緊盯業者改善脫班。

「要到台北上班
車，未料排隊人
乘國光客運184
時能解」。

議員張桂綿表示，疫後
找替代方案，同樣往返
數十公尺；市府提供從
畫從南崁到機捷A10站

宜蘭縣搭學生公車注意！國光客運減班 「這些路線」啟動代駛

Some concluding remarks

- Motivation for bus operators to join electrification: subsidy and financial planning based on transparent cost structure
- Sophisticated problem contexts depending on transit and energy markets: needing to be supported by reliable ridership and electricity supply
- Holistic and robust policy-making that coordinates perspectives of different stakeholders and against development variability
- Monitoring and data management platform to better understand the market and operational characteristics of electric bus systems

Mobility2Grid Workshop
@ Kyoto, May 8th 2024

Thanks for listening & Questions are welcome!

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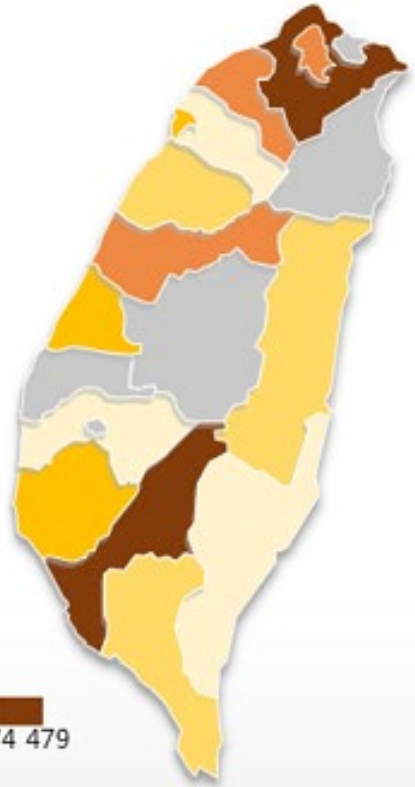

新北市	479	花蓮縣	16
高雄市	274	金門縣	13
臺北市	243	屏東縣	11
臺中市	239	苗栗縣	10
桃園市	119	嘉義縣	8
臺南市	92	澎湖縣	4
彰化縣	34	臺東縣	3
新竹市	28	新竹縣	3

電動巴士累計登記數

註：因有甲地領牌乙地運行狀況，所以各縣市登記數並不等於該縣市運行數量