EPFL
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Decision-aid Methodologies in Transportation
Spring 2016

Exercise session 2

Location of wayside feeding stations for electric buses

1 Introduction

In the last few decades, there has been a growing concern about pollution in major cities, and in particular about the large contribution of road transportation. According to the World Resource Institute (2006), 65% of global CO2 emissions come from energy use, with 21% coming from transportation due to its dependence on fossil fuels. To curb CO2 emissions in the transportation sector, a key and viable approach is the use of renewable energy resources to power electric vehicles.

Some of the main operators of electric vehicles are urban transportation companies that use wired electric buses for public transportation. The history of electric buses dates back to 1882 in Germany. For a hundred years of development, this system has seen a remarkable evolution. Conventional electric buses, commonly known as trolleybuses, need to draw electricity from overhead wires using spring-loaded trolley poles. Such a design pattern is the source of drawbacks such as:

- An unsightly jumble of overhead catenary wires (i.e., the so called visual pollution).
- The catenary wires limit the accessibility and flexibility of the trolleybus systems. For example, if some roads of the trolleybus system are closed for maintenance, trolleybuses could be forced to make a detour of several kilometers off their route in order to stay on the wires.

Recently, with the advances in energy storage technology, electric battery public transportation systems have been introduced and tested in several cities around the world (e.g. TOSA bus system). The new solution fully uses the efficiency of an electric traction chain while avoiding the inconvenience of a heavy energy storage system or of the maintenance constraints of catenary infrastructures, and ultimately the inherent visual pollution of such systems.

2 Problem statement

As shown in figures 1 and 2, the bus system has two key elements:

1. Identical electric buses with on-board batteries
2. Wayside feeding stations

Figure 1: TOSA bus system

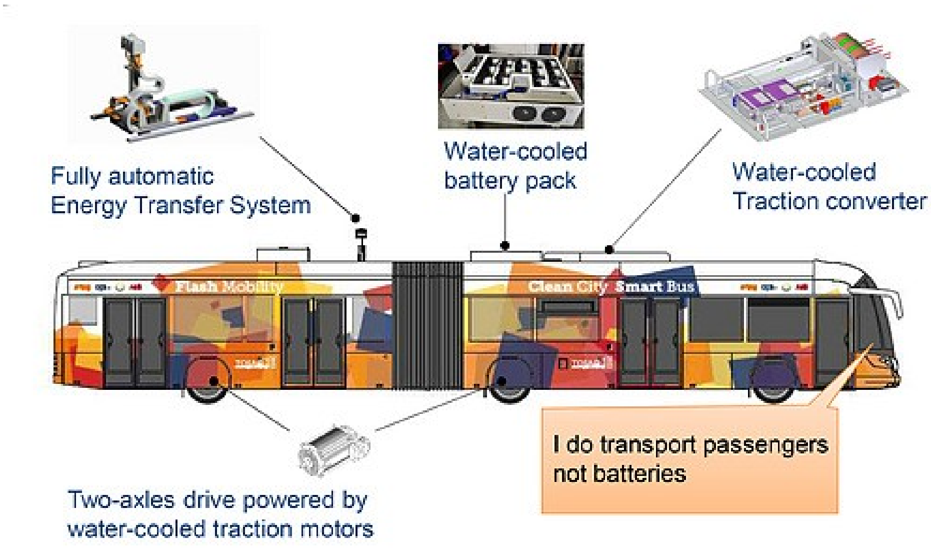

Figure 2: TOSA bus and wayside feeding station

The battery will definitely run out of energy at some point during the bus tour. Therefore, in order to guarantee that all buses can complete their tours and return back to the terminal, wayside feeding stations should be installed at appropriate stops along the bus line. Wayside feeding stations can only be installed at the bus stops.

There are two types of feedings stations:

1. CFS (conventional feeding station): when charging the bus it draws directly from the energy grid. It has a power of 800 kW, and can be used for a limited time (due to bus stop congestion). The transferred charge is equal to the power of the CFS times the time spent charging. The CFS costs 60'000 CHF to install.
2. FFS (fast feeding station): it has an energy storage and is used for an immediate charge. It can provide a charge of 15 kWh at a time and costs 110'000 CHF to install. The energy storage of the FFS is recharged from the grid after the bus leaves it.

The city of Geneva has decided to implement a line of electric buses and to buy buses with battery capacity of 30 kWh. The line starts from the terminal and has 39 additional bus stops. Buses start their tour from the terminal and visit the stops consecutively, charging at the stops where feeding stations are available.

The following restrictions are imposed:

1. A bus can always be fully charged at the terminal before starting a new tour.
2. An FFS is able to fully recharge its energy storage between two consecutive bus visits.
3. The on-board battery should always be charged to at least 60% of its capacity.

The city is looking for a decision support tool to minimize the implementation cost of the system. As a group of experts, your task is to provide a decision support tool for the city of Geneva to implement the TOSA bus system.

3 Tasks

1. Read carefully the description of the problem and propose a schematic representation of it. Determine the decision variables and the objective function (descriptive).
2. Based on the defined framework, provide the description of the constraints that have to be respected.
3. Beside the provided information, determine what type of additional information is required in order to present the problem mathematically.
4. Provide the mathematical description of the problem in the following order:
   (a) Define sets and indices
   (b) Define parameters
   (c) Define variables
   (d) Objective function
   (e) Constraints
5. Implement your mathematical model in CPLEX with the provided data.
6. As this project is established for the first time, the city authorities are not sure about the reliability of the buses' energy consumption. Given data from field test measurements, how would you guide the authorities in installing the feeding stations?

7. The 60% rule for battery charge has to do with assuring a long battery life. However, it may lead to inflexibilities or an excessively expensive system. Is it possible to model this rule as a special soft constraint, such that it is possible to violate it, but at a penalty? How can we interpret this penalty?

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