First Technical Report EkoCS-Trans[1]
Literature Review

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The aim of the four-year Vinnova-funded project NEtworK Optimization for CarSharing Integration into a Multimodal TRANSportation System (EkoCS-Trans) is to research conditions which can increase the number of people that become members of carsharing (CS) organizations and actively use the service. To this end, we will develop a decision support tool combining optimization and simulation for the design of a CS network. We will add CS usage to an existing transport model system, and we will develop a precise mathematical framework for the optimization of the design of a CS system.

We will show how the optimal design of a CS system depends on the demand structure, and where CS stations should be located, which size and fleet mix they should have, and how we can integrate CS-based one-way trips into the urban transportation system such that a broader spectrum of customer requests can be served without invoking too high operational cost and energy consumption of re-allocating empty vehicles. Given different scenarios of a service-level dependent CS demand in the transport model system, this will lead to an iterative process of demand-sensitive service optimization and service-sensitive demand re-estimation.

The first steps in the project plan are:

(i) A literature review
(ii) Development of an optimization model for a CS system
(iii) Addition of the transport mode CS in to an existing transport model system

With this report, we mainly aim to give an overview on (i), the literature review. For (ii), we have developed a model that allows for optimization of station location, station size, and demand fulfillment. We have also started the model development for the case that one-way and round-trips are mixed within a single CS system (allowing certain stations, like train stations, to be accessed by one-way trips only). The trip demand estimation (with trip start and end position and time, and, in case of fixed stations, stations used) will be the output of a MATSim multi-agent transport simulation (`www.matsim.org`).

[1] `http://webstaff.itn.liu.se/~chrsc91/projects/EkoCS-Trans/`

The CS model representation (iii) is the ongoing work in the project, the CS system will be connected to a public transport modeling component, which is readily available within MATSim. Additionally, this modeling effort will make use of the rich model components for mobility-on-demand services that are already available within MATSim. A concrete instance of the model system will be implemented for Stockholm, where MATSim instances for road traffic [1, 2, 3] and public transport (developed in the ongoing project Waterborne Urban Mobility, funded by SLL and Trafikverket, and the completed European project SMART-PT) are already available. The optimization output (station locations, fleet size, type of stations) will be the input for the transport simulation.

CS Systems

CS is a service, which allows the user to benefit from the advantage of a private car without owning one. The increased number of privately-owned cars also heightens their negative side effects like the amount of greenhouse-gas emissions, road congestion, and a lack of parking spaces. From the user point of view, CS can reduce the cost of using a car in comparison to the cost associated with car ownership, like cost of purchasing, maintenance, fuel, parking charges etc., while the user can still get the benefit of the car according to the user's need. There are different types of CS systems: one-way, round-trip and free-floating system. In one-way CS, the user can pick up a car at one CS station and drop it at another, in round-trip CS, the user has to return to the same station where he/she started; and in free-floating CS, the user can park the car in all parking spots in a specified area. At present, there are only round-trip services operated by the CS companies in Sweden (e.g., Sunfleet/M), and we estimate that the constraint that the users need to return to the start station contributes to only a small proportion of the population using this service—as it restricts the type of trips. With round-trips no flexibility in the choice of the station is offered, as the user has to return to the same station. However, if a user is going to work or the city centre, using a CS car from a round-trip systems would mean to pay for the complete working day (during which the car would also be idle). Similarly, trips to airports, train stations etc. are prohibited in these systems. Hence, we think that there should be a shift from round trips to mixed trips, where round trips and one-way trips to certain destinations are combined. The disadvantage of one-way trips is that the vehicles have to be relocated as the system may have imbalances in the car distribution: for example, more cars will be in the city center/around working facilities during the day, and more cars in residential areas during the evening/night. This may lead to shortage of parking spaces and shortage of vehicles at different stations. In this case relocation of vehicles is necessary. This relocation can be expensive for the CS company. Two main approaches of relocation were taken: user-based and operator-based. In operator-based relocation methods, the staff members of the company help to relocate the vehicles, whereas in user-based relocation, the users do this job by various methods like trip joining where multiple users share a ride in a single vehicle when they want to travel from a station with a shortage of vehicles to one with an oversupply.

CS systems also vary according to the type of usage: peer-to-peer (P2P) CS, where owners of private cars share their vehicles with other people; and business-to-consumer (B2C) CS, where there is a CS company and users (customers) [4]. Our work will mostly deal with the B2C CS.

In general, three main levels of decisions can be distinguished: strategical, tactical, and operational decisions. For CS, these relate to, e.g., the number, size and location of station; the fleet size, vehicle distribution, and staff number; and the daily management of the system, especially, the relocation management; respectively.

The first CS company,"Selbstfahrergenossenschaft", was founded in 1948 in Zurich, Switzerland ([5]). Sharing transportation is a way to maximise the use while decreasing the cost imputed to each user so that people can also afford to use expensive items (which was a case in earlier days as common man could not afford a private car). Even these days, expenses are quite high for owing a vehicle, so CS can be a cheaper alternative.

Literature Review

Our focus in this report is mostly on mathematical models for problems related to our CS systems, and the simulation of these systems.

Station Location. One of the problems that we consider is setting up stations so as to increase CS usage. A similar work is done by Rickenberg et al. [6] who provide decision support for planning stations optimally for round-trip systems. In order to enhance usability, a decision support system (DSS) helps the user to import, edit, export and visualize data. The DSS allows parameter setting and visual optimization results that enable instant validation, comparison and assessment of results and scenarios. The objective of the optimization model is to find the best location and size of CS stations while satisfying consumer demand and preferences, and minimizing the total cost. To show the applicability, the DSS and the underlying model were validated as an example for a CS company in Hanover, Germany, with a defined data set.

Yoon et al. [7] used an iterative, simulation-based approach to evaluate the potential of zones in a service area for a dynamic, pooled ride-hailing service. The demand for transport is modeled with an individual agent. Each agent holds one or more plans, which describes the daily activity schedule as well as travel in between activities by transport mode. Initial plans have to be provided and these may be modified during the process of demand adaptation and supply.

Homem et al. [8] also developed an optimization model—a mixed-integer linear program (MILP)—for solving the one-way CS problem which they also used for a case study in Lisbon. Homem et al. [8] concluded that the trip imbalance situation may lead to very high cost for the company. Another conclusion was that the financial losses could be reduced through appropriate choice with respect to the number, location and the size of the stations, but positive profits could be achieved if the CS trips were optimally selected from the total demand, either by previous reservation or by rejecting the trips when there are no vehicles available at the stations.

Vehicle Relocation. Repoux et al. [9] mostly focused on how to model and simulate system's operations to analyse the way the vehicle distribution and service rate evolves with time for one-way CS systems for electric cars. The objective was to maximize customer satisfaction, i.e., minimize unserved demands while offering most flexible service to the customers. Repoux et al. [9] designed a simulator to analyze the behavior to understand how any change in the system impacts its efficiency and forecast the performance after the modification.

The simulator, an event-based simulator, is composed of different real physical entities of CS such as stations, spots, vehicles and relocation personnel. For instance, a vehicle can be available, occupied, under service or under relocation. Other classes describe action and movements of personnel and vehicles such as demand, trip and relocation. The authors take various factors into account:

- Request type— short-term or reservations: In-advance reservations are automatically accepted by the system. The CS organization is reminded two hours before the trip, such that the vehicle can be relocated to the specific location. Short-term demand is always examined by the system but the trips can be refused if they cannot be served. After the trip, the vehicle is available again for the next user.
- Vehicle allocation in rentals: Vehicle allocation depends on demand type. When a reservation arrives, the operator should be able to bring a car to a specific location. To check short term demand, the simulator checks at the station closest to the demand if the vehicle is available and the whether it is charged. If yes, the vehicle is assigned to the user and if not, the nearby stations are checked (within a range of 500 meters). If a vehicle is available, the customer is assigned that or else the demand is rejected.
- Vehicle allocation in relocation: The choice process is the same as for vehicle allocation for short term rentals except that it is limited to the station from which the relocation must be done and the minimum battery level to allow relocation is equal to the minimum value to allow rental plus some additional battery equal to the consumption of the relocation trip. If battery is too low according to this criterion or no vehicle is to be found due to other changes in the simulator, the relocation is not done and the optimization reruns to be able to task the personnel.
- Partial floating: A vehicle can be dropped off outside a station in a close range if the station is already full. The vehicle will however not be charged which may be problematic if its battery level is already low. In the simulator, this feature is managed by adding another category of spots, named extra-spots. They do not allow charging of vehicles, but link the vehicles to the station.

Performing relocation has two main objectives: relocate vehicles in order to serve a demand which was planned in advance and that the operator has to serve, and to balance the system so that the demand in the short-term has a higher chance to be served without penalizing in-advance reservation. Choosing relocations corresponds to finding the shortest path between the two distributions, i.e., reaching the ideal distribution of the system with minimum effort and cost from personnel. The ideal distribution comprises of many criteria like a station should be in the minimum range for the user (within 500 metres), for short-term demand, we do not know which vehicles have to be available at the station, so a range for this number can be set arbitrarily or based on historical data, a minimum value can be defined equal to the number of reservations beginning at a station in the two coming hours; and to avoid accumulation of vehicles at one station, the vehicles should be spread equally enough among stations inside the same cluster.

To find an optimal vehicle relocation, when a system already exists, mathematical programming is one of the best ways to solve the problem. Carlier et al. [10] modeled the problem as an optimization problem using an integer linear program (ILP). They use a time extended graph, which comprises of a set of nodes, a set of arcs, and arc capacities. After the input is taken into consideration, the optimization problem is modeled with the objective to maximize the number of demands and minimize both the number of relocations and the total number of vehicles. In order to test the linear mathematical model Carlier et al. [10] generated data using a random generator implemented to emulate real demand data over time. All data depending on the time are generated over a 24 hours period, segmented into T time steps. The total number of time steps is user-settable and can vary form 24 to 1440 hours. The generator is based on two phases: station and demand generation. The following instance is taken into consideration, N=10 stations, T=144 time steps and a demand of M=500. The upper bound of relocation operations and the number of vehicles $\in \{0, 10, .., 80\}$. The observation is that computation time remains quite low, in order of half a second for Linear Programs (LPs) and two seconds for ILPs. Building the mathematical program takes longest with 34 sec. For each non-integer optimal value Carlier et al. [10] gets by solving the LP model, its integer part is always equal to the optimal value of the corresponding ILP model.

Febbraro et al. [11] developed a CS simulator, with the use of an innovative, user-based technique to relocate vehicles across stations for one-way trip CS systems. The aim was to minimize the rejection ratio of reservations in any period through the attempt to have enough vehicles in each zone to satisfy demand. Here, the vehicles are relocated by users that ended their trips at a destination close to the zone with a shortage of vehicles. For this purpose, the system is modeled as a discrete event system (DES), and a relocation method is proposed on the basis of an ILP. The choice of the DES framework was driven by the need to model the complex macrodynamics of CS in a stochastic environment.

To evaluate the model and the efficacy of the relocation procedure, the car-sharing model and optimization procedure were tested in the traffic-restricted zone of Turin, Italy. With a DES model and a relocation process that had its basis in the solution of an ILP, it was shown that the number of vehicles needed to run the system efficiently, as measured by rejected reservations, could be reduced significantly, even when vehicle relocation was accomplished exclusively by users.

The economic success of CS systems has often been associated with a number of city characteristics as given by Homem et al. [12]:

- Parking pressure: places where parking is scarce and/or expensive make CS a more attractive option
- High density: high population density brings a large customers basis to CS
- Mixed uses: business CS uses during the workday can be paired with residential uses in mornings/evenings/weekends

Homem et al. [12] developed an optimization approach to depot location in one-way car sharing systems where vehicle stock imbalance issues are addressed under three trip selection schemes. The objective is to maximise the profit of car sharing organisations considering all revenue and costs involved.

Three schemes for trip selection in one-way CS systems were considered:

- The first scheme assumes that the CS company has total control over the selection of trips and is free to accept or reject a trip according to profit maximization. Such scheme is possible only if there is a central management agency which can control the decision to accept or reject trips to maximize the profit.
- The second scheme assumes that all the trips requested by the client will be accepted.
- The third scheme is a hybrid one, in which there is no obligation of satisfying all the trips between existing depots, but rather, they can only be rejected if there are no vehicles at the pick-up depot.

Three optimization models were developed by Homem et al. [12] based on the above three schemes where the objective was to maximize the profit. With a case study, Homem et al. [12] observed that the most profitable scheme was the first scheme where the CS company had the full control over the acceptance and rejection of trips. The second profitable scheme was number three and number two was the least profitable.

Carlier et al. [10] investigated the optimization of CS one-way systems which can be integrated to a one-way multimodal transportation system. The optimization focuses on fleet dimensioning when station locations and accurate demands are given. They proposed LPs based on flows for maximizing the overall demand the system can absorb and minimizing the number of vehicles and relocation operations needed.

Travel Demand. Travel demand estimation of one-way CS can be categorized into: survey and analysis, discrete choice modelling, agent-based simulation. The discrete choice modelling has been employed widely in travel demand analysis with the most common application being in choice of the travel mode, aim and destination. Agent-based simulation (see Vosooghi et al. [13]) is more sophisticated and a common solution for estimating the travel demand of one-way CS . The travel demand emerges from interaction of four types of agents in the transportation system: node, arc, traveler and vehicle. There are three major challenges in travel demand estimation: data, computation time, and calibration and validation. Other than agent-based simulation, there is also activity-based multi-agent simulation. Here, the demand estimation framework of one-way CS is structured as follows: a synthetic population is created for demographic data, activity plans and activity locations are generated for each synthetic individual with mode and route choices, the traffic simulation and plan execution are done to find performance measures, activity planning and mode decisions are revised for each individual, and this is repeated as an iterative process until average performance measures for all agent stabilize.

It is estimated that shared cars can replace between one and 6.5 personal vehicles (see [14]); moreover, CS tends to decrease the frequency of trips carried out by impulse, meaning CS not only makes people more aware of the cost per trip, but also demands that each trip must be planned. Also the supply of variety of vehicles, which are often newer and more fuel-efficient compared to private vehicles, can motivate the optimization of the size and characteristics of the vehicle, depending on the purposes of the trip.

Lage et al. [14] collected data for the city of Sao Paulo in Brazil from a public and free database. In order to understand the transport demand in the city, for each district, socioeconomic, transportation and land-use information was collected from the database. After the collection, compatibility test and spatialization of the data, performed in open source Geographic information system (GIS) software (QGIS), the authors investigated which districts have the largest number of entities such as train/subway stations, hotels, shopping malls, leisure and cultural facilities, and so on, which have the potential to generate trips and—consequently—transport demand. For identifying the best location, the authors developed a methodology to prioritize the most relevant information for the implementation of location of the CS stations. A prioritization matrix based on weights was developed to score the information, according to three hypothetical scenarios. In the first scenario the transportation data was prioritized, in the second scenario, priority was the flow of people and in the last scenario the land-use data was assigned the maximum value weight, prioritizing the residential areas and the commercial and service areas.

Lage et al. [15] also observed different scenarios where different areas were marked according to various aspects. The analysis made it possible to define the profile of the potential users of CS systems. Once the profile of targeted users is known, socioeconomic and spatial data allows mapping of these users and their destinations while using CS. Once the most popular origins and destinations were known, the database used in the study made it possible to identify the locations that are candidates to receive CS stations.

The five major demographic markets for CS are: neighbourhood, business, college, low-income and commuter, see Mathew et al. [15]. Universities have been enthusiastic to partner with CS for several reasons, e.g., offering an amenity to faculty, staff, and students; projecting a progressive, environmentally-conscious image; and reducing on-campus demand. A typical CS user is in the age group of 21 and 55 years, has a high level of education, is professionally employed, is concerned with environmental issues, and lives alone, compare Mathew et al. [15]Hence, CS operators find that university markets are easier to target as everyone has the same destination.

Multi-Agent Transport Simulation MATSim MATSim (see Ciari [16]) was developed jointly at IVT in Zurich and at TU Berlin, and published under GNU license. MATSim is a fast, dynamic agent-based and activity-based transport simulation. The idea is to let a synthetic population of agents act in a virtual copy of the real world. The synthetic population reflects census data while the virtual world reflects the infrastructure such as road network, land use, and the available transport services and activity opportunities. Each agent has a plan which represents a chain of activities which he is supposed to perform during the simulation day. Agents try to perform optimally according to a utility function that defines what is useful for them. The performed activities gives a positive utility while the travel gives negative utility. One virtual day is iteratively simulated. From iteration to iteration, a predefined amount of agents are allowed to change some of their daily decisions to search for a plan with a higher utility. The choice of dimensions are:

- Starting time and duration of the activity
- Location of activities
- Mode of transport
- Route
- Parking

From the transport planning perspective for CS services, it is crucial to represent availability of vehicles at local level and also the dimensions mentioned above like trip embedded in the whole activity. The combination of these features can be found in MATSim, which is therefore a suitable framework for carsharing modeling.

The simulation model for CS has been calibrated to reproduce actual modal share for carsharing in the Zurich, Switzerland region (Horni et al. [17]). It was made using booking data from the Swiss operator Mobility.With the same data, the results were validated along several dimensions. Since Mobility offered only round-trip based carsharing until now, only this model could be validated. Dimensions included in the validation process were: distance from the last activity to the pick-up station, departure times, purpose of the rental and temporal length of the rental.

The IHOP project series aims at building Sweden's next generation strategic transportation model system. Canella et al. [3] (IHOP1) investigated the feasibility of deploying a dynamic and disaggregate network simulation package. Canella et al. [2] (IHOP2) developed a technical framework for integrating travel demand models and network assignment packages through the MATSim technology. Canella et al [1] (IHOP3) moved on to ensure an economically consistent analysis of the travel behavior simulated in such a system. We will integrate our CS model in this Stockholm model.

Autonomous Cars. Some other related work consider autonomous vehicles and CS. Autonomous vehicle technology is becoming a reality these days.

Autonomous cars and CS can go hand in hand in a more distant future for which some of the work is mentioned by Hanan et al [18].

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