Simulating individual charging behaviour in MATSim

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Introduction

The use of electric vehicles (EVs) is on the rise, and government initiatives are actively promoting their adoption. However, compared to internal combustion vehicles (ICVs), EVs still have a limited range and require more frequent recharging, making the availability of charging infrastructure a crucial factor in their attractiveness. With the European Union's plan to phase out the registration of new ICVs by 2030, it is essential to evaluate the necessary infrastructure and its optimal location to meet the charging needs of the population.

There are various options for charging EVs, including public charging stations at parking lots, home charging, workplace charging provided by employers, and charging facilities at supermarkets and other establishments. The interplay between car users' charging needs, preferences, infrastructure availability, and competition for charging slots is complex, making agent-based modeling an ideal tool for understanding potential constraints and assessing the best ways to develop the infrastructure.

Our objective is to develop functionality in MATSim that enables the simulation of charging behavior by agents, allowing us to better understand the dynamics of EV charging and optimize the development of the necessary infrastructure.

Concept

The new functionality that has been added to MATSim to represent charging behaviours consists of two components: (1) the simulation of charging behavior in the daily mobility simulation, and (2) the longer term decision-making of the agents regarding which charger to use and when.

For the daily simulation, we cover the major case where an agent already has an idea of when and where it wants to charge the car. The most common case is that this would happen during an activity (for instance while the person is at work). In the default case, an agent would drive to the activity, perform the activity, and drive away from the activity (Figure 1a). When charging, the agent should now drive to the charger, plug the car, walk to the activity, perform the acitivty, walk back to the charger, unplug the vehicle, and drive away from the charger (Figure 1b).

Besides the standard case, the new components also allow the agent to charge along a trip, in which case the person needs to wait for a predefined duration while the car is plugged. Furthermore, we provide the functionality to simulate dynamic decision-making behavior. This is especially the case if a planned charger is occupied: We then allow the agent to wait for a limited time, and/or drive to another charger, and repeat the process up to a limited number of times (Figure 1c). That logic can be augmented by more intelligent elements such as a booking system in which agents can reserve charging slots even before approaching the intended charger.

The second major component is an extended decision-making process, which happens in the replanning phase of MATSim. The goal is to establish stable charging plans for the agents in which they intentionally choose to use certain chargers, at strategic locations for an optimal duration given the constraints posed by their general daily plan. By (semi-)randomly selecting new locations and slots, agents optimize their charging behaviour while maximizing a *charging score* that is calculated based on their decisions. This charging score includes, for instance, high penalties for an agent's state-of-charge dropping to zero, for reaching a certain lower limit during the day, or for arriving below a predefined limit at the end of the day.

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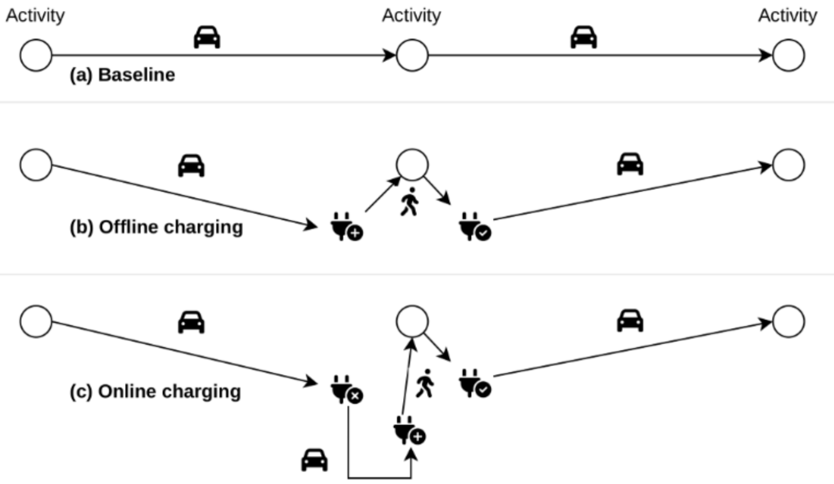

Figure 1: Charging behaviour inserted into an agent's plan

Implementation

Within-day Electric Vehicle Charging (WEVC): The simulation of charging behavior in the mobility simulation is handled by the new Within-day Electric Vehicle Charging package. Its main entry point is an interface (`ChargingSlotProvider`) that returns a list of `ChargingActivity`s that consists of (1) either a trip or an activity in the agent plan, (2) a planned charging station (`Charger`), (3) and a planned duration (for leg-based charging). The WEVC component then, at the beginning of the simulation, equips the temporary agent plan with the respective elements as shown in Figure 1. In particular, legs leading to a charging activity are rerouted to the planned charger locations and `plug interaction` activities are inserted. Those are initially kept at infinite duration to make an agent stop there. As soon as the agent arrives at a `plug interaction` activity, WEVC starts the plugging process and lets the agent wait until the process is finished. Then, the remaining elements of the trip (walk to the main activity; walk back to the charger; ...) are inserted and modified. Alternatively, if the car cannot be plugged successfully, the plan is repeatedly rewritten to lead the agent to a new charger. For that, the interface `ChargingAlternativeProvider` may propose an alternative charging slot (charger and, optionally, duration). If no new alternative is provided, the charging process must be aborted and the agent continues the initial plan without charging.

The WEVC generates various events about charging attempts at a charger (`StartChargingAttemptEvent`, `EndChargingAttemptEvent`), and charging processes (`StartChargingProcessEvent`, `EndChargingProcessEvent`), which are sequences of unsuccessful and potentially successful attempts. In combination with the already existing charging events (`ChargingStartEvent`, `ChargingEndEvent`, ...) detailed histories of charging behaviour in the simulation can be obtained. Likewise, the respective events are used for scoring the charging plans.

Strategic Electric Vehicel Charging (SEVC): The charging plans are handled by the Strategic Electric Vehicle Charging package. It relies on WEVC and is, in principle, a streamlined implementation of the `ChargingSlotProvider` interface. In SEVC, each standard plan in MATSim has an attribute called `chargingPlans` which contains a list of charging plans. Each `ChargingPlan` is a sequence of activity- or trip-based ChargingActivitys and has a score. As for standard MATSim, SEVC mutates and selects between available `ChargingPlans`. This is implemented as a standard replanning strategy that is executed based on a configruable probability in MATSim's replanning. A major advantage of that architecture is that standard plans, when they are mutated, are copied including their attributes. This way, the observed charging plans are preserved.

Note that this process is compatible with other replanning strategies as, in the beginning of each simulated day, SEVC will verify that the `ChargingActivity`s in the currently selected `ChargingPlan` are still compatible with the structure of the standard plan (the selected trips are still performed by car, the selected activities are still accessed by car, ...) and only in that case, an existing `ChargingActivity` is deemed active and provided by SEVC. In return, this means, that a previously deactivated `ChargingActivity` may get active again if, for instance, modes along the plan are changed once more.

Besides the replanning mechanism, SEVC optionally provides default implementations for the `Chargin-`

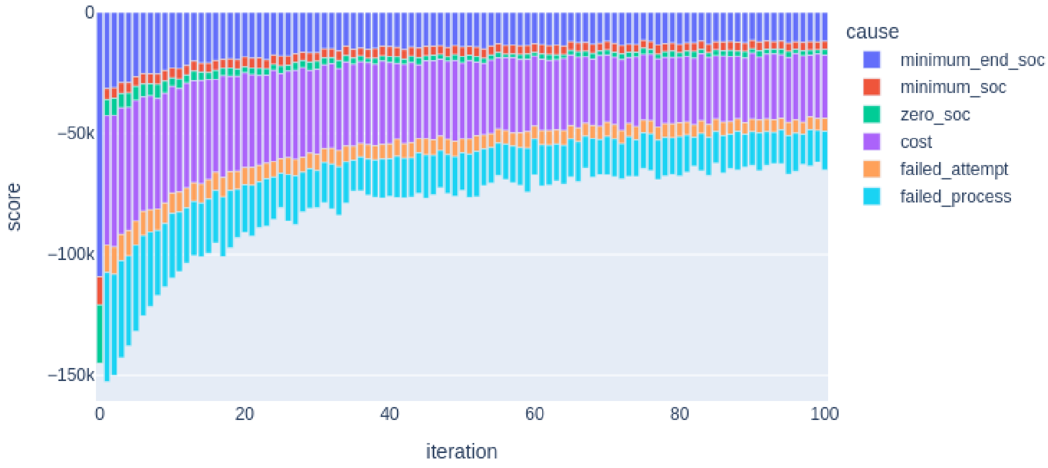

Figure 2: Evolution of charging scores during an example simulation

`gAlternativeProvider`. Both the long-term and dynamic planning make use of a pool of chargers that are attributed in specific ways. For instance, SEVC provides schemes to define the list of agents (by identifier) that have access to a specific charger and efficient code infrastructure is provided to look up viable chargers quickly. This way, home chargers or workplace chargers can be defined without effort. Furthermore, SEVC provides various pricing models from simulation-wide flat fares, to individual per-charger tariffs based on the energy consumed or charging (and blocking) duration, to elaborate tariff systems in which agents (via attribute) may possess certain subscriptions that are only compatible with certain charging tariffs for which, in turn, only certain chargers are available.

Finally, it should be noted that SEVC can be run in two main configurations: Either, as explained above, it can be used in a fully integrated way with existing MATSim simulations. In that case, it is also possible to feed back the charging score to the overall score of the MATSim plan (scaled by a factor) to integrate the quality of the charging plan into overall decision-making. Alternatively, an existing MATSim simulation can be configured such that SEVC is the only active replanning strategy. In that case, the modeler forces the agents to follow their existing plans, but makes them find an optimal way of charging their vehicle under that constraint. More implementation details and an overview of the configuration options are given in the MATSim repository[1].

Example

The framework has been tested using a MATSim simulation for the city of Hanover to which home, work, and public charging infarstructure has been defined. Figure 2 shows a standard output from SEVC, which is an analysis on the composition of scores observed over the iterations. One can see how, initially, the charging scores are highly negative since no charging actvities are defined in the agents' plans. Over the iteration, various scoring components decrease because agents slowly find better plan configruations and make smarter decisions. Especially the reduction of the *cost* component of the score indicates that agents try different chargers and select those that cost them the least amount of money, under the trade-off of being able to use the charger (and not having to abort the charging process).

[1]`https://github.com/matsim-org/matsim-libs/pull/3635`