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Does ride-sourcing absorb the demand for car and public transport in Amsterdam?

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***Abstract*—The emergence of innovative mobility services, is changing the way people travel in urban areas. Such systems offer on-demand service (door-to-door or stop-to-stop, individual or shared) to passengers. In addition to providing flexible services to passengers, past studies suggested that such services could effectively absorb the demand for private cars thereby reducing network congestion and demand for parking. This study investigates the potential of a ride-sourcing service to absorb the demand for public transport and private cars for the city of Amsterdam. Results indicate that a ride-sourcing vehicle could potentially serve the demand currently served by nine privately owned vehicles and that a fleet size equivalent to 1.3% and 2.6% of the total public transport trips, are required to provide door-to-door and stop-to-stop times comparable to those yielded by the current public transport system. Results from the modal shift indicate that most PT trips are substituted by active modes and most car trips are substituted by ride-sourcing service.**

***Index Terms*—ride-sourcing, agent-based simulation, public transport, demand responsive service**

I. INTRODUCTION AND OBJECTIVE

Urban areas around the world face an increasing need for efficient mobility of people. The recent advancements of various ICT platforms have facilitated the emergence of innovative mobility solutions. Users and the service providers often interact through an online platform such as an application in a smartphone. Such service systems offer users the flexibility to plan their daily activities without going through the hassle of planning for their trip (in a line/schedule based service such as a bus, tram, or metro) well in advance. There is initial evidence that, traditional modes of transport such as privately owned car, line/schedule based public transport are increasingly losing their market shares to innovative mobility solutions such as Cabify, Lyft, Uber, Car2Go, DriveNow, ZipCar [1] and [2]. It is thus timely and important to assess the impact of such systems on the mobility of users and its ability to substitute alernative modes such as car and public transport.

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Studies related to city-wide replacement of private vehicles with shared autonomous vehicles have been performed for Berlin, Austin, and Lisbon [3] - [5]. These studies look into the potential of SAVs (shared autonomous vehicles) to replace private car trips, indicating that one shared autonomous vehicle could replace the demand served by ten privately owned cars. A more recent study, for the city of Munich, suggests a replacement ratio of 10 to 4 indicating that the demand of ten privately owned cars could be served with 4 shared autonomous vehicles [6]. While these studies look into the potential of SAVs to replace the demand served by private cars (a notable exception is [5], which replaced metro services with SAVs), the potential of such services to replace public transport trips have largely been overlooked in the literature to the best of our knowledge.

This study aims at exploring the impact of a ride-sourcing service on the mobility of users and its potential as a replcement for private car and public transport trips for the city of Amsterdam. The rest of the paper is organised as follows. Section 2 describes the modelling framework to assess the mobility system. The next section describes the scenarios considered for simulation. This is followed by results and analysis. We conclude the work by providing the key findings and direction for future research.

II. MODELLING FRAMEWORK

The modelling framework is shown in Fig. 1. The input modules comprise of the *Network*, *Demand*, and *Supply*. The *Network* refers to the super-network which consists of the sub-networks of road and line/schedule based public transport. The sub-network of line/schdule based public transport involves the route network for public transport modes (e.g. train, tram, metro, bus) along with their stop locations. *Demand* includes all passengers with a set of origin and destination points in the network. In this study it is assumed that the passengers have full knowledge of the route network and schedules of the line/schedule based public transport (PT) system. *Supply*

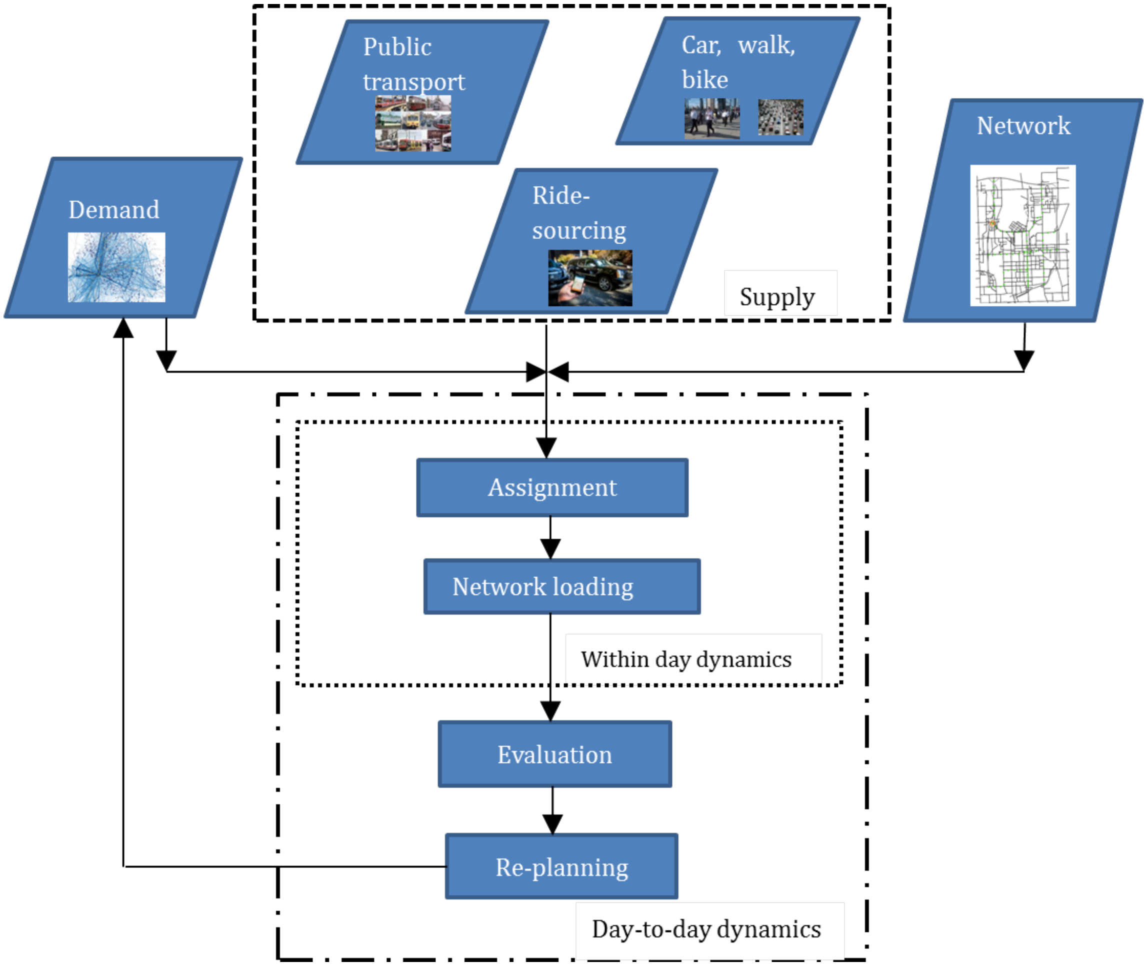

Fig. 1. Modelling framework

comprises of the modes available to each user for travelling from their origin to their destination. The modes available are: car (privately owned), walk, bike, public transport, and ride-sourcing. The public transport network pertains to line-based and schedule-based services that follow a pre-defined route and schedule operated by a fleet of vehicles.

Ride-sourcing services, are considred in this study as demand responsive services picking up passengers from their origin and dropping them off at their destination (door-to-door service) operated by a centrally controlled fleet of vehicles. The central dispatching unit assigns incoming travel requests to vehicles in real time. The service offered is taxi-like (does not allow simultaneous sharing of vehicles). The vehicle dispatching algorithm is based on [3] and [7].

The open-source multi-agent traffic simulation framework MATSim [8] is used in implementing the model. Each user of the transport system is represented as an agent with a set of travel plans. Once the plans have been performed, each agent evaluates the executed travel plan based on the service experienced. The altered set of travel plans forms the demand for the subsequent simulation cycle. This sequence of assignment, network loading, scoring and re-planning forms an iteration which corresponds to a day. This process is continued till a convergence criteria is achieved. In MATSim, plans are scored according to utility functions. The scoring of a plan has two parts, namely, utility for performing the activity and a travel disutility for performing the trip. The travel disutility is scored using a mode specific constant, the direct disutility of travelling, disutility for waiting and transfer if any, and the disutility associated with monetary travel cost. The typical scoring of an activity *q* and a travel leg with mode *m* is shown in (1) and (2).

$$S_q^{act} = \beta_q^{dur} \cdot t_q^{dur} \tag{1}$$

$$\begin{aligned} S_m^{leg} &= C_m + \beta_m^{trav} \cdot t_m^{trav} + \beta^{money} \cdot \gamma_m \cdot d_m^{trav} + \\ &\quad \beta_m^{wait} \cdot t_m^{wait} \end{aligned} \tag{2}$$

where,

t_q^{dur} is the duration of the performed activity q
t_m^{trav} is the travel time for mode m
t_m^{wait} is the waiting time for mode m
C_m is the mode specific constant for mode m
γ_m is the fare per unit distance for mode m
d_m^{trav} is the total distance travelled with mode m
βs are behavioral parameters of users

The β values have been set to the default values as suggested in MATSim [8] and the mode specific constants are calibrated to achieve plausible modal share for Amsterdam.

III. APPLICATION NETWORK

The model is applied to the network centered around Amsterdam, The Netherlands (Fig. 2). The network is comprised of 17,375 nodes, 31,502 links, and 2,517 public transport stops which includes train, tram, bus, and metro. The demand data consists of 168,103 agents (representing 20% of the population), and is adopted from the national activity-based demand model, Albatross [9]. The following modes are considered by the model: car, walk, bike, public transport, and ride-sourcing.

IV. SIMULATION SCENARIOS

Four simulation scenarios are considered. The first scenario is the *Base Scenario*. Modes of private car, walk, bike, and PT are simulated until equilibrium state is obtained (stable demand for all the modes). In the second scenario, all the public tranport trips from the *Base Scenario* are replaced by a fleet of ride-sourcing vehicles. Similarly in the third scenario, all the car trips are replaced by a fleet of ride-sourcing vehicles. The demand-supply matrix for the first three scenarios are shown in Fig. 3 which shows the demand for each mode and the modes considered (supply). In the fourth scenario, the ride-sourcing service competes with all the existing modes in the base case (car, walk, bike, and PT). In each iteration, the users execute their travel plans, score them and replan their travel strategies. The users can alter their travel strategies in the following ways: 1) Change the mode of travel, 2) Change the route of travel 3) Change the departure time.

V. RESULTS AND ANALYSIS

This section presents the results of the scenarios considered. The mode share (%) at equilibrium for the *Base Scenario* is shown in Table I. For scenarios two and three where PT and car trips are replaced by ride-sourcing services respectively, we first need to determine a fleet size of ride-sorcing vehicles that could provide levels of service comparable to those offered by the PT and car trips in the *Base Scenario*. We consider total travel time as an indicator of level of service. To this end, for scenario II and III we perform a sensitivity analysis with the fleet size of ride-sourcing services for travel times of users.

TABLE I
MODE SHARE IN % FOR BASE CASE AT EQUILIBRIUM

Car	Walk	Bike	PT
29	28	22	21

Fig. 4 - 6 show the travel time distribution for a range of fleet sizes of ride-sourcing vehicles for scenarios II and III. It is to be noted that the plots indicate a fleet required to completely replace all the trips performed by PT (Scenario II) or car (Scenario III) in the base case (i.e. demand is inelastic). It becomes evident from Fig. 4 that a fleet size of 2% of the total demand (2834 vehicles) attains waiting times that are similar to those of the replaced PT trips from the *Base Scenario*. Overall the waiting time of users decreases monotonically with increase in fleet size. The trend is super-linear till 2% after which the trend becomes sub-linear. Fig. 5 shows the total travel time (access/egress walk time + waiting time at the stops + in-vehicle time) value as function of fleet size for scenario II. It can be observed that a fleet size of 1% of the total demand (1417 vehicles) is able to achieve a similar travel time with respect to door-to-door travel time for PT users as in the *Base Scenario*. These fleet sizes represents 1.3% and 2.7% of the PT trips in the *Base Scenario*. Similarly, a fleet size of 2% (2834 vehicles) is able to provide a similar level of service with respect to stop-to-stop time. The total travel time stabilises after 2% of fleet size with the travel time showing no considerable differences.

Fig. 6 shows the total travel time as a function of the fleet size for the third scenario. From the figure it can be seen that the average travel time steadily decreases with an increase in fleet size of ride-sourcing services till 3% fleet size (4251 vehicles). After this point the average travel time stabilises. Hence we can concur that a fleet size of 3% provides near to similar levels of service (total travel time) to those experienced by car trip users in the *Base Scenario*. The fleet size of 3% (4251 vehicles) corresponds to 9.1% of the total number of private cars in the *Base Scenario*.

Next we analyze the modal use changes when removing certain modes from supply network. Fig. 7 - 10 show the migration plots which depict the modal shift from the *Base Scenario* to each of the modes available in the second and third scenarios. From Fig. 7 it can be seen that, for the case when the bus network is removed from the PT network, most of the users that switched into traveling by ride-sourcing have previously traveled by car. About half of the car users switch to ride-sourcing. Moreover, there is a considerable shift from bike to ride-sourcing. Most of the previous bus users switch to either walking or ride-sourcing. When bus and tram networks are removed from the PT network, the active modes attracts more users from PT in the base case with a marginal increase of ride-sourcing share from PT. This stems from the higher ridership for tram compared to bus that cannot be substituted by the remaining PT modes (metro and train). When the entire PT network is removed, we observe an increase in the share of PT trips that are substituted by ride-sourcing, arguably due to the longer trips performed by metro which are less likely to be replaced by active modes. Fig. 10 shows the migration plots for Scenario III when no car trips are possible anymore. Ride-sourcing becomes the most common mode of transport in this scenario. Ride-sourcing trips include former car travelers as well as former users of all other modes - walk, bike, and PT.

In Scenario IV, we analyse the impact of ride-sourcing services in competition with car, walk, bike, and PT. We perform a sensitivity anaylsis on the fleet size of ride-sourcing services to investigate its effect on the market share. Fleet sizes

Fig. 2. The model application network of Amsterdam

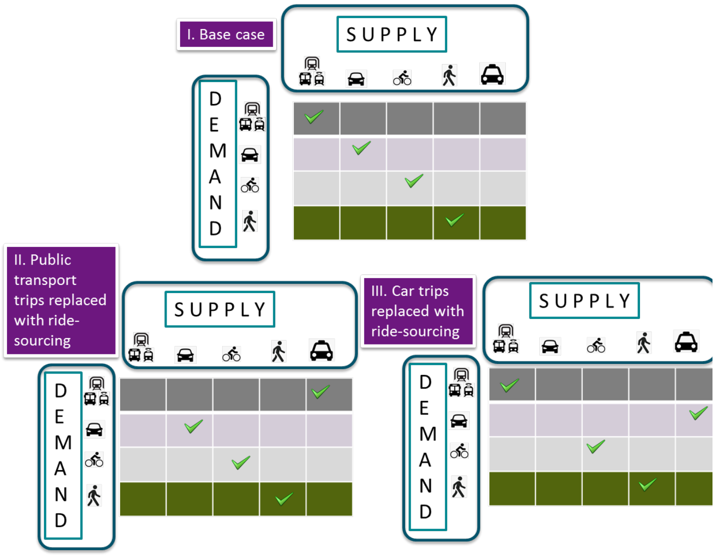

Fig. 3. Demand-supply scenario design for scenarios I, II, and III

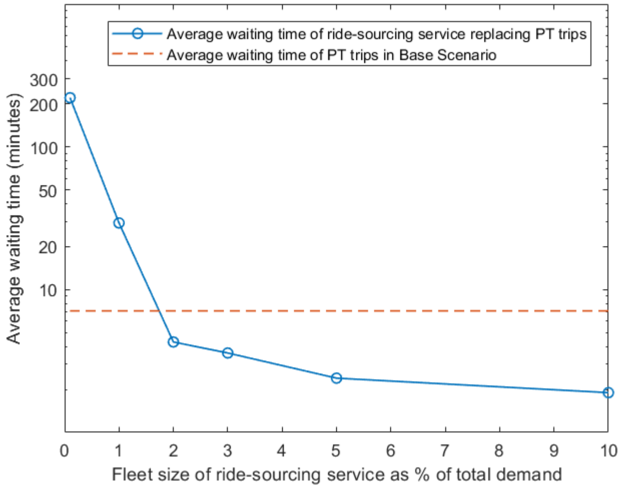

Fig. 4. Average waiting time versus fleet size for Scenario II

considered represent 0.1%, 1%, 2%, 3%, 5%, and 10% of total demand. Table II shows the fleet size considered for simulation and the market share of ride-sourcing services. As can be seen from Table II, the market share of ride-sourcing service increases monotonically with increase in fleet size which can

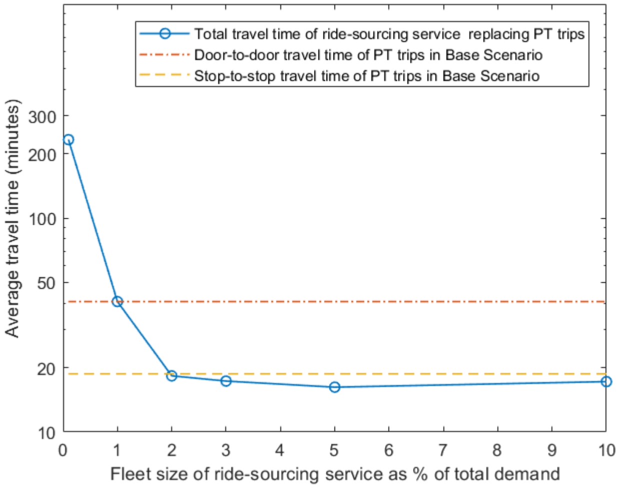

Fig. 5. Total travel time versus fleet size for Scenario II

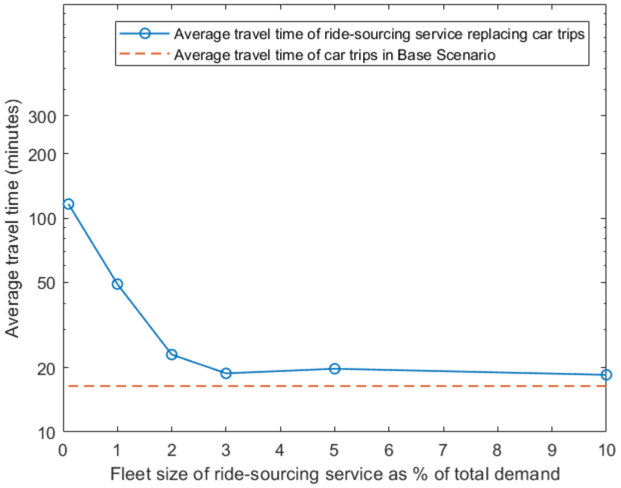

Fig. 6. Total travel time versus fleet size for Scenario III

TABLE II
FLEET SIZE AND MODE SHARE (%) OF RIDE-SOURCING SERVICE FOR SCENARIO IV

Fleet size (% of total demand)	**Market share(%)**
0.1	16
1	24
2	40
3	44
5	47
10	55

be explained by Figure 11 which shows the development of average travel time with increasing fleet size. The figure indicates a steady decrease in travel time with a super-linear trend till 5% fleet size and from 5% to 10% the trend is sub-linear. The reduction in average travel time with increasing fleet size makes it an attractive service.

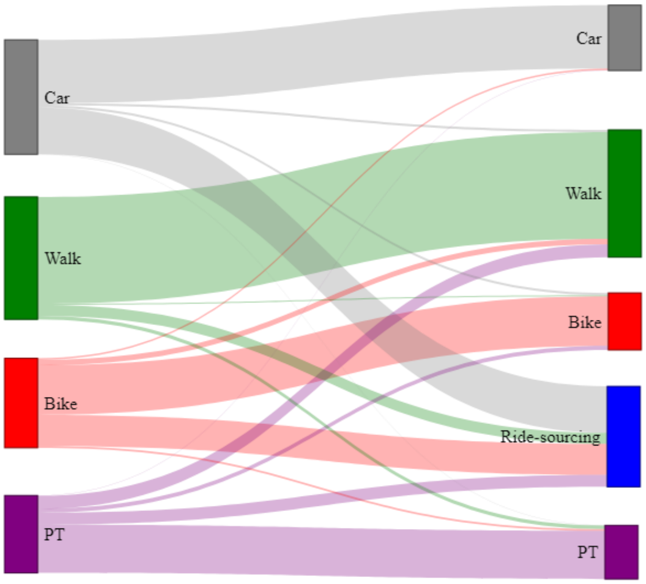

Fig. 7. Migration plots for Scenario II when bus network is removed

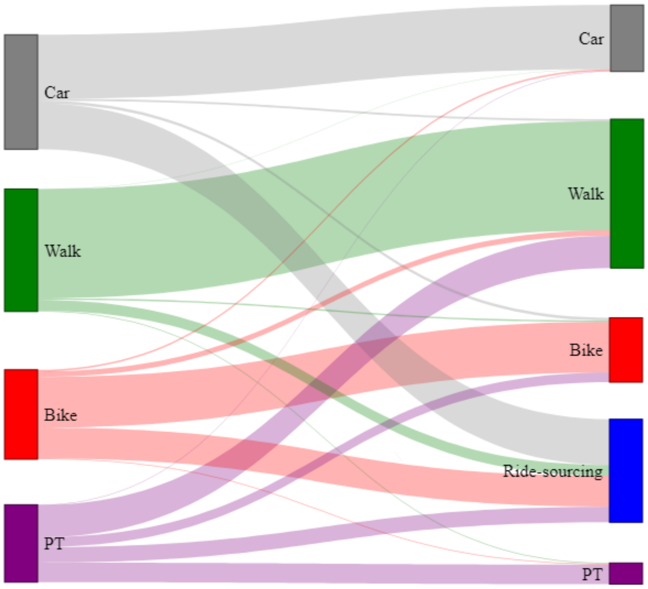

Fig. 8. Migration plots for Scenario II when bus and tram networks are removed

VI. CONCLUSION

This study assessed the impact of a ride-sourcing service on the mobility of users and its potential to replace private car and PT trips for the city of Amsterdam, The Netherlands. An agent based simulation framework was adopted for model implementation. Scenarios in which ride-sourcing service replaced PT and car trips and one in which ride-

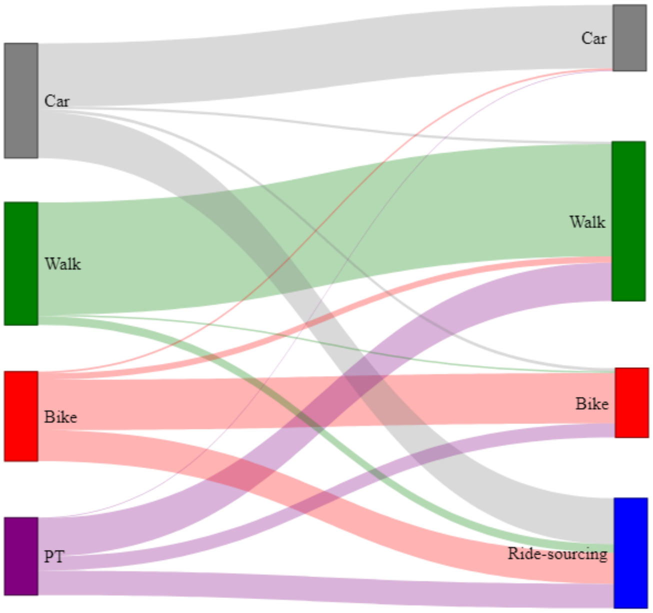

Fig. 9. Migration plots for Scenario II when the entire PT network is removed

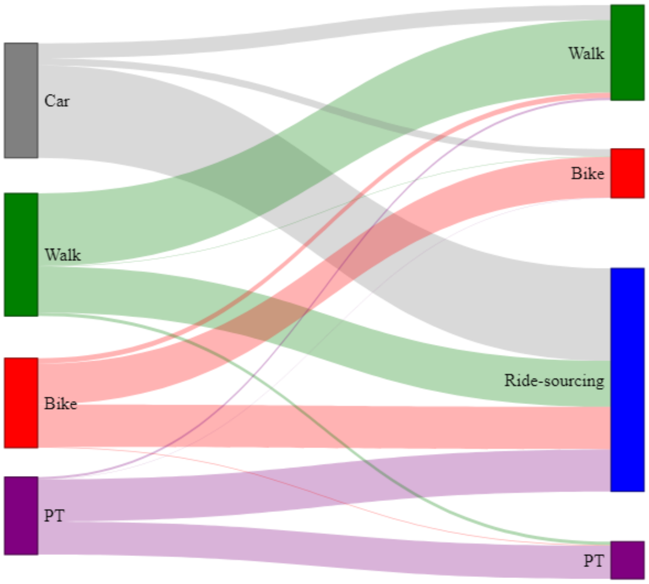

Fig. 10. Migration plots for Scenario III

sourcing service compete with modes of car, walk, bike, and PT were considered. Sensitivity analysis related to the fleet size of ride-sourcing service indicates that a fleet of 1% and 3% of the total demand considered are sufficient to provide similar levels of service in terms of travel time to those attained in the *Base Scenario* for PT and car trips, respectively. The study shows a replacement ratio of 1 to 9 for car trips which is comparable to similar studies where a replacement ratio of 1 to 10 was indicated. A steady increase in modal share of ride-sourcing service is observed with increase in its fleet size. The average travel time showed steady decrease with increase in fleet size and the travel time starts to flatten out around 5% of the fleet size. The trends in the modal shift reveal that, for Scenario II, most PT trips are substituted by active modes and most users attracted to ride-sourcing have previously traveled by car while also attracting a significant share of former bike users. And for Scenario III, most of the car trips are substituted by ride-sourcing. A future direction of research includes asessing the impact of a shared service (where passengers shares a ride) on the mobility of users in Amsterdam.

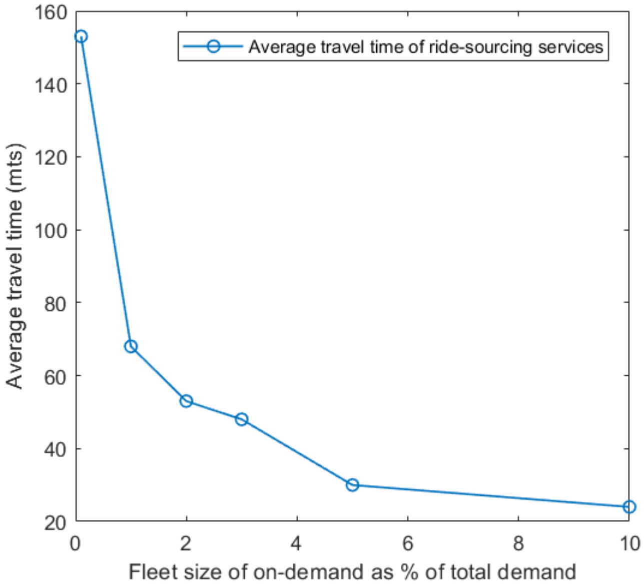

Fig. 11. Average waiting time of ride-sourcing service versus fleet size, Scenario IV

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