Electric Bus Fleet Mileage Maximization with a Given Schedule using Integer Programming

Marius Madsen, Hochschule Niederrhein, Marius.Madsen@hs-niederrhein.de
Marc Gennat, Hochschule Niederrhein, Marc.Gennat@hs-niederrhein.de

Overview

Local public transport in Krefeld is provided by SWK MOBIL GmbH, a municipal company, using buses and trams. SWK is discussing a purchase of electric buses. Economic analyses conclude that electric buses are currently uneconomical compared to diesel buses, although the mileage-related costs are lower. According to former studies, higher capital expenditures cannot be compensated. [6]

In previous works a heuristic was used to check under which conditions electric standard buses (12 meters) and electric articulated buses (18 meters) can be operated cost-efficient in Krefeld [2]. Hereby cost-efficient means the same or lower total costs of ownership compared to diesel-powered buses. For this purpose, it was investigated how a combination of given cycles can be used to maximize electrical operating kilometers in order to benefit from lower mileage-dependent costs.

In this contribution the optimal mileage of the electrical bus fleet is computed by integer linear programming. This result and its computing time are compared with the heuristic from [2].

Given Public Transport Schedule

The scheduling software used by SWK organizes and stores cycle information according to the standard interface *ÖPNV-Datenmodell 5.0* [7]. Cycle data are generated for all different day types. Travel times, stops, routes and line numbers are available for each cycle. A cycle starts with depot exit and ends with depot entrance [5]. As an example Fig. 1 shows 18-meter bus cycles on a Monday.

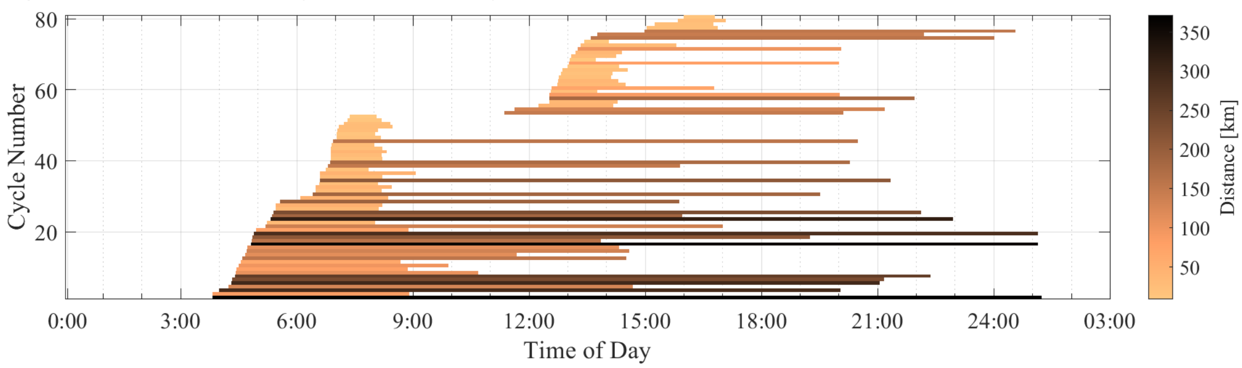

Fig. 1: 18-Meter Bus Cycles on a Monday

Maximization of Electric Operated Mileage with an Algorithm

A bus can travel several short cycles during day instead of a long one. If an electric bus travels several short cycles in a row and is recharged in the depot between the cycles, a longer total daily mileage is achievable. This results in a combined system of opportunity and overnight charging [4]. Energy requirements of individual cycles and days vary depending on the bus type, weather, battery design and cycle specifications. Depending on the day, there are about 80 cycles. To find the combination of cycles with highest mileage per day a greedy algorithm was developed [2]. This algorithm identifies for each bus the combination of cycles that ensures the highest mileage.

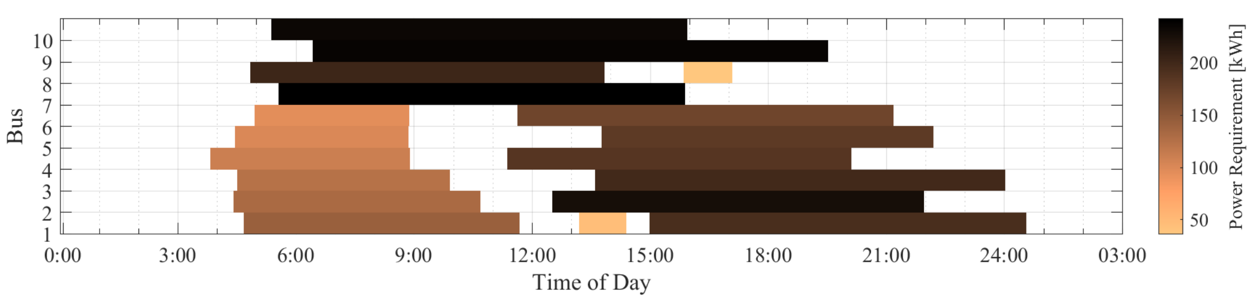

Fig. 2: Resulting Cycle Sequence for ten 18-Meter Buses Using the Algorithm. Sum Mileage: 2272 Kilometers

As an example, Fig. 2 shows a result for ten 18-meter buses with a battery size of 250 kilowatt hours each. For a single bus, this procedure calculates the best solution. For multiple buses, an optimal solution cannot be guaranteed using this algorithm. The computing time for the ten buses was 0.05 seconds.

Methods

To compare computing times and resolved kilometers, the problem is formulated as an integer linear optimization problem in the following. Referring to traveling salesman problems [1], a similar approach is used. This problem is solved by the commercial solver Gurobi [3] and its results are compared with those of the algorithm from [2]. The objective function is formulated with

$$J = \max_x \; c^T x, \qquad A \in [0,1]^{m \times n}, b \in \mathbb{R}^m, c \in \mathbb{R}^n, x \in [0,1]^n,$$
$$\text{subject to } A \cdot x \leq b$$

whereby n represents the number of buses times the number of cycles. The binary decision vector is noted as x, and c contains the lengths of the individual cycles for all electric buses. The inequality constraints of this integer linear optimization can be passed to the solver as A and b. This results in the following constraints:

1. A certain cycle can only be used by a maximum of one electric bus per day.
2. A bus cannot run several cycles simultaneously. Additional time must be considered for maneuvering at the depot and for a possible change of driver.
3. The state of charge must be positive all times. In addition, the batteries can be charged to a maximum of 100 %.

Results and Conclusions

The MILP-Solver [3] determines the global optimum result for ten electric buses within 1.48 seconds. The result is shown in Fig. 3.

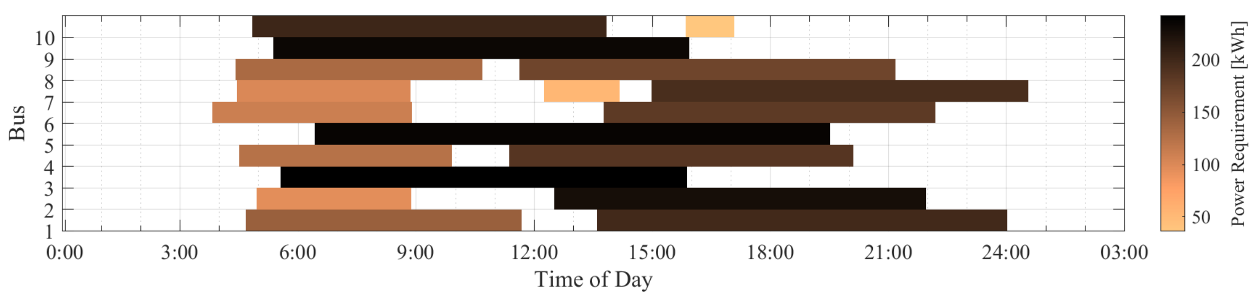

Fig. 3: Resulting Cycle Sequence for ten 18-Meter Buses Using MILP-Solver. Total Mileage: 2277 Kilometers

In this example the algorithm computes a total mileage of 2272 kilometers - 0.25 percent shorter than the optimal solution, but this task was solved 30 times faster. For the computation of all day types with different climate conditions, battery sizes, bus types and number of busses, the IP has to be executed several hundred thousand times. The optimal solution for a complete year of bus fleet planning demands a computation time of approximately three month using the commercial solver Gurobi [3]. Thus, the previous used algorithm is much faster and delivers the good approximation to the optimal solution in a few days.

References

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