

1 **Reconnecting Rural Communities: The Potential of Demand Responsive Transport in**
2 **Lusatia, Germany**

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1 ABSTRACT

2 This study explores the potential costs and benefits of implementing a demand-responsive trans-
3 port (Demand responsive transport (DRT)) service into the Multi-Agent Transport Simulation
4 (MATSim) Open Lausitz Scenario, which describes the region of Lausatia, Germany – a for-
5 mer mining region currently undergoing structural transformation and revitalization. Using the
6 agent-based transport simulation framework MATSim, the proposed DRT service is simulated and
7 evaluated within a real-world model for the region, which is generated from mobile phone data and
8 calibrated against survey data.

9 Conventionally, simulating DRT services is time-consuming, and the results are highly
10 sensitive to numerous parameters and setups of simulations. To address this issue, an innovative
11 simulation approach for DRT services is developed, in which explicit DRT simulations during the
12 iterative MATSim process are replaced by an estimation-based model. This approach enables the
13 efficient evaluation and comparison of multiple case studies with different DRT service designs.

14 More specifically, the proposed DRT service primarily covers one of the larger cities in the
15 region, Hoyerswerda, as well as several surrounding areas, including major interchange points to
16 the regional railway lines. The pricing scheme of the local public transport (pt) system is applied to
17 the DRT service (2.3 €/ride for trips in Hoyerswerda + distance-based pricing for all other trips).

18 Depending on the service area, users of the DRT service achieve an average travel time gain
19 between roughly four to seven minutes. The utility gains through travel time savings make up for
20 roughly 25% to 40% of all utility gains. For each service area setup, the majority of utility gains
21 are obtained through monetary utility gains through saving cost by using the DRT service. For
22 each service area setup, the biggest share of DRT users switches from transport mode car. While
23 the travel time gains for this subgroup are not as high as for users of other modes – DRT and car
24 travel with a similar speed –, former car users benefit from switching from the rather expensive
25 private car to the cheaper DRT service. Overall, the utility gains for DRT users do not exceed the
26 cost for the implementation and operation of the service, which results in a cost benefit ratio below
27 1.0.

1 INTRODUCTION

2 In rural Germany, it is a common problem that public transport (pt) connections are thinned out
3 or even removed completely. The remaining transit lines often operate with low frequencies and
4 high transfer times between different lines. The above also applies to pt trips between the city
5 of Hoyerswerda in the rural region of Lusatia, Germany and the nearby bigger city of Cottbus.
6 Currently, pt passengers with the destination Cottbus and located in Hoyerswerda have to travel
7 to Hoyerswerda main station by bus, take a train connection to Ruhland and change to the train
8 connection to Cottbus or take a regional bus connection to Cottbus.

9 While a direct train connection between Hoyerswerda and Cottbus could potentially save
10 a huge amount of travel time, its construction would cost a lot of financial and time resources. A
11 potentially viable alternative to the construction of a regional train connection is the implemen-
12 tation of a Demand responsive transport (DRT) service in the area as its implementation may be
13 realized in a rather short time period. Additionally to the connection between Hoyerswerda and
14 different train stations with direct regional train connections to Cottbus (Ruhland or Spremberg),
15 a DRT service would bring the benefit of providing a transport offer in and around Hoyerswerda
16 itself.

17 The above and the general trend in transport research towards smart mobility systems – see
18 e.g. the research projects Digitaler Drilling Nachhaltige Mobilität (DiTriMo)¹ or Smart Mobility
19 Lab² which both have a focus on the region of Lusatia, Germany – make the simulation of a
20 DRT service an interesting research question.

21 There are, however, several challenges related to the simulation of DRT systems, espe-
22 cially in large scale scenarios. The first challenge is the long simulation time. When simulating
23 DRT services, route calculations and optimization need to be performed repeatedly and this takes a
24 significant amount of time. For some of the more advanced operational strategies, the optimization
25 process is highly demanding in terms of computational power. Such as in (1), a good solution
26 quality comes with a price of very long computational time. Furthermore, iterative approaches
27 are commonly used in agent-based transport simulation frameworks (as in traditional assignment).
28 This means the online optimization of DRT schedules will be repeated many times, which makes
29 it sometime prohibitively expensive to simulate DRT services in a large scenario.

30 Additionally, most of the existing studies in the literature that project the potential reactions
31 of people to DRT systems rely on hypothesis and assumptions. As more and more DRT systems
32 are being rolled out in different places, we are able to get more data. For example, from the Kel-
33 Ride project and the NaMAV³ project, we acquire the real-world operational data from the DRT
34 operators. By comparing the real-world operational data with the simulated DRT services, sys-
35 tematic discrepancies are often observed, particularly in service quality and mode choice behavior.
36 These discrepancies may further undermine the reliability of the simulation results.

37 Therefore, in this study, we use an innovative approach to perform DRT simulation, namely
38 an estimation-based DRT simulation approach. This new simulation approach can effectively ad-
39 dress the challenges associated with the conventional simulation procedure. More details of this
40 approach is covered in the Methodology section.

41 This addresses the research question by first giving an overview over related work in Sec-

¹<https://www.tu.berlin/vsp/forschung/projekte/ditrimo>

²<https://tu-dresden.de/smart-mobility-lab>

³<https://www.tu.berlin/vsp/forschung/projekte/namav>

tion 2. Section 3 introduces the agent-based transport simulation framework Multi-Agent Transport Simulation (MATSim) as well as the estimation-based approach to simulate DRT. Further, the specifications of the MATSim Open Lausitz Scenario are presented. Section 4 explains the different simulation cases, which are analyzed and discussed in Sections 5 and 6.

2 RELATED WORK

Thanks to its flexibility, DRT has been investigated in various studies as a potential mobility solution for rural and sparsely populated areas, where conventional fixed-route public transport services often suffer from low demand and limited efficiency. In particular, flexible and demand-oriented mobility concepts have been discussed as promising approaches to improve accessibility and connectivity in underserved regions (2). Other works examined the trade-offs associated with highly flexible DRT systems and showed that increasing flexibility may improve user convenience and accessibility while simultaneously reducing operational efficiency and increasing operational costs (3). Apart from that, DRT can also be used to provide transport service dedicated to specific groups in rural regions, such as for student transport (4).

At the same time, previous studies highlighted substantial uncertainties regarding actual demand and user acceptance of rural DRT systems. Empirical analyses revealed that the behavioral intention to use DRT services depends strongly on factors such as familiarity, reliability, and existing mobility habits (5). Furthermore, conflicting expectations between policymakers, operators, and users, together with weak user acceptance, were identified as major challenges for the successful implementation of rural DRT systems (6). With the help of the actual operational data, Schlenther et al. (7) calibrate the mode choice parameters for the DRT in an agent-based model and use it to project the reaction of the residents to a small-scale autonomous DRT service in a small town in a rural region.

Overall, previous research demonstrates the potential of DRT to improve rural mobility and accessibility. However, comprehensive evaluations that jointly consider user utility gains, modal shifts, operational costs, and economic viability on a regional scale remain limited. Furthermore, explicit DRT simulations are computationally expensive and highly sensitive to operational configurations and various aspects in the simulations, which complicates the systematic comparison of multiple service designs. The present study addresses these gaps by introducing an estimation-based DRT simulation approach within MATSim and applying it to the real-world scenario of Lausitz, projecting the potential riderships and predicting the costs and benefits of the DRT operation.

3 METHODOLOGY

3.1 MATSim

This study uses MATSim, an open-source tool for large scale agent based transport simulations, as framework to depict the transport system of the modeled area. MATSim has already been applied to model several regions/cities including Berlin (8), Kelheim (7), Mexico City (9) and many more.⁴ In general, MATSim models combine transport supply and demand to depict a typical working day. The transport demand is displayed in the form of a synthetic population of persons or agents. Each agent typically possesses up to five variations of a daily plan – a chain of activities and legs in between. After the simulation of the day (mobsim – mobility simulation), each performed plan

⁴see <https://matsim.org/examples/>

1 is scored with a utility function (scoring; see Section 3.1.1 for a detailed explanation). Some
 2 agents are then allowed to adapt their plans (replanning). They may change routes, transport
 3 mode, start/end time of activities and switch to an alternative, already existing plan. The circle
 4 of mobility simulation, scoring and replanning is repeated until a user-equilibrium or a previously
 5 defined number of iterations has been reached (10).

6 3.1.1 Scoring

7 The utility score of a performed daily plan S_{plan} consists of the sum of all activity scores $S_{act,q}$ and
 8 the sum of all leg scores $S_{trav,mode(q)}$, with activity q , and number of activities N :

$$9 \quad S_{plan} = \sum_{q=0}^{N-1} S_{act,q} + \sum_{q=0}^{N-1} S_{trav,mode(q)}. \quad (1)$$

10 Typically, utilities of activities are positive, whereas (dis)utilities of legs are negative because we
 11 assume that the time spent on a leg is time which an agent cannot use to perform an activity.
 12 Therefore, it is time that an agent "loses". In the transport model used for this study, an activity
 13 score is calculated as

$$14 \quad S_{act,q} = S_{dur,q} + S_{late.ar,q}, \quad (2)$$

15 where the sub-score of performing an activity $S_{dur,q}$ is defined as

$$16 \quad S_{dur,q} = \beta_{perf} \cdot t_{typ,q} \cdot (1 + \ln(t_{dur,q}/t_{typ,q})). \quad (3)$$

17 Here, the typical time spent at the activity $t_{typ,q}$ is multiplied with β_{perf} (see Table 1; the same
 18 value for all activities) and then one plus the logarithm of the actual time spent at the activity $t_{dur,q}$
 19 divided by $t_{typ,q}$.⁵ The sub-score of late arrival at an activity is defined as

$$20 \quad S_{late.ar,q} = \beta_{late.ar} \cdot (t_{start,q} - t_{latest.ar,q}) \quad (4)$$

21 if the starting time of an activity $t_{start,q} > t_{latest.ar,q}$, the latest possible penalty free activity starting
 22 time. If not, $S_{late.ar,q}$ is 0. $\beta_{late.ar}$ is set to -18.0 util/h by default (see Table 1). Please note that
 23 some components of the activity score are set to 0. Therefore, they are not listed in Equation 2.
 24 For a full description of MATSim's activity scoring function see (11).

25 A travel score $S_{trav,q}$ is calculated including several sub-terms:

$$26 \quad S_{trav,q} = C_{mode(q)} + \beta_{trav,mode(q)} \cdot t_{trav,q} + \beta_m \cdot \frac{y_{avg}}{y_a} \cdot \Delta m_q \\ + (\beta_{d,mode(q)} + \beta_m \cdot \frac{y_{avg}}{y_a} \cdot \gamma_{d,mode(q)}) \cdot d_{trav,q} + \beta_{transfer} \cdot x_{transfer,q} \quad (5)$$

27 with $C_{mode(q)}$ as alternative-specific constant (ASC), travel time $t_{trav,q}$ and marginal utility of trav-
 28 eling per mode $\beta_{trav,mode(q)}$, the agent-specific marginal utility of money $\beta_m \cdot \frac{y_{avg}}{y_a}$ with the average
 29 income of the model's population and the agent-specific income multiplied with the the change in

⁵The formulation "1 + ln($t_{dur,q}/t_{typ,q}$)" is mathematically equivalent to the often found ln($t_{dur,q}/t_{0,q}$) for the normally used value of $t_{0,q} = t_{typ,q}/e$.

1 monetary position (caused by transport fares or tolls) Δm_q , the traveled distance $d_{trav,q}$ multiplied
 2 with the sum of the mode-specific monetary distance rate $\gamma_{d,mode(q)}$ multiplied with the agent-
 3 specific marginal utility of money and the mode-specific marginal utility of distance $\beta_{d,mode(q)}$ and
 4 the marginal utility of transfer when using pt multiplied with $x_{transfer,q}$, which counts the number
 5 of transfers between pt-lines. Compared to the travel utility function in (11), Equation 5 replaces
 6 the general marginal utility of money β_m by an agent-specific marginal utility of money $\beta_m \cdot \frac{y_{avg}}{y_a}$,
 7 as derived by (12). The above income-dependent marginal utility of money also impacts an agent's
 8 willingness to pay for saving time on travels, the value of travel time savings (VTTS):

$$9 \quad VTTS_{a,q} = \frac{-\beta_{trav} + \beta_{perf} \cdot \frac{t_{typ,q}}{t_{dur,q}}}{\beta_m \cdot \frac{y_{avg}}{y_a}}. \quad (6)$$

10 In Equation 6, the marginal utility of travel time savings (numerator) is monetized by dividing it
 11 by the (income-dependent) marginal utility of money. The marginal utility of travel time savings
 12 includes contributions of the time saved by a shorter travel time $-\beta_{trav}$ as well as implicit utility
 13 gains by performing an activity in the saved travel time $\beta_{perf} \cdot \frac{t_{typ,q}}{t_{dur,q}}$.

14 3.2 DRT simulation with the estimation-based approach

15 As mentioned in the introduction, there are several challenges and limitations with the simulation
 16 of DRT services by using the existing simulation approaches. A new approach based on the concept
 17 of estimate and teleport has been developed. The schematic drawing of this new approach is
 18 presented in Figure 1.

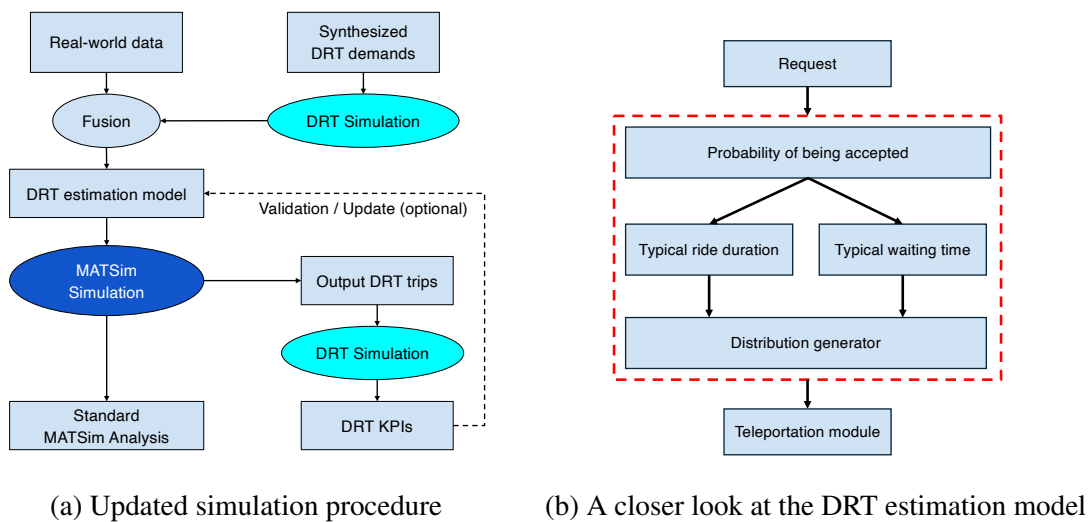


FIGURE 1: Illustration of the new simulation procedure with DRT

19 Figure 1a illustrates the new work flow of the simulation. The key idea of this new approach
 20 is to teleport DRT trips based on the DRT estimation model. Instead of simulating DRT systems
 21 explicitly within the main MATSim simulation loop, we first build a DRT estimation model accord-
 22 ing to real world data (when available) and systematic preliminary DRT simulations. The MATSim
 23 DRT extension (i.e., DRT Contrib) can be used to perform the preliminary DRT simulations based

1 on hypothetical demands. Other simulation or optimization tools can also be used to construct the
2 DRT estimation model.

3 During the MATSim simulation, no explicit DRT simulation will be carried out. This not
4 only speeds up the simulation procedure, but also reduces the potential noise and inaccuracy of
5 the output. After the MATSim simulation, the standard output, including mode share and potential
6 DRT trips, will be written out as usual.

7 In order to acquire the key performance indices (KPIs) of the DRT systems (e.g., required
8 fleet size, VKT, service quality experienced by each individual passenger), post-simulation can be
9 carried out based on the output DRT trips generated by the main simulation. The post-simulation
10 can be performed either with the MATSim DRT extension or other simulation or optimization tools.
11 Since the post-simulation is based on fixed DRT demand, there is no need to include a high number
12 of iterations as in the standard MATSim simulation procedure. This means the computational
13 workload for the post-simulation is also low. Furthermore, with a fixed demand, the output of the
14 DRT simulation is much more reproducible and reliable.

15 After the post-simulation, we can compare the simulated service quality to that in the esti-
16 mation model. If the service quality acquired from the post-simulation deviates significantly from
17 the originally estimated value, then we either adjust the setup for the DRT (i.e., for the case where
18 the service quality is pre-defined, and we need to reach the service quality with necessary number
19 of vehicles and other parameters) or update the DRT estimation model (i.e., for the case where the
20 DRT fleet and the operation parameters are fixed, and we need to determine the service quality we
21 can achieve). When we update the DRT estimation model, a new MATSim simulation needs be
22 performed based on the updated DRT estimation model (i.e., going through the optional validation
23 / update loop in the figure). This procedure can be repeated until the observed service quality from
24 the post-simulation matches the estimated value.

25 3.2.1 A closer look at the DRT estimation model

26 The DRT estimation model provides estimation for the following three parameters for each request:
27 waiting time, ride duration, and probability of the request being accepted. For the estimation of
28 waiting time and ride duration, a typical value will be generated. On top of the typical value, an
29 artificial disturbance can also be added, such that uncertainties and day-to-day fluctuations can be
30 simulated. Figure 1b summarize the work flow of the DRT estimation model.

31 *Estimation of the typical waiting time*

32 Typical waiting time $t_{wait,typical}(r)$ can be interpreted as the amount of time a passenger expects
33 to wait before a vehicle arrives. Depending on the available data and required level of details, the
34 typical waiting time can be constant or time-, location-, and person-dependent.

35 *Estimation of the typical ride duration*

36 To estimate the typical ride duration of a trip, we use a linear model. The typical ride duration
37 $t_{ride,typical}$ is calculated based on the direct car travel time t_{direct} on the network, taking into account
38 the traffic conditions at the departure time. A slope k and constant term C are then used to calculate
39 the typical ride duration of that trip:

$$40 \quad t_{ride,typical}(r) = k \cdot t_{direct}(r) + C \quad (7)$$

1 To identify the value of k and C , we can apply linear regression to real-world data or to the outputs
 2 of preliminary simulations based on synthesized demands.

3 By default, we assume the typical ride durations of all the requests follow the same model.
 4 When additional data is available, the parameters in the typical ride duration model can also be
 5 request-dependent (i.e., k and C become $k(r)$ and $C(r)$). The interface also allows a more complex
 6 relation (e.g., non-linear mapping) to be implemented.

7 *Modelling the uncertainty in DRT systems*

8 To simulate the day-to-day fluctuations and uncertainty in the DRT system, artificial disturbance
 9 can be applied to the estimated waiting times and ride durations. At each iteration, random numbers
 10 will be drawn from pre-defined random distribution models and they will be used to perturbate the
 11 estimated waiting time and ride duration of each trip individually:

$$12 \quad t_{wait,estimated}(r) = t_{wait,typical}(r) \cdot \gamma_1 \quad (8)$$

13

$$14 \quad t_{ride,estimated}(r) = t_{ride,typical}(r) \cdot \gamma_2 \quad (9)$$

15

$$16 \quad \gamma_1 \sim D_1 \quad (10)$$

17

$$18 \quad \gamma_2 \sim D_2 \quad (11)$$

19 Two common random distribution models are included in the infrastructure of the estimator: log-
 20 normal distribution and normal distribution.

21 The log-normal distribution is a suitable distribution model because of its non-negativity
 22 and a longer tail at the upper end. The probability density function (PDF) of a log-normal distri-
 23 bution is as follows:

$$24 \quad f(x) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left(-\frac{(\ln x - \mu)^2}{2\sigma^2}\right) \quad (12)$$

25 where $x > 0$. σ and μ are key parameters that determine the shape of the distribution. To deter-
 26 mine the values of σ and μ , we can perform data fitting based on real-world operational data or
 27 preliminary simulations.

28 When limited data or information about the distribution is available, the normal distribution
 29 is a good alternative. It needs to be pointed out that the value of x in the normal distribution
 30 $\mathcal{X} \sim \mathcal{N}(\mu, \sigma^2)$ may be negative, which may cause some problems when interpreting the values
 31 (e.g., negative waiting time). As a result, special attention needs to be paid when creating the
 32 distribution. One simple way to solve this problem is to add an upper and/or lower bound to the
 33 values generated from the normal distribution. If a value is below the lower bound (e.g., minimum
 34 waiting time is 0), then the lower bound value will be returned. And vice versa for the upper bound.
 35 This, however, may change the mean value of the distribution. A correction mapping of the values

1 may be necessary. The correction mapping can be built based on the average value of the modified
 2 normal distribution (μ') and the average value of the original normal distribution (μ):

$$3 \quad c(x) = \frac{\mu}{\mu'} \cdot x \quad (13)$$

4

$$5 \quad \mu' = \int_a^b xf(x)dx + \int_{-\infty}^a f(x)dx \cdot a + \int_b^{\infty} f(x)dx \cdot b \quad (14)$$

6 where a and b are the lower and upper bound, respectively. $f(x)$ is the distribution function of the
 7 original normal distribution $\mathcal{N}(\mu, \sigma^2)$.

8 If neither of the above-mentioned random distribution models can properly describe the
 9 distribution of the ride duration and waiting time in the DRT system, then a custom distribution
 10 model can be constructed. An interface is provided for the implementation of custom distributions.

11 As indicated in the Equation 8 to 11, the two distribution models D_1 and D_2 are indepen-
 12 dent. That is to say, distributions with different parameters or even different distribution types can
 13 be used for the waiting time estimation and ride duration estimation respectively.

14 *Probability of rejection*

15 In the actual operation of the DRT, especially for private operators, it is possible that some of the
 16 requests are rejected due to various reasons. In order to simulate this situation, the estimation
 17 for rejection is included. Similar to the waiting time estimation, the probability of being rejected
 18 can be a constant value throughout the service area. It can also be location-, time-, and request-
 19 dependent. For the cases where we do not want to include rejections (e.g., for transport planning),
 20 we can simply set the probability of rejection to 0.

21 It is to be noted that, if a DRT request is rejected in the MATSim simulation, the agent
 22 will either get stuck at that leg, causing the subsequent elements in the plan to be abandoned, or
 23 “walk” to the destination (i.e., teleported to the destination at the speed of walking). In either case,
 24 it is likely that the agent will end up with a rather poor score. This may lead to some additional
 25 fluctuation in the mode choice. Therefore, special care needs to be given when the probability of
 26 rejection is set to a non-zero value.

27 **3.3 Transport model setup**

28 This study introduces the MATSim Open Lausitz Scenario version 2.0. It models transport demand
 29 and supply for the Lausitz region, which is situated in East-Germany. The exact spatial model
 30 scope is depicted in Figure 2.

31 *3.3.1 Demand*

32 The passenger transport demand is derived based on mobile phone data from the a Germany-wide
 33 mobility model. The passenger demand represents a typical weekday (Tuesday to Thursday) and
 34 includes all synthetic agents that a) perform at least one activity in the study area (see Figure 2) or
 35 b) cross the study area when traveling (15).

36 Goods traffic is accounted for in two facets: The long-distance freight traffic in the study
 37 area is cut out from a Germany-wide freight model, developed by (16). The trips in the freight
 38 model are based on data from the German Federal Ministry of Transport (BMV) and calibrated

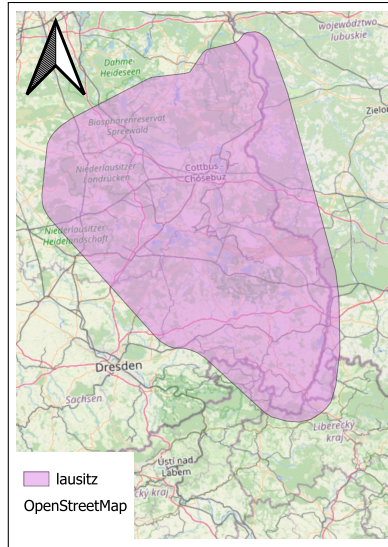


FIGURE 2: Spatial model scope of the MATSim Open Lausitz Scenario. Own illustration based on (13, 14).

1 against count data from the German Federal Highway and Transport Research Institute (BASt). It
 2 includes domestic as well as international long-distance freight trips.

3 Additionally to the long-distance freight trips, small scale commercial traffic trips based on
 4 a model by (17) are included into the MATSim Open Lausitz Scenario. Hence, the long-distance
 5 freight traffic displays goods shipped to regional hubs, from which it is then distributed into to
 6 study area by the small scale commercial traffic.

7 3.3.2 Supply

8 On the supply side, we create and adapt the traffic network – including link capacities, allowed
 9 transport modes, allowed speed, length, road type and number of lanes – based on (14), down-
 10 loaded on 2023-01-01. The transport network has a finer granularity in the Lausitz region (up to
 11 residential streets) and is more coarse in the rest of Germany (only motorways and primary roads
 12 included). The schedule for pt is added based on General Transit Feed Specification (GTFS) data
 13 for Germany for 2023-01-11 (18).

14 3.3.3 Transport modes

15 In the base transport model, agents are allowed to travel with transport modes bike, car (as a driver),
 16 pt, ride (car as a passenger) and walk(ing). Here, bike and car are so-called network modes, which
 17 means that for these modes paths of agents are routed and simulated on the transport network.
 18 Walking agents are modeled by multiplying the Euclidean distance between a walk-leg's origin
 19 and destination with a beeline factor of 1.3, which approximates a routed distance without having
 20 to implement a fine-grain network of walking links – also known as teleported mode. Ride (car as
 21 a passenger) is a somewhat hybrid transport mode. Routes are calculated based on the transport
 22 network, but ride users are teleported based on the calculated network route's travel time. This is
 23 done for computational reasons. pt is fully based on the input GTFS schedule. Thus, pt vehicles
 24 do not share network links with network modes car and bike (see above), but operate on a dummy
 25 links, which are Euclidean connection between transit stops. The speed on the pt specific network

1 links is set such that travel times match the transit schedule.

2 3.3.4 Replanning strategies

3 The agents of the different synthetic subpopulations – person, long-distance freight and small
4 scale commercial traffic – are assigned different sets of replanning strategies between iterations.
5 Person agents may change the route for some legs, change the transport mode of some legs (with
6 constraints), move starting/end time of activities or switch to another plan of their set of plans.
7 Long-distance freight agents as well as small scale commercial traffic agents may change their
8 route or switch to another plan of their set of plans.

9 3.3.5 Scoring parameters and cost

10 For transport modes car and ride – additionally to the pure travel (dis)utilities – different cost
11 components are applied. In addition to the distance based monetary distance rate ($-2.5 \text{ Eu}/m$; see
12 Equation 5), car users have to pay a daily monetary constant ($-13.22 \text{ Eu}/d$), which is not included
13 into the travel (dis)utility in Equation 5. Both cost values for car are calculated based on (19–23).
14 The calculation is displayed in Table 7 in the supplementary material of this study. With the
15 ride mode we approximate the marginal utility of traveling and monetary distance rate associated
16 with the ride itself plus the monetary distance rate which is caused for the driver. This is done
17 because we assume that additionally to the dis(utility) of the ride trip itself, the rider also loses the
18 opportunity to perform an activity during that time which is paid for by the passenger/ride user.
19 However, due to computational reasons, we do not physically simulate ride, but teleport it. Thus,
20 the marginal utility of traveling for transport mode ride is calculated as follows:

$$21 \quad \beta_{trav,ride} = (\alpha_{ride} + 1.0) * \beta_{trav,car}. \quad (15)$$

22 The monetary distance rate for transport mode ride only considers the cost for the driver and the
23 passenger, it has no opportunistic component:

$$24 \quad \gamma_{dist,ride} = \alpha_{ride} * \gamma_{dist,car}. \quad (16)$$

25 Based on Equations 15 and 16 the marginal utility for transport mode ride is $-12 \text{ utils}/h$ and the
26 monetary distance rate $-5.0 \cdot 10^{-4} \text{ Eu}/m$ (also see Table 1). The parameter α_{ride} ranges between
27 1.0 (no additional dis(utility) for the driver because the agent would have taken the trip even with-
28 out taking along the passenger) and 2.0 (the driver takes this trip only because he/she has to give
29 the passenger a ride). The value for α_{ride} potentially differs between different scenario setups (e.g.
30 urban vs. rural area). Therefore, it is calibrated (see Section 3.3.6).

31 Transport fares of mode pt are handled via a combination of a fare zone based and a dis-
32 tance base approach: As the case study in Section 4 concentrates on the city of Hoyerswerda, the
33 corresponding pt fare zone and its trip fare of $2.3 \text{ Eu}/ride$ is implemented. It is valid for all pt trips
34 starting and ending in the fare zone. All other trips are priced based on a Germany-wide distance
35 based fare (24). All of the above cost values are based on data from different years. Therefore,
36 they are projected to the reference year 2021 using the German consumer price index. All used
37 cost values are displayed in Table 1.

38 The mode parameters for all freight-related modes are adopted from their respective models
39 (see Table 6 as well as Section 3.3.1).

1 3.3.6 Model calibration

2 All of the above parameters impact the calibration of the transport model. The model is recognized
 3 as calibrated when the modal split in the study area matches a reference modal split. For this
 4 model, the reference modal split is filtered out of the Germany-wide household survey on mobility
 5 *Mobilität in Deutschland* (mobility in Germany) (MiD) 2017 (25). The target modal split is reached
 6 by automatically adapting the ASC (see Equation 5) per mode based on (26). Moreover, the
 7 model's modal distance distribution has to match the reference modal distance distribution, which
 8 is also extracted from MiD 2017. Calibration of the modal distance distribution is achieved by a)
 9 adapting the marginal utility of traveling $\beta_{trav,mode(q)}$ of Equation 5 where applicable. E.g., cycling
 10 long distances might be more uncomfortable than other modes because of the physical effort it
 11 takes, thus the marginal utility of traveling is adapted.

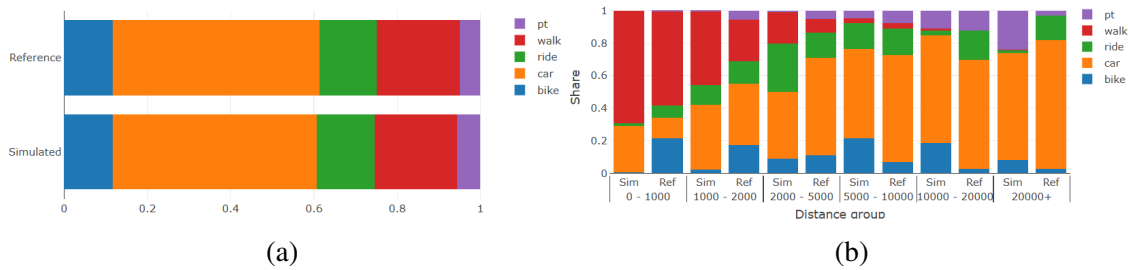


FIGURE 3: Simulated modal split (3a) / distance distribution (3b) vs. reference (MiD 2017) modal split / distance distribution. Own illustration based on (27).

12 Figure 3 shows the model's general calibrated modal split as well as the calibrated modal
 13 distance distribution compared to their references (for the study area displayed in Figure 2). The
 14 resulting values for ASC and marginal utilities of traveling per mode are shown in Table 1.

TABLE 1: MATSim parameters used in the Open Lausitz Model. Empty cells: Values equal zero.

mode	bike	car	pt	ride	walk
daily monetary constant [€]		-13.22			
ASC [util]	-2.22	0.29	-2.46	-0.39	
marginal utility of distance [util/m]					
marginal utility of traveling [util/hr]	-4.0			-12.0	
monetary distance rate [€/m]		-0.00025		-0.00050	
marginal utility of money [€/util]			1.0		
marginal utility of late arrival [util/h]			-18.0		
base marginal utility of performing [util/h]			6.0		

15 3.3.7 Hard facts

16 The MATSim Open Lausitz Scenario is simulated in a scale of 10%, which means that one agent
 17 in the model represents 10 persons in reality. This is done due to computational reasons. The
 18 resulting population contains 119055 agents, which travel on a network with 474764 links and
 19 264369 nodes. The capacity of the network links is adapted according to the above mode scale.

1 4 CASE STUDY

2 In this section, we define the setup of DRT service areas which are simulated with MATSim. The
3 setup is based on two trains of thought:

4 • First, through a Decision theater (DT) involving citizens of Hoyerswerda we learned that
5 residents are unhappy with the pt connection between Hoyerswerda and Cottbus. To
6 get from Hoyerswerda to Cottbus, one has to travel to Hoyerswerda main station, take
7 the train to Ruhland and change trains to a connection to Cottbus. There is no direct
8 connection between the two cities.

9 Based on the previous, three different service area setups are defined. Agents located in
10 Hoyerswerda are allowed to travel by DRT to

- 11 1. Ruhland railway station,
- 12 2. Ruhland railway station or Spremberg railway stations or
- 13 3. the two mentioned or Cottbus main station.

14 The railway stations in Ruhland and Spremberg both offer direct connections to Cottbus
15 and other bigger cities like Dresden, Leipzig or Görlitz.

16 • Second, an Origin-Destination (OD) analysis for trips to/from Hoyerswerda (see Table 8)
17 shows that a high number of trips start/end in Bautzen, Bernsdorf, Kamenz, Senftenberg,
18 Spremberg-Schwarze Pumpe and Weißwasser.

19 Thus, two additional service area setups are defined:

- 20 4. Enabling DRT rides between Hoyerswerda and Ruhland railway station as well as the
21 city of Spremberg – including the railway stations and its district Schwarze-Pumpe.
- 22 5. Service area setup 5) includes all the previously mentioned areas plus service areas in
23 the surrounding cities Bautzen, Bernsdorf, Kamenz, Senftenberg and Weißwasser.

24 The service area setups are summarized in Table 2.

25 All five service area setups include a base service area in and around Hoyerswerda. Addi-
26 tionally to the connections to/from the mentioned railway stations and cities, agents are allowed to
27 travel within this area by DRT. It is the only area which allows internal DRT trips.

28 Figure 4 shows all single service areas including the base service area, which is split into
29 two parts: The smaller area displaying the city borders of Hoyerswerda and the bigger one a radius
30 of around 10 km around Hoyerswerda. The service areas are used to create a DRT stop for every
31 link inside the given shapes.

32 The above service area setups (also see Table 2 and Figure 4) are simulated with DRT
33 vehicles with a capacity of one passenger. This means that DRT passengers are not pooled. All
34 service area setups apply a DRT fare equal to pt. In general, the modal parameters for transport
35 mode DRT are configured equal to the modal parameters for transport mode pt. It is meant to be
36 a feeder transport mode to/from railway stations with potential additional value of traveling in and
37 around Hoyerswerda or to highly frequented cities surrounding Hoyerswerda.

38 In this study, the DRT estimation approach described in Section 3.2 is used. It allows for
39 faster simulation of DRT by splitting it up into two steps (see Section 3.2). For the first estimation

TABLE 2: All simulated service area setups. For geographical location and size of the different areas, see Figure 4.

Case	Service Areas
Ruhland	Hoyerswerda, Hoyerswerda extended, Ruhland railway station
Ruhland-Spremberg	Hoyerswerda, Hoyerswerda extended, Ruhland railway station, Spremberg railway station
Ruhland-Spremberg-Cottbus	Hoyerswerda, Hoyerswerda extended, Ruhland railway station, Spremberg railway station, Cottbus main station
Ruhland-Spremberg-Schwarze Pumpe	Hoyerswerda, Hoyerswerda extended, Ruhland railway station, Spremberg railway station, Spremberg-Schwarze Pumpe
Regional DRT	Hoyerswerda, Hoyerswerda extended, Ruhland railway station, Spremberg railway station, Spremberg-Schwarze Pumpe, Cottbus main station, Bautzen, Bernsdorf, Kamenz, Senftenberg, Weisswasser

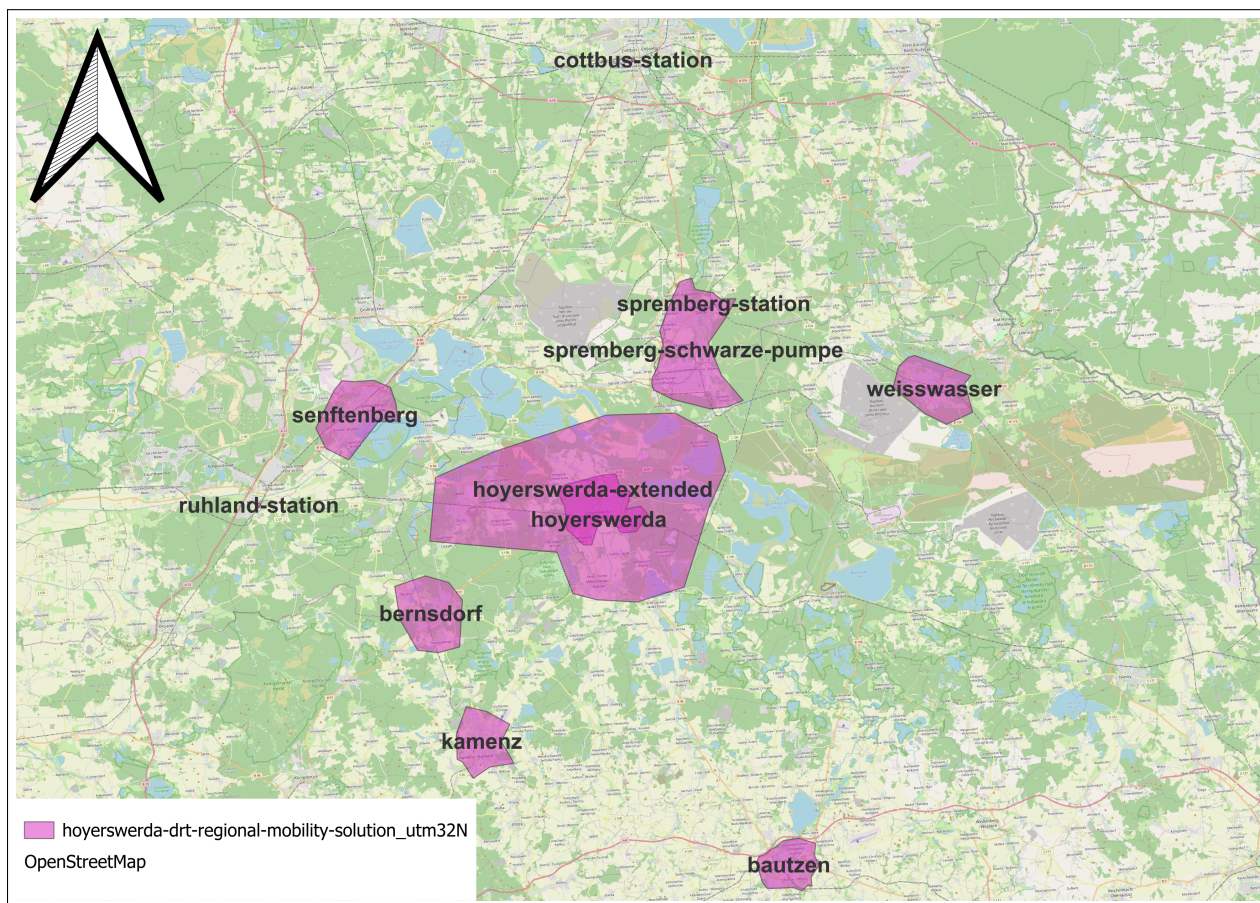


FIGURE 4: Regional DRT service area. This includes all the single service areas for the other service areas setups. Own illustration based on (13, 14).

1 step we need a typical waiting time for each service area which is why Hoyerswerda is split into

1 two different service areas. The service area outlining the city borders of Hoyerswerda has a typical
 2 waiting time of 300 s, the one surrounding Hoyerswerda a typical waiting time of 600 s.

3 As shown in Equations 7 and 9, the estimated DRT ride time consists of the linear typical
 4 ride time multiplied with a normal distribution of the ride time. For the calculation of the typical
 5 ride time parameters k and C in Equation 7 are set to 1.0 and 0 respectively. The values are justified
 6 by a) the simulation of DRT vehicles with a capacity of 1 passenger per vehicle which means that
 7 no detours due to other passengers in the same DRT vehicle are expected (see above) and b) the
 8 fact that the DRT service exclusively operates in a rural area, where the potential of traffic jams
 9 impacting the ride time is low. The above leads to $t_{ride,typical} = t_{direct}$.

10 The typical waiting time for each policy run is set to 900s, which is assumed to be the
 11 highest acceptable waiting time for a DRT ride. As this study applies specific waiting times for
 12 different DRT service areas the estimation algorithm ensures that the lower value of the aforemen-
 13 tioned is used as typical waiting time for a specific DRT service area. For the typical waiting time
 14 per DRT service area see Section 4. Similar to the estimation of the ride time, for the calculation of
 15 the estimated waiting time the typical waiting time is multiplied with a value drawn from a normal
 16 distribution (see Equation 8). The standard deviation for both normal distributions (as in ride time
 17 normal distribution and waiting time normal distribution) is set to 0.3, which was determined from
 18 existing previous DRT simulations. In this study, we set the probability of rejection to 0, meaning
 19 that all the requests will be served by the DRT system.

20 5 RESULTS

21 In this section, we analyze the various policy cases against the base case. All analyses only consider
 22 the subpopulation of those synthetic persons that use DRT in the policy case. Note that this implies
 23 that for each analysis the considered subpopulation in the base case is different, which is also why
 24 base case values vary from policy to policy.

25 5.1 General results

26 In this subsection, where applicable, values are scaled to 100%. Over all service area setups the
 27 number of DRT users ranges from 4370 to 9020 (see Table 3). The more service areas a case
 28 covers, the more agents use DRT. Case *Regional DRT* stands out, as it produces almost double the
 29 number of DRT users (9020) as the other cases (4370–5300 DRT users). This difference can also
 30 be seen in the number of DRT trips, where in case *Regional DRT* agents use DRT for 24700 trips
 31 and in the other cases for 12480–14450 trips.

TABLE 3: General statistics for all DRT policy cases. The statistics describe the respective subpopula-
 tions that use DRT in the policy case. This is also the reason why the base case values vary from policy
 to policy.

Case	Ruhland	Ruhland- Spremberg	Ruhland- Spremberg- Cottbus	Ruhland- Spremberg- Schwarze Pumpe	Regional DRT
DRT users	4,370	4,580	4,780	5,300	9,020
DRT trips total	12,480	12,760	13,480	14,450	24,700
Trips per user	2.86	2.79	2.82	2.73	2.74
DRT only trips	12,270	12,240	12,910	14,000	23,810

continued on next page

Case	Ruhland	Ruhland- Spremberg	Ruhland- Spremberg- Cottbus	Ruhland- Spremberg- Schwarze Pumpe	Regional DRT
DRT intermodal trips	210	520	570	450	890
DRT intermodal trip share	0.02	0.04	0.04	0.03	0.04
Fleet size	157	180	202	225	472
Mean travel time base [s]	1,736	1,891	1,951	2,032	2,365
Mean travel time policy [s]	1,486	1,637	1,685	1,693	1,968
Mean travel time gain [s]	249	254	266	339	397
Mean travel distance base [m]	8,447	9,827	10,428	10,535	14,064
Mean travel distance policy [m]	8,911	10,120	10,774	10,884	14,412
Mean trip velocity base [m/s]	4.87	5.20	5.35	5.19	5.95
Mean trip velocity policy [m/s]	5.99	6.18	6.40	6.43	7.32
Mean score base [util]	111	109	108	109	104
Mean score policy [util]	114	112	112	113	110

1 In all service area setups only 2% to 4% of the DRT trips are made in combination with a pt
2 ride. With 2% intermodal trips case *Ruhland* is the lowest of these. Compared to the other service
3 area setups the case features the lowest number of intermodal access/egress points between pt and
4 DRT which explains the lower share of intermodal DRT trips.

5 DRT fleet sizes vary from 157 vehicles in case *Ruhland* and 472 vehicles in case *Regional*
6 *DRT*. Please note that – as found in (28) – the scaling factor of for DRT fleet size is not proportional.
7 Thus, the above fleet sizes are the result of the fleet sizes obtained in the 10% MATSim policy cases
8 multiplied by a factor of 4.5 (see Figure 2(d) in (28)). In comparison to the base case, agents save
9 between 249s (case *Ruhland*) and 397s (case *Regional DRT*) on average when using DRT. This
10 translates into mean trip velocity gains of 5.99km/h to 7.32km/h for DRT trips. In contrast to
11 mean travel time and velocity, the mean travel distance over all cases increases by 293m to 464m
12 (compared to the base case). This is caused by differences in the routing algorithm. While network
13 routes (e.g. for transport mode car) are routed directly between the locations of two activities,
14 DRT routes are routed with detours to/from DRT stops. Although the DRT stop network is rather
15 detailed – one stop per link in the service area (see Section 4), detours may emerge because the
16 network of links in the transport model is rather coarse.

17 The increase in travel time and trip velocity ultimately more than compensate the increased
18 mean travel distances and leads to score gains. Depending on the service area layout the mean score
19 gain for DRT users ranges between 3 and 5. With the selected scoring function values (see 1), this
20 corresponds to between 30 and 50 minutes. This is much more than the travel time gains (cf.
21 Tab. 3); Sec. 5.2 will show that the monetary gains, i.e. synthetic travelers switching from self-paid
22 car to partially subsidized DRT, are much larger than the travel time gains.

23 Figure 5 shows the net income distribution of DRT users over all cases compared to the
24 general income distribution in the model. In general, the income distributions in all cases more
25 or less resemble the model's general net income distribution. We can observe differences in the
26 income groups of 500 € to 1499 €, where DRT users are overrepresented, and the income groups
27 starting from 1500 € upwards, where they are underrepresented (compared to the overall income
28 distribution). Thus, according to the simulation the DRT service is above-average attractive for
29 agents with a monthly net income from 500 to 1500 € than for more affluent agents. This is caused
30 by MATSim's built in income-dependency (see Section 3) which leads to less affluent agents using
31 transport modes bike and pt while more affluent agents use transport mode car. This translates into
32 something like "Agents who can financially afford to use a private car will do so" (as also found
33 in (9, 29)).

34 Figure 6 shows the modes of DRT trips in the base case. It reveals a similar modal shift
35 behavior for cases *Ruhland*, *Ruhland-Spremberg* and *Ruhland-Spremberg-Cottbus* (with some sta-
36 tistical noise). This is not surprising as the three service areas only differ in the number of served
37 intermodal railway stations. For the other two cases (*Ruhland-Spremberg-Schwarze Pumpe* and
38 *Regional DRT*) we can see that with increasing service area size the share of modal shifts from
39 pt and car increase, at the expense of ride and bike. For ride, the explanation of the decrease –
40 especially for case *Regional DRT* – lies in its rather low average trip distance of 5km, which is less
41 than half of the average trip distance for car (11.6km) and a fifth of the average trip distance for
42 pt (25.5km). In contrast to ride, bike trips have an average distance similar to car (9.6km). But, as
43 shown in Table 1, bike is assigned a marginal utility of traveling of -4 – also see Section 3 and
44 especially Equation 5 – which punishes bicycle trips with longer durations/distances. The former
45 causes the drop-off of modal shift from bike to DRT in case *Regional DRT*. Additionally, from the

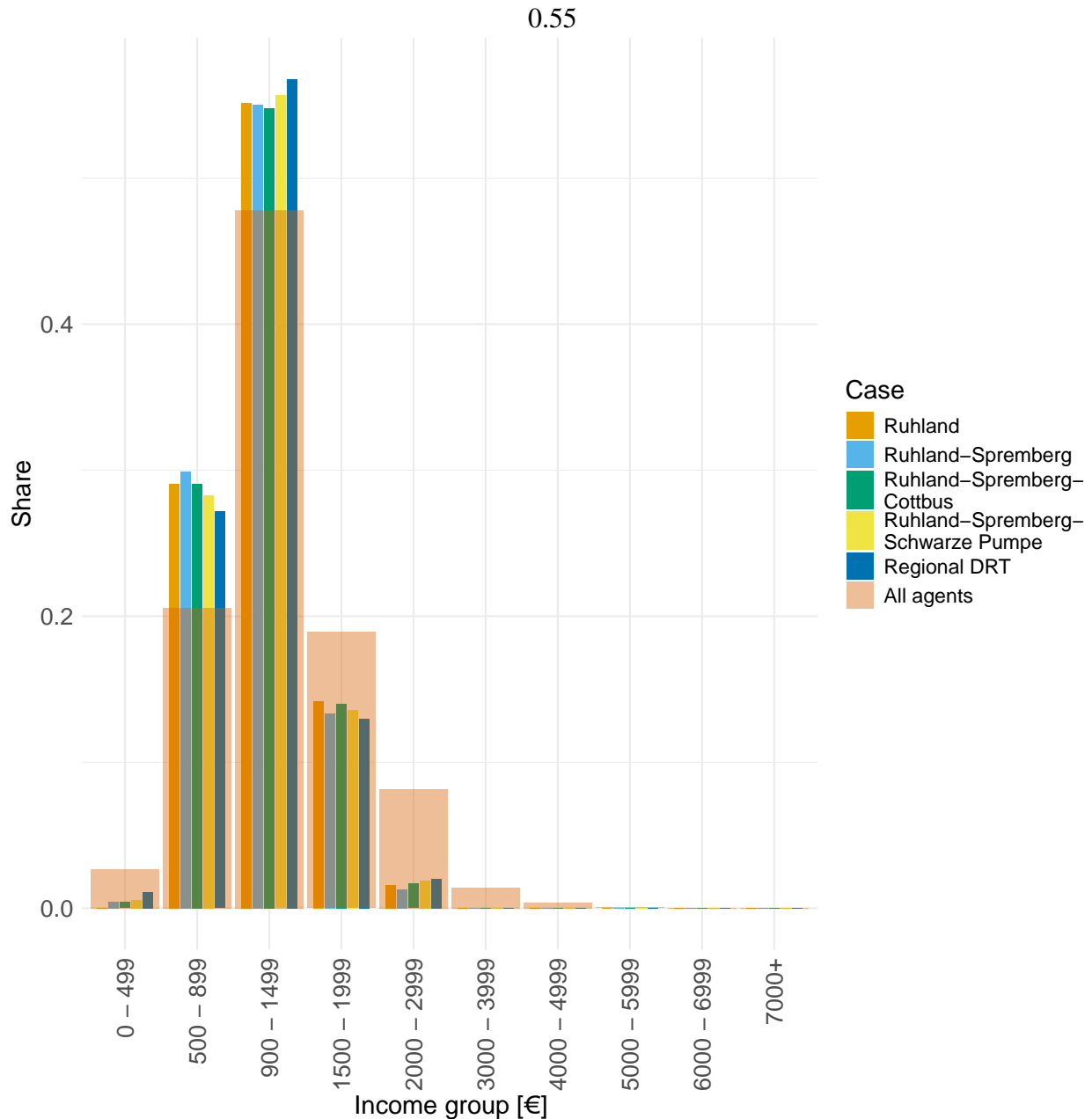


FIGURE 5: Net income distribution for all service area setups . Own illustration.

1 OD-relations in Table 8 we can see that for most of the OD-relations between the zones the share
 2 of bike trips is small ($\ll 10\%$). Only between Bernsdorf/Senftenberg and Hoyerswerda we can
 3 observe a share of bike trips $\geq 10\%$.

4 To understand the increase of modal shifts from pt and car in cases Ruhland-Spremberg-
 5 Schwarze Pumpe and Regional DRT we need to take a closer look at OD-relations between
 6 Schwarze Pumpe and Hoyerswerda as well as the cities covered by case Regional DRT and Hoy-
 7 erswerda in Table 8. The table shows that the majority of agents traveling between Hoyerswerda
 8 and the zones do so by car (51% to 76%) with pt trips in second place (11% to 45%). The high

1 shares of pt trips are somewhat surprising if one takes into account the general modal share of
 2 pt trips in the study area (5.5 %, see Figure 3a). The former and the mentioned long average
 3 trip distances for the two modes cause the increase in modal shifters to DRT for cases Ruhland-
 Spremberg-Schwarze Pumpe and Regional DRT. The above modal shifts lead to modal shares for

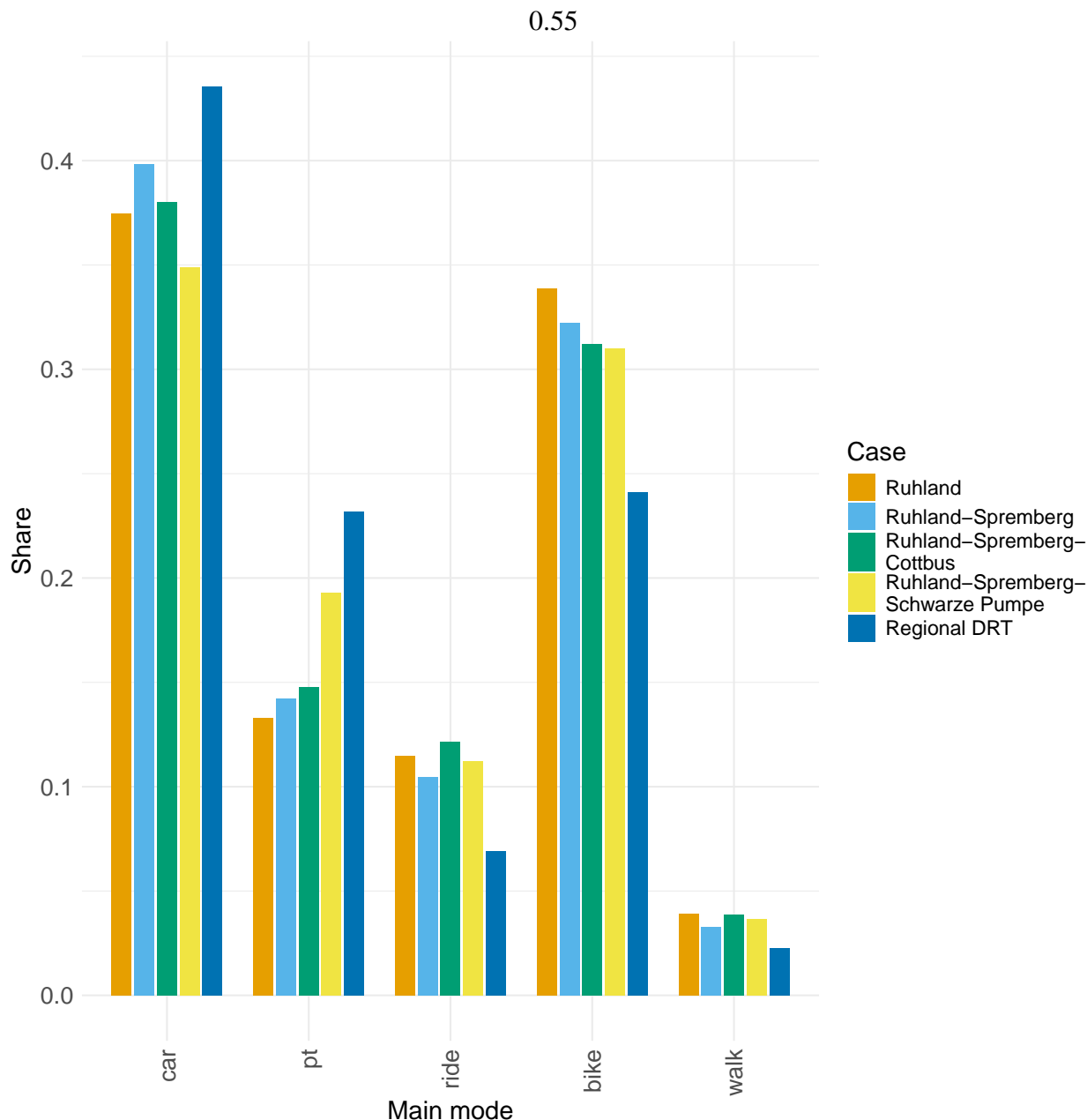


FIGURE 6: Mode of DRT trips in the base case per policy case. Own illustration.

4
 5 DRT of 3 % to 7 % for trips starting or ending in the DRT service area and of up to 1 % for the
 6 study area.⁶

⁶See Lausitz DRT Dashboard for modal shares in DRT service area and Trips Dashboard for modal shares of service area in: <https://vsp.berlin/simwrapper/public/de/lausitz/projects/DiTriMo/v2.0/>

1 Regarding spatial analysis DRT users mainly live in Hoyerswerda and surroundings. We
 2 see that with every additional service area residents from in and around that additional service area
 3 are attracted to the DRT service.

4 **5.2 Econometric assessment**

5 In this section, the benefits as well as cost for each DRT service area setup are compared.

6 *5.2.1 Benefit*

7 For users of the DRT service, the transportation model yields **monetized travel time gains** ranging
 8 from 1.4 M €/a to 5.2 M €/a. The pure travel time savings account for only a small portion of
 9 the total monetized benefit gains from the MATSim scores (approx. 1/3). The **monetized total**
 10 **score gains** derived from the MATSim scores for users of the DRT service range, depending on
 11 the service areas, from just over 5 M €/a to just under 16 M €/a. The difference between travel
 12 time gains and total utility gains arises in all service areas through savings in monetary costs. This
 13 benefit component is the largest single benefit component in all service area configurations (see
 14 Table 4).

TABLE 4: Econometric metrics **for DRT users** in all DRT policy cases compared to the base case. All values are scaled to 100%.

Case	Ruhland	Ruhland- Spremberg	Ruhland- Spremberg- Cottbus	Ruhland- Spremberg- Schwarze Pumpe	Regional DRT
Monetary benefit [util/d]	15,118	17,298	17,259	16,498	41,676
Time benefit [util/d]	4,170	3,762	4,181	7,106	14,166
Direct travel benefit [util/d]	-5,396	-6,156	-6,192	-5,077	-13,291
Overall score benefit [util/d]	13,892	14,904	15,248	18,526	42,551
Monetized score benefit [€/d]	13,892	14,904	15,248	18,526	42,551
Monetized score benefit [M €/a]	5.1	5.4	5.6	6.8	15.5

15 *5.2.2 Cost*

16 The costs per DRT service area configuration depend on the simulation output variables: fleet
 17 kilometers and number of fleet vehicles (see Table 5). The above parameters are combined with
 18 cost parameters from (19), which reviewed and further developed the vehicle cost calculation using
 19 the methodology of the German Federal Transport Infrastructure Plan (Bundesverkehrswegeplan).
 20 For example: In the ‘Ruhland Bhf’ service area, DRT mileage amounts to approx. 70,000 km/d;
 21 with a cost per km of just over 14 ct, this results in approx. 10,000 €/d. 157 vehicles are required.
 22 Hence, vehicles cost just under 40 k €/d; a maximum mileage of just over 220,000 km/vehicle
 23 is assumed; based on this and other assumptions, fixed costs per day for all 157 vehicles amount
 24 to just under 16 €/d. Labor costs for drivers are assumed to be 29.64 €/h; resulting in personnel
 25 costs of approximately 53 k €/d. This results in total costs of approximately 78 k €/d. Yearly,
 26 the above results in DRT operating costs of between just over 23 M €/a and just under 73 M €/a.
 27 At the same time, the DRT service generates additional revenue of between just under 4 M €/a and

- 1 approximately 9 M €/a. This results in a subsidy requirement of between just under 20 M €/a
 2 and just under 64 M €/a.

TABLE 5: Cost calculation per service area. All cost values are projected to 2021.

Case	Ruhland	Ruhland-Spremborg	Ruhland-Spremborg-Cottbus	Ruhland-Spremborg-Schwarze Pumpe	Regional DRT
Fleet distance (100pct) [km/d]	68260	80509	92228	100958	233377
No. fleet vehicles (100pct)	157	180	202	225	472
Vehicle operation time [h/vehicle-d]	11	11	11	11	11
Fix cost [€/vehicle-d]	97.43	100.13	101.72	100.4	109.2
Personnel cost [€/vehicle-h]	29.64	29.64	29.64	29.64	29.64
Distance cost [ct/km]	14.35	14.35	14.35	14.35	14.35
Total distance cost [€/d]	9798	11557	13239	14492	33500
Total personnel cost [€/d]	52552	60055	66701	70132	157460
Total fix cost [€/d]	15337	18014	20587	22580	51573
Total cost [€/d]	77687	89626	100527	107204	242534
Total cost [M €/a]	23.3	26.9	30.2	32.2	72.8
Total revenue [M €/a]	3.8	3.8	4.3	4.2	9.0
Total subsidy requirement [M €/a]	19.6	23.1	25.8	27.9	63.7

3 6 DISCUSSION

4 **All in all**, the effects of the DRT system are complex:

- 5 1. People who switch from pt to DRT pay the same amount of money but travel signifi-
 6 cantly faster.
- 7 2. People who switch from individual motorized transport to DRT travel less comfortably
 8 but pay significantly less money.
- 9 3. People who switch from other modes of transportation to DRT pay more money but
 10 travel faster.

11 In particular in the case of item 2, payments previously made privately are replaced by government
 12 financial support. Whether this is a viable approach in an era of tight budgets, and how it might
 13 be structured if implemented, remains an open (research) question at this point – for example,
 14 the On-Demand service KEXI in Kelheim, a similarly structured and very successful service, was
 15 discontinued due to the district's inability to bear the financial burden.

16 7 CONCLUSION

17 The presented study implemented the MATSim Open Lausitz Scenario in version 2.0. A DRT
 18 service was introduced into the model in five different service area setups. When analyzing utility
 19 gains of DRT users, it is crucial to differentiate between the different subgroups of mode switchers
 20 – e.g. agents switching to DRT from car rather gain utility from saving money while former bike
 21 users rather gain utility by saving travel time.

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9 SM, KN; **Resources:** SM, KN; **Software:** SM, CL, KN; **Supervision:** KN; **Validation:** SM, KN;
10 **Visualization:** SM; **Writing – original draft:** SM, CL, KN; **Writing – review & editing:** SM,
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1 8 SUPPLEMENTARY MATERIAL

2 8.1 Parameters of freight modes

TABLE 6: MATSim parameters for freight modes used in the Open Lausitz Model. Empty cells: Values equal zero.

mode	longDistanceFreight	truck8t	truck18t	truck40t
daily monetary constant [€]				
ASC [util]				
marginal utility of distance [util/m]				
marginal utility of traveling [util/hr]	-10.0	-6.0	-6.0	-6.0
monetary distance rate [€/km]	-0.002			

3 8.2 Car cost calculation

TABLE 7: Calculation of fix cost (per day) and distance based cost (per m) for car.

Vehicle Type		VW Golf 1,4 Trendline	
Model		VW Golf	
List price (excl VAT, incl. tires)	Eu	17406	see (19), Table 8-32
Cost of tires		431	see (19), Table 8-32
Life span	a	12	see (19), Table 8-32
Annual distance	km/a	11896	see (19), Table 8-32
Tire distance	km	50000	see (19), Table 8-32
Operating days per year	d/a	250	
Number of households in Germany	mio	39.722	see (20)
Number of private cars in Germany	mio	38.623	see (23)
Base year (= 2012) → 2021		1.12	Inflation based on (21)
Yearly			
Interest	Eu/a	147.95	Interest of 1.7% per year on list price, divided by two as approximation of interest paid over life span
Vehicle depreciation	Eu/a	1414.58	(list price - tires) / life span
Parking cost	Eu/a	403.00	see (19), Table 8-32
Mandated vehicle checks	Eu/a	49.00	see (19), Table 8-32
Insurance	Eu/a	352.61	see (22) p. 13. Div by # of households, mult by # of cars, div by 1.19 to remove VAT (re-added later).
Vehicle tax	Eu/a	103.71	see (22) p. 13. Div by # of households, mult by # of cars, div by 1.19 to remove VAT (re-added later).
Annual fixed costs without VAT	Eu/a	2470.86	
Annual fixed costs with VAT	Eu/a	2940.32	
Annual fixed costs per day with VAT	Eu/d	11.76	
Base year (= 2012) → 2021	Eu/d	13.22	Inflation based on price index; see (21).
Vehicle operational costs [Euro per km]			
Tire cost	Eu/100km	0.86	Cost of tires dived by tire distance
Repair cost	Eu/100km	7.48	see (19), Table 8-32
Distance-dependent variable cost without VAT (excluding energy)	Eu/100km	8.34	

Distance-dependent variable cost with VAT (excluding energy)	Eu/100km	9.93	
Base year (= 2012) → 2021	Eu/100km	11.16	
Energy			
Energy consumption (petrol)	l/100km	7.90	Petrol consumption as 59.244 g/km (fleet average 2010) from hbefa.net, divided by 750g/l.
Cost per liter (incl. VAT)	Eu/l	1.57	
Distance-dependent energy cost (incl. VAT)	Eu/100km	12.40	
Base year (= 2012) → 2021	Eu/100km	13.94	Inflation based on price index; see (21).
	ct/km	22.32	
	ct/km	24.72	
	ct/km	47.04	
Values for MATSim:			
Costs per day(fixed)	Eu/d	13.22	
Costs per meter (var. dist)	Eu/m	0.000251	

1 8.3 OD analysis

TABLE 8: OD-relations between different zones in the base case. For the zones, see Figure 4. Zone cottbus_extended is not a DRT service area, but a zone created for this OD-analysis with a radius of approx. 16 km around the city.

From	To	Main mode	Trips	Share
hoyerswerda-extended	cottbus_extended	all	1200	1.00
hoyerswerda-extended	cottbus_extended	car	760	0.63
hoyerswerda-extended	cottbus_extended	pt	390	0.32
hoyerswerda-extended	cottbus_extended	bike	50	0.04
cottbus_extended	hoyerswerda-extended	all	900	1.00
cottbus_extended	hoyerswerda-extended	pt	280	0.31
cottbus_extended	hoyerswerda-extended	car	580	0.64
cottbus_extended	hoyerswerda-extended	bike	40	0.04
hoyerswerda-extended	spremberg-schwarze-pumpe	all	2760	1.00
hoyerswerda-extended	spremberg-schwarze-pumpe	car	1810	0.66
hoyerswerda-extended	spremberg-schwarze-pumpe	pt	680	0.25
hoyerswerda-extended	spremberg-schwarze-pumpe	bike	240	0.09
hoyerswerda-extended	spremberg-schwarze-pumpe	walk	10	0.00
hoyerswerda-extended	spremberg-schwarze-pumpe	ride	20	0.01
spremberg-schwarze-pumpe	hoyerswerda-extended	all	2970	1.00
spremberg-schwarze-pumpe	hoyerswerda-extended	car	2010	0.68
spremberg-schwarze-pumpe	hoyerswerda-extended	bike	250	0.08
spremberg-schwarze-pumpe	hoyerswerda-extended	pt	680	0.23
spremberg-schwarze-pumpe	hoyerswerda-extended	ride	20	0.01
spremberg-schwarze-pumpe	hoyerswerda-extended	walk	10	0.00
hoyerswerda-extended	weisswasser	all	490	1.00
hoyerswerda-extended	weisswasser	pt	220	0.45
hoyerswerda-extended	weisswasser	walk	10	0.02
hoyerswerda-extended	weisswasser	car	250	0.51
hoyerswerda-extended	weisswasser	bike	10	0.02
weisswasser	hoyerswerda-extended	all	530	1.00
weisswasser	hoyerswerda-extended	car	320	0.60

From	To	Main mode	Trips	Share
weisswasser	hoyerswerda-extended	pt	200	0.38
weisswasser	hoyerswerda-extended	bike	10	0.02
hoyerswerda-extended	bautzen	all	480	1.00
hoyerswerda-extended	bautzen	car	310	0.65
hoyerswerda-extended	bautzen	pt	150	0.31
hoyerswerda-extended	bautzen	bike	20	0.04
bautzen	hoyerswerda-extended	all	400	1.00
bautzen	hoyerswerda-extended	pt	130	0.32
bautzen	hoyerswerda-extended	car	260	0.65
bautzen	hoyerswerda-extended	walk	10	0.03
hoyerswerda-extended	kamenz	all	2190	1.00
hoyerswerda-extended	kamenz	car	1670	0.76
hoyerswerda-extended	kamenz	pt	400	0.18
hoyerswerda-extended	kamenz	bike	120	0.05
kamenz	hoyerswerda-extended	all	1970	1.00
kamenz	hoyerswerda-extended	pt	360	0.18
kamenz	hoyerswerda-extended	car	1480	0.75
kamenz	hoyerswerda-extended	ride	20	0.01
kamenz	hoyerswerda-extended	walk	20	0.01
kamenz	hoyerswerda-extended	bike	90	0.05
hoyerswerda-extended	bernsdorf	all	2630	1.00
hoyerswerda-extended	bernsdorf	car	1650	0.63
hoyerswerda-extended	bernsdorf	pt	430	0.16
hoyerswerda-extended	bernsdorf	bike	530	0.20
hoyerswerda-extended	bernsdorf	ride	10	0.00
hoyerswerda-extended	bernsdorf	walk	10	0.00
bernsdorf	hoyerswerda-extended	all	2750	1.00
bernsdorf	hoyerswerda-extended	car	1840	0.67
bernsdorf	hoyerswerda-extended	pt	400	0.15
bernsdorf	hoyerswerda-extended	bike	480	0.17
bernsdorf	hoyerswerda-extended	ride	10	0.00
bernsdorf	hoyerswerda-extended	walk	20	0.01
hoyerswerda-extended	senftenberg	all	1900	1.00
hoyerswerda-extended	senftenberg	car	1410	0.74
hoyerswerda-extended	senftenberg	ride	30	0.02
hoyerswerda-extended	senftenberg	bike	240	0.13
hoyerswerda-extended	senftenberg	pt	210	0.11
hoyerswerda-extended	senftenberg	walk	10	0.01
senftenberg	hoyerswerda-extended	all	2000	1.00
senftenberg	hoyerswerda-extended	car	1520	0.76
senftenberg	hoyerswerda-extended	bike	200	0.10
senftenberg	hoyerswerda-extended	ride	20	0.01
senftenberg	hoyerswerda-extended	walk	20	0.01
senftenberg	hoyerswerda-extended	pt	240	0.12