THE DESIGN OF CHARGING INFRASTRUCTURE FOR ELECTRIC VEHICLES AND ITS PROPERTIES

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Motivation

- It is expected to continue electrification of individual and public transport in order to reduce CO_2 emissions in densely populated urban areas.
- Advances in battery technologies and continuously decreasing prices of electric vehicles may soon increase the interest in converting fleets of vehicles serving urban areas into electric.
- High purchase costs of a new electric vehicle can be more easily compensated by lower operational costs.
- To overcome problems with insufficient charging infrastructure or to avoid delays in charging, caused by interaction with other electric vehicles, a choice of a fleet operator can be to build their own charging infrastructure.

Literature review

Refuelling literature

Mehrez, A. Stern H., I., (1985) Optimal refuelling strategies for a mixed-vehicle fleet, Naval Research Logistics Quarterly, Vol. 32, pp. 315–328.

Prediction of the future expansion of electric vehicles

Sears, J., Glitman, K., and Roberts, D. (2014). Forecasting demand of public electric vehicle charging infrastructure. In Technologies for Sustainability, 2014 IEEE Conference, pages 250–254.

Paffumi, E., Gennaro, M. D., Martini, G., and Scholz, H. (2015). Assessment of the potential of electric vehicles and charging strategies to meet urban mobility requirements. Transportmetrica A: Transport Science, 11(1):22–60.

Flow refuelling location model

Kuby M., Lim S. (2005) The flow-refuelling location problem for alternative-fuel vehicles. Socio-Econom. Planning Sciences, Vol. 39(2):125–145.

MirHassani, S. A. and Ebrazi, R. (2013). A Flexible Reformulation of the Refuelling Station Location Problem. Transportation Science, 47(4):617–628.

Yildiz, B., Arslan, O., and Karasan, O. E. (2016). A branch and price approach for routing and refuelling station location model. European Journal of Operational Research, 248(3):815–826.

Literature review

GPS Data – MIP – Metaheuristics – Simulation

Tu, W., et. al. (2016) Optimizing the locations of electric taxi charging stations: A spatial-temporal demand coverage approach, Transportation Research Part C, Vol. 65, pp. 172–189.

Xi, X., Sioshansi, R., and Marano, V. (2013). Simulation–optimization model for location of a public electric vehicle charging infrastructure. Transportation Research Part D: Transport and Environment, 22:60–69.

Our previous contribution

Koháni M., Czimmermann P., Váňa, Matej Cebecauer and Ľuboš Buzna (2017). Location-scheduling optimization problem to design private charging infrastructure for electric vehicles, In: Operations Research and Enterprise Systems, Revised selected papers from ICORES 2017, Communications in Computer and Information Science, Springer (Accepted for publication).

Mathematical model

$$\text{Minimize} \sum_{i \in I} s_i \tag{1}$$

$$\text{subject to} \sum_{c \in C} B_{itc} x_{ct} \leq s_i \qquad \text{for } i \in I, t \in T \tag{2}$$

$$d_{cr} + \sum_{t \in N_{c,r}} x_{ct} s \leq \beta \qquad \text{for } c \in C, r \in R_c \cup \{r_c\} \tag{3}$$

$$d_{cr} \leq d_{c,r-1} - u_{cr} + \sum_{t \in N_{c,r-1}} x_{ct} s \qquad \text{for } c \in C, r \in R_c \cup \{r_c\} \tag{4}$$

Mathematical model: notation

C - the set of vehicles,
I - the set of candidate locations to locate charging stations,
R_c - ordered sequence of parking events for vehicle $c \in C$,
N_{cr} - the list of time intervals $t \in T$ that overlap with parking events $r \in R_c$,
$s_i \in N_0$ represents the number of charging points allocated to station $i \in I$,
$x_{ct} \in \{0, 1\}$, if vehicle $c \in C$ is being charged during the time interval $t \in T$, then $x_{ct} = 1$,
$d_{cr} \geq 0$ corresponds to the state of the battery of vehicle $c \in C$ at the beginning of the parking event $r \in R_c$,
u_{rc} - driving distance of the vehicle $c \in C$ between parking events $r - 1$ and r,
$B_{itc} \in \{0, 1\}$ - $B_{itc} = 1$ when vehicle $c \in C$ is parking at location $i \in I$ during the time interval $t \in T$,
β - capacity of battery (maximum driving range).

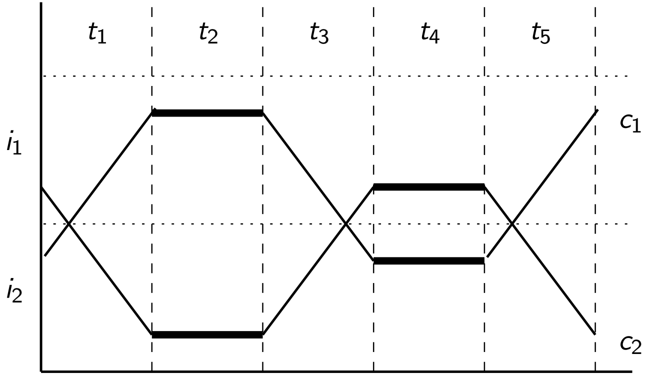


Diagram illustrating parking events and movements of vehicles.

The flow model

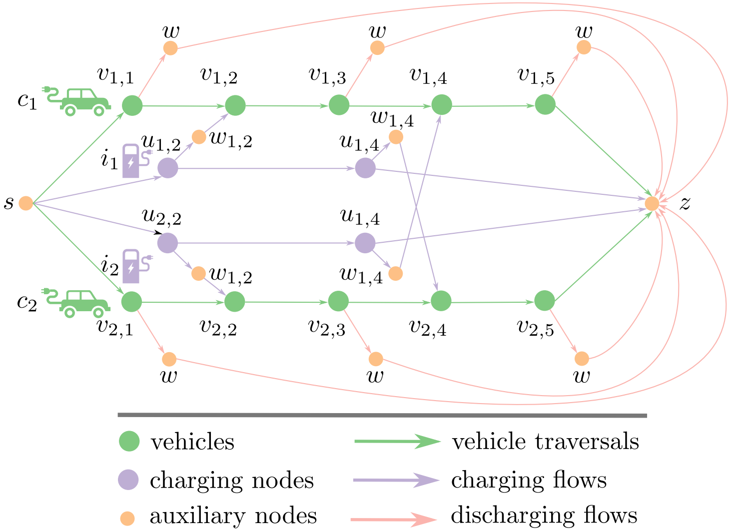
The optimal solution

is equivalent to the feasible flow with the minimum number of non-zero flows on given edges.

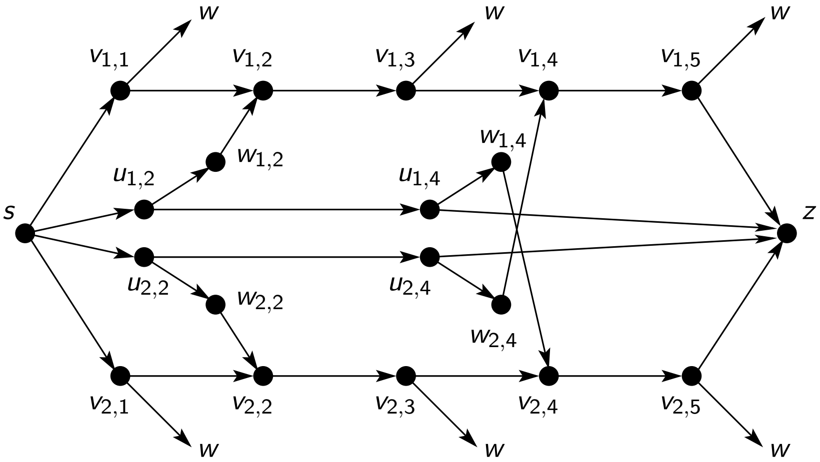
The starting solution

that we use in suggested heuristic is minimum feasible flow.

The flow model

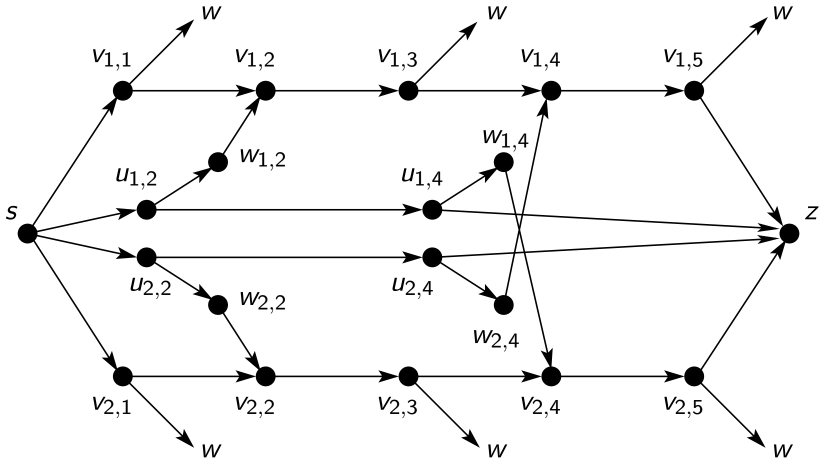


The flow model



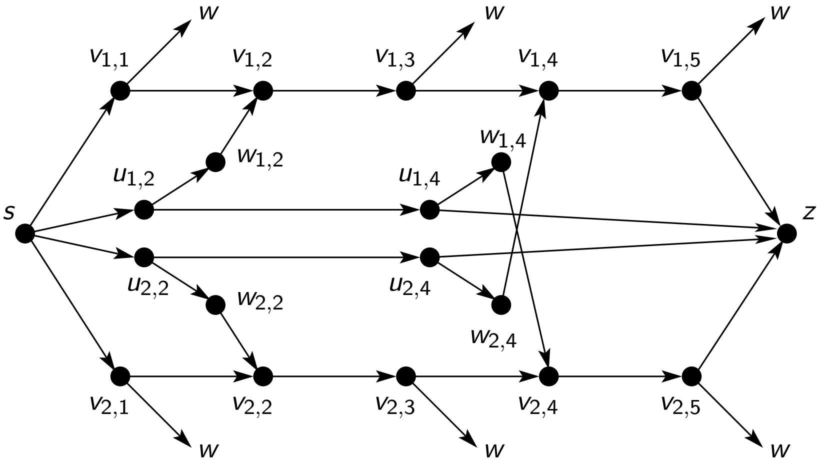
Lower and upper bounds: $(v_{i,t-1}, v_{i,t}), (v_{i,n}, z) \rightarrow \langle 0, \beta \rangle$

The flow model



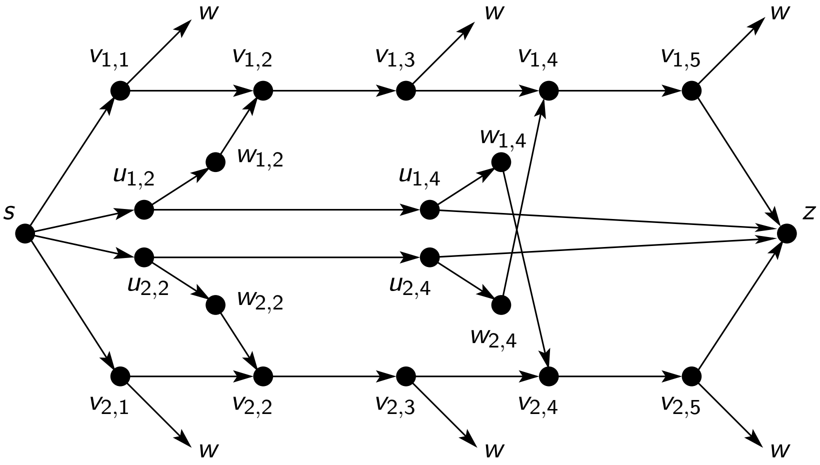
Lower and upper bounds: $(s, u_{i,2}), (u_{i,t-2}, u_{i,t}), (u_{i,m}, z) \rightarrow \langle 0, |T_S| \rangle$

The flow model



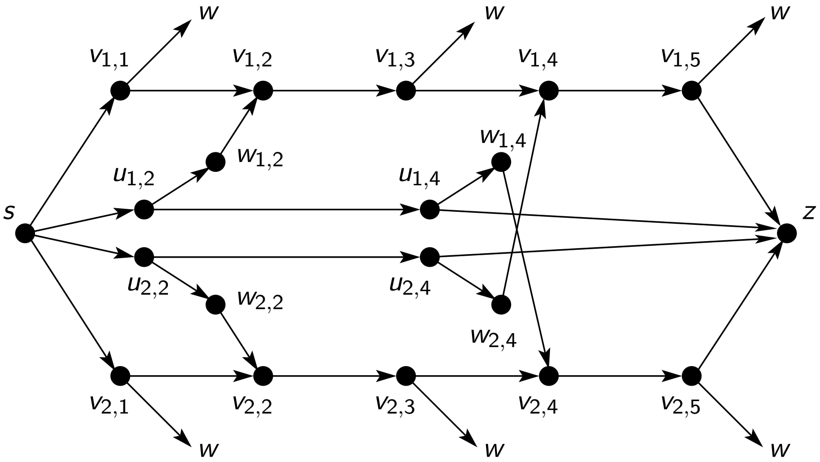
Lower and upper bounds: $(u_{i,t}, w_{i,t}), (w_{i,t}, v_{j,t}) \to \langle 0, 1 \rangle$

The flow model



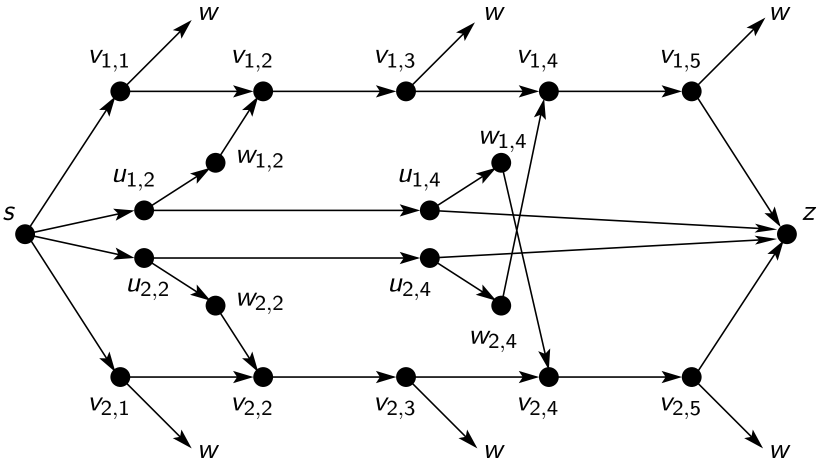
Lower and upper bounds: $(v_{i,t}, w) \rightarrow \langle 1, 1 \rangle$

The flow model



Lower and upper bounds: $(s, v_{i,1}) \to \langle \beta, \beta \rangle$

The flow model

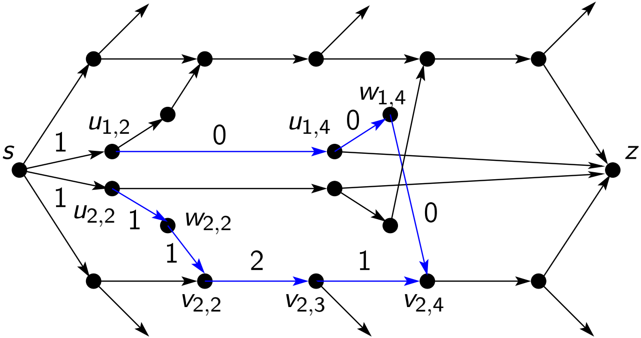


Lower and upper bounds: $(w, z) \to \langle 0, \infty)$

The flow model

Feasible solution

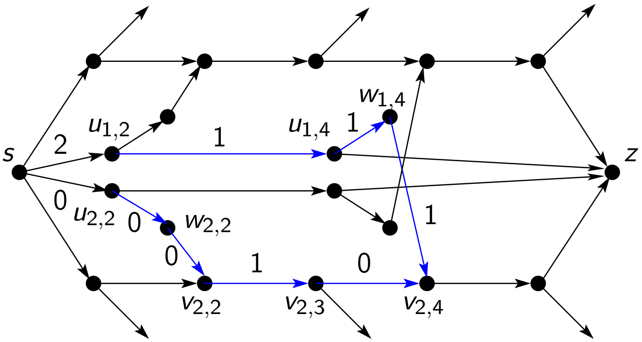
= feasible flow $\longrightarrow$ solvable in polynomial time.



The flow model

Sparse solution

= minimum number of non-zero flows on edges $(s, u_{i,2})$.
Heuristics that uses augmenting paths between pairs $\{u_{i,2}, u_{j,2}\}$.



The flow model

Heuristic

Input is the network G with feasible flow x and subnetwork G'.
For each pair of vertices $u_{i,2}, u_{j,2} \in V_2$ such that
$0 < x(s, u_{i,2}) \leq x(s, u_{j,2}) < |T_{even}|$ **do**:
$\longrightarrow$ **while** there is an augmenting path $P(j, i)$ with reserve r from $u_{j,2}$ to $u_{i,2}$ in G' **do**:
$\longrightarrow \longrightarrow$ add the edges $(s, u_{j,2})$ and $(s, u_{i,2})$ to $P(j, i)$ to form a (non-oriented) cycle
$\longrightarrow \longrightarrow$ $C = (s, u_{j,2}, \ldots, u_{i,2}, s)$,
$\longrightarrow \longrightarrow$ change the flow x in C as follows:
$\longrightarrow \longrightarrow$ **if** (u, v) is the forward edge in C, **then** $x(u, v) = x(u, v) + r$,
$\longrightarrow \longrightarrow$ **if** (u, v) is the reverse edge in C, **then** $x(u, v) = x(u, v) - r$,
$\longrightarrow$ process another pair of vertices.

Conclusions

The IP model of the location-scheduling optimization problem to design private charging infrastructure for electric vehicles.

The flow model of the mentioned problem.

Methods for solution of the problem.
Minimum feasible flow, sparse solution.

Thank you for your attention.

Acknowledgements

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