

THE POTENTIAL OF DEMAND RESPONSIVE TRANSPORT AS A
COMPLEMENT TO PUBLIC TRANSPORT: AN ASSESSMENT
FRAMEWORK AND AN EMPIRICAL EVALUATION.

Prepared for the 97th Annual Meeting of the Transportation Research Board 2018

Submission date: 1st August 2017

Submission date after re-review: 6th November 2017

Word Count: Text (5999) (incl. abstract: 156) + tables/figures (6*250=1500) = 7499 words

María J. Alonso-González (corresponding author)

Delft University of Technology
Faculty of Civil Engineering and Geosciences
Transport & Planning
P.O. Box 5048
2600 GA Delft, The Netherlands
Telephone: +31 6 152784066
Fax number: +31 15 273179
Email Address: M.J.AlonsoGonzalez@tudelft.nl

Theo Liu

Delft University of Technology
Faculty of Civil Engineering and Geosciences
Transport & Planning
P.O. Box 5048
2600 GA Delft, The Netherlands
Telephone: +31 6 152789341
Fax number: +31 15 273179
Email Address: T.L.K.Liu@student.tudelft.nl

Oded Cats

Delft University of Technology
Faculty of Civil Engineering and Geosciences
Transport & Planning
P.O. Box 5048
2600 GA Delft, The Netherlands
Telephone: +31 6 152781384
Fax number: +31 15 273179
Email Address: O.Cats@tudelft.nl

Niels Van Oort

Delft University of Technology
Faculty of Civil Engineering and Geosciences
Transport & Planning

P.O. Box 5048
2600 GA Delft, The Netherlands
Telephone: +31 6 15908644
Fax number: +31 15 273179
Email Address: N.vanOort@TUDelft.nl

Serge Hoogendoorn

Delft University of Technology
Faculty of Civil Engineering and Geosciences
Transport & Planning
P.O. Box 5048
2600 GA Delft, The Netherlands
Telephone: +31 6 15278575
Fax number: +31 15 273179
Email Address: S.P.Hoogendoorn@TUDelft.nl

1 **ABSTRACT**

2 Demand Responsive Transport (DRT) offers a collective flexible travel alternative that can
3 potentially complement Fixed Transit (FT). The combination of an on-demand and line-based
4 services holds the promise of improved mobility and increased service coverage. However,
5 insofar it remains unknown whether DRT services deliver such much anticipated improvements.
6 This study presents an assessment framework to evaluate the performance of DRT and related
7 changes in accessibility and performs an empirical analysis for a recently introduced DRT
8 service in the Netherlands. The framework includes a performance benchmark between DRT and
9 FT based on the computation of generalized journey times of the DRT rides and the FT
10 alternatives, and it can help identify whether DRT is used as complement or substitute of FT.
11 The framework covers the spatial and temporal dimensions, and the explicit consideration of
12 rejected trips is an integral part of the evaluation. Results suggest large accessibility
13 improvements for DRT users, especially for some underserved origin-destination pairs.

1 INTRODUCTION

2 Reducing car use is high on the agenda for transportation planners, yet the flexibility and
3 convenience that car provides makes it often a more attractive alternative than traditional fixed
4 transit (FT). To compete with private car use, line-based FT can benefit from embracing new
5 flexible services that have appeared in urban areas so as to improve and complement its services.
6 Specially, Demand Responsive Transport (DRT) services (sometimes also known as collective
7 on-demand services or paratransit), can potentially complement FT in urban areas.

8 Even if DRT services are not a new innovation (they were already recommended for the
9 future urban transportation in the sixties (1)), only recent technological advancements have
10 enabled their real-time large scale operation. As a result, new urban DRT services have
11 appeared, both in the USA (e.g., Bridj, Lyftline, UberPOOL, Via) and in Europe (such as Abel in
12 Amsterdam, Kutsuplus in Helsinki, Padam in Paris or Radiobus di Quartiere in Milan). To better
13 understand the utilization of these services and the role they play in relation to FT, a systematic
14 assessment framework is proposed in this study.

15 Several studies have aimed at helping planners design DRT systems. These studies help
16 estimating the needed capacity for a given level of service and the resulting operating costs (2),
17 or assessing if DRT should substitute FT for a given scenario (3), (4). Research has also
18 evaluated via simulation the impact that DRT services would have in real urban networks, such
19 as in Hino (Japan) (5), Lisbon (Portugal) (6) or New York City (USA) (7). However, little is
20 known about how these services perform in real settings. A notable exception is Kutsuplus,
21 “apparently the world’s first fully automated, real-time demand-responsive public transport
22 service” (8), which operated between 2012 and 2015 in Helsinki, and for which a final project
23 report is available. However, despite Kutsuplus being implemented as part of the public transport
24 system, its final report does not include an analysis on the extent to which the new service
25 improved the mobility in comparison to the already existent alternatives.

26 This study fills this gap by introducing a DRT assessment framework that analyzes the
27 improvement in mobility that a DRT system adds to the transportation network based on
28 empirically observed usage patterns. Current DRT assessment frameworks contemplate the
29 concept of DRT at high level without including concrete indicators (9) or focus on Key
30 Performance Indicators (KPI) that consider DRT in isolation from other modes (10). In this
31 study, the accessibility gains (i.e., the increased easiness to reach the required or desired
32 activities (11)) that DRT granted for the performed trips are examined.

33 The main objective of this study is to help transportation authorities in assessing the
34 improvement in mobility that DRT users have experienced in relation to the co-existing FT
35 alternatives. After a detailed description of the framework, it is applied to a DRT system in the
36 Netherlands. Based on the observed results, the impacts of DRT as a complement to FT are
37 discussed.

38 39 METHODOLOGY

40 The proposed DRT assessment framework covers three aspects. First, it analyzes the DRT
41 system characteristics. Second, it examines DRT operation, involving both DRT usage and
42 performance. Last, based on the operational characteristics of the system, a series of accessibility
43 indicators are examined. This framework is depicted in FIGURE 1 and its components are
44 detailed in the subsequent sub-sections.

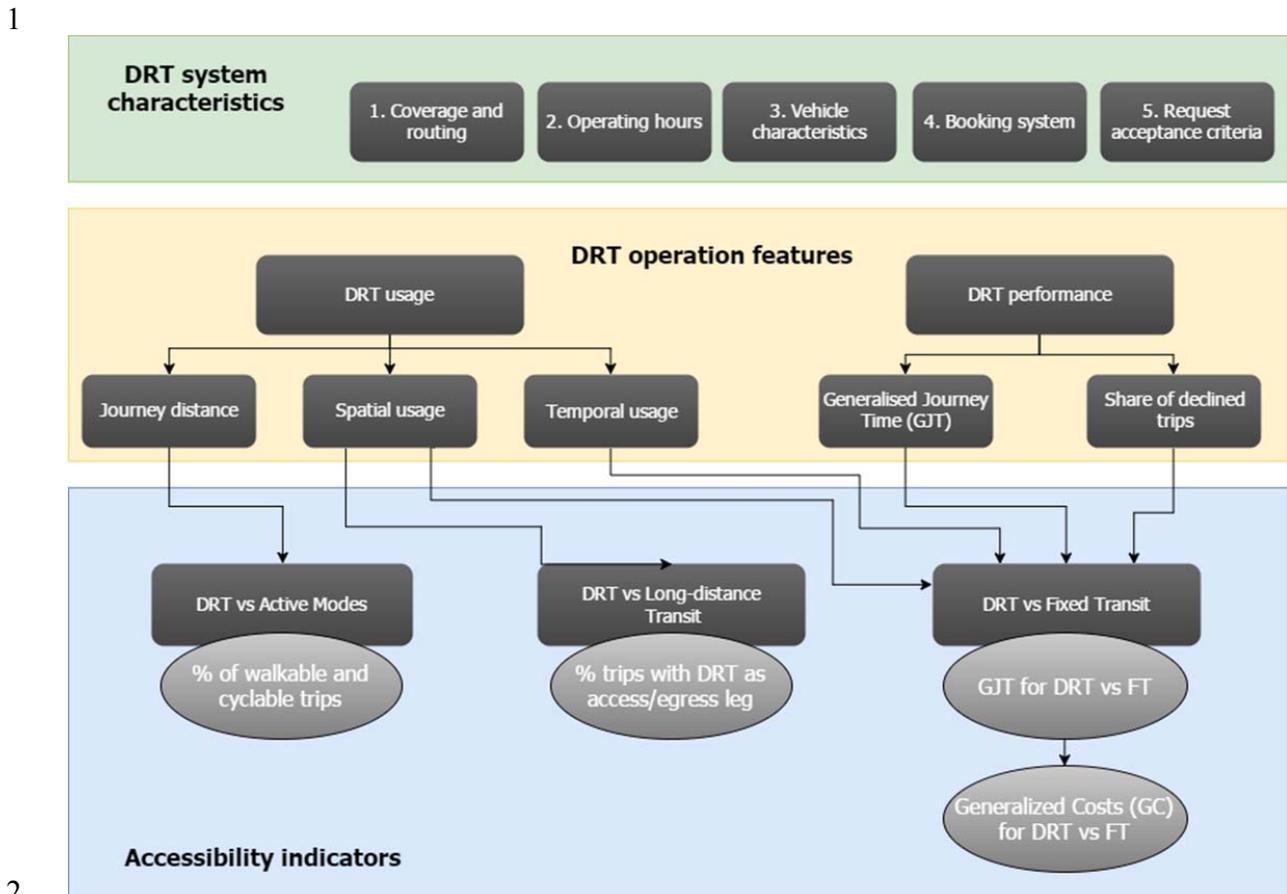


FIGURE 1 Assessment Framework.

DRT System Characteristics

Before analyzing the DRT operation, it is necessary to understand the intrinsic characteristics of the system under consideration (upper box of FIGURE 1). We highlight five aspects of the DRT system:

1. Coverage and routing. Defined by the operating area and the degree of flexibility in the operation. The latter can range from a fully flexible door-to-door service, to more rigid configurations where only partial deviations from a planned route are possible.
2. Operating hours. Equivalent to the service span considered in FT.
3. Vehicle characteristics. DRT fleets often consist of minibus vehicles, with previous research suggesting that a vehicle capacity of eight is the preferred vehicle size (12). Fleet size is also a key design variable of DRT systems since it will determine the different routes that can be covered simultaneously by the system.
4. Booking system. The system can allow for instant bookings in real-time, require advanced bookings or allow for both options. Traditionally, dial-a-ride schemes relied on telephone reservations, but large-scale real-time DRT systems require internet connection to perform the bookings in an efficient manner.
5. Request acceptance criteria. Time required to the pick-up point or vehicle availability are the often used criteria in deciding whether a request is accepted or rejected.

1 **DRT Operation Features**

2 Because of its inherently dynamic interaction with demand, DRT performance is directly tied to
3 its usage (13). As such, both aspects are an integral part in DRT operation (see middle box of
4 FIGURE 1).

5 6 *DRT usage*

7 DRT usage is analyzed in terms of demand patterns. Three important aspects can be highlighted:
8 journey distance, spatial usage patterns and temporal usage patterns. Journey distance can
9 provide insights into the modes that would compete with DRT. For instance, short trips might
10 substitute walking and cycling. The analysis of spatial usage reveals which origins, destinations
11 and routes are most frequently used. This can shed light on areas with high demand which may
12 not be conveniently served by FT. Lastly, the temporal usage identifies peaks in the operation,
13 both by time of the day and by day of the week. Traditionally, transport demand in general and in
14 particular public transport services tend to exhibit two daily peaks, following commuting
15 patterns. Since shopping and social trips have been identified as the most recurrent trip purposes
16 for DRT trips (14), different temporal usage patterns might be expected for DRT.

17 18 *DRT operation*

19 Regarding DRT operation, the presented framework considers two aspects: the Generalized
20 Journey Time (GJT) and the share of declined trips. The GJT represents the perceived passenger
21 journey time. It is calculated by multiplying the time of the different segments of the door-to-
22 door journey by different weighting factors so as to transform them into equivalent in-vehicle
23 time (15). The different segments to take into account are the walking time (t^f), the waiting time
24 (t^w), the in-vehicle time (t^v), and the number of transfers (n^t). The GJT can be expressed as

$$25 \quad GJT = \alpha_f \cdot t^f + \alpha_w \cdot t^w + t^v + \alpha_t \cdot n^t,$$

26 where α represent the different weighting factors. The estimation of these α has been the subject
27 of a large number of public transport studies, e.g., (16), (17). It is important to note that the
28 waiting time can be expected or unexpected, with unexpected waiting time being valued by
29 passengers as 2-3 times longer than expected waiting times (18). As such, an accurate and up-to-
30 date forecast of the pick-up times in DRT services is of outmost importance to lower GJT.

31 This study also includes the share of declined trips by the operator as a separate element
32 in this assessment since it is an important reliability indicator of the DRT system. A systematic
33 analysis of the declined trips can also help improve the DRT service and search for inequalities
34 in operation (e.g., some zones may have a higher share of declined or less profitable trips and
35 may thus suffer from more recurrent cancellations). Moreover, DRT operators could be
36 penalized when declining trips for which no adequate FT alternative is available.

37 38 **Accessibility Indicators**

39 Following the analysis of DRT operation, this paper proposes a series of indicators that measure
40 the change in accessibility attributed to the DRT service. These are depicted in the ovals in
41 FIGURE 1.

42 43 *DRT vs. Active Modes*

44 DRT can be seen as a competitor of walking and cycling for admissible walking and biking
45 distances. The threshold for admissible walking and cycling distances needs to be adjusted based
46 on the DRT setting, since these values differ by region (19), as well as by trip purpose and

1 population subgroup (20). The first accessibility indicator expresses the share of walkable and
 2 bikeable trips as follows:

$$3 \quad \% \text{ walkable trips} = \frac{\text{number of trips shorter than the walking threshold}}{\text{total number of trips}}$$

$$4 \quad \% \text{ bikeable trips} = \frac{\text{number of trips shorter than the biking threshold}}{\text{total number of trips}}$$

5
 6 The smaller these shares are, the less the actual DRT usage is competing with active
 7 modes. Note that although the former is a subset of the latter, biking is not always a feasible
 8 alternative (e.g., lack of a bicycle or cycling knowledge). As a result, including both indicators
 9 serves to, depending on the setting, better assess the actual competition of DRT with active
 10 modes.

11 *DRT vs. Long-distance Transit*

12 DRT operation is often restricted to a certain area. For trips that extend beyond these boundaries,
 13 DRT can be used as a complementary mode and connect passengers with long distance transit
 14 modes such as train, long distance bus, or regular bus for the case of DRT acting as a feeder. The
 15 second accessibility indicator is thus expressed as:

$$16 \quad \% \text{ trips with DRT as access or egress leg} \\ = \frac{\text{transit trips that use DRT as an access or egress leg}}{\text{total number of trips}}$$

17
 18 The larger this share is, the more DRT constitutes a connecting service to long distance
 19 transit.

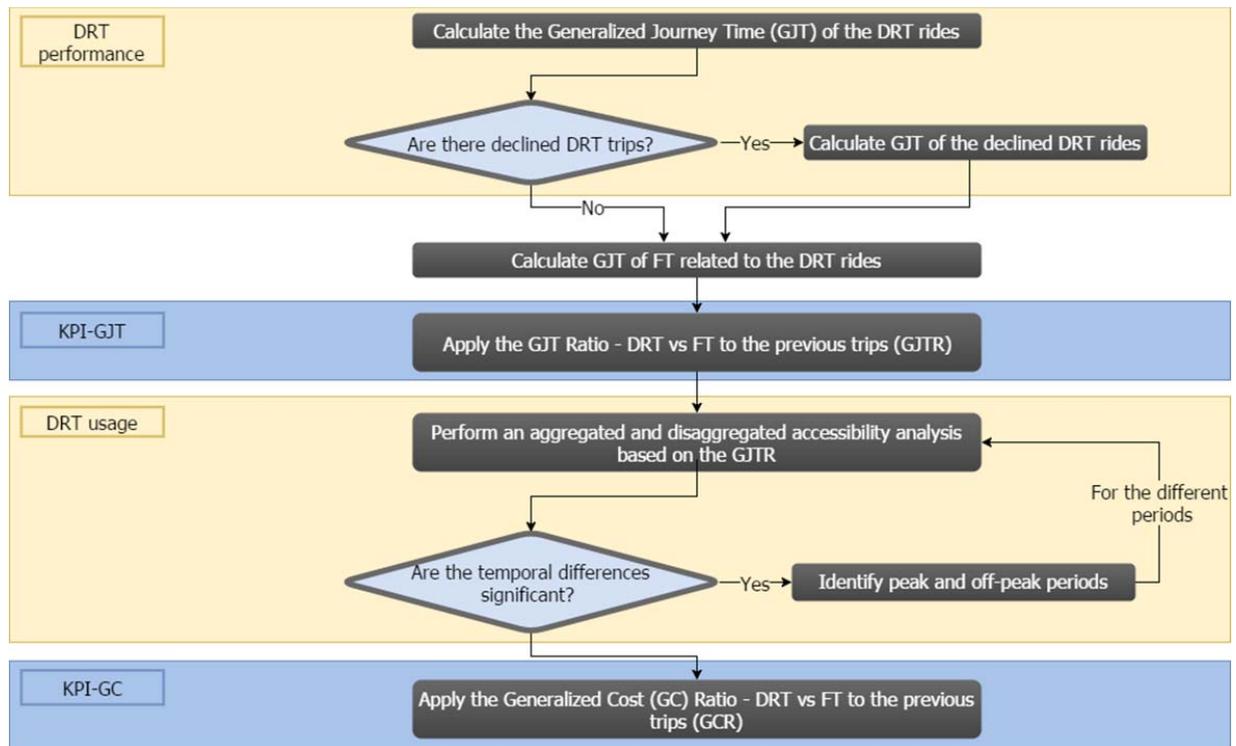
20 *DRT vs. Fixed Transit*

21
 22 DRT can also be used as the main mode of transport, competing with FT. This is the more
 23 general scenario due to the similitudes that DRT and FT exercise. In order to address this key
 24 aspect, the assessment framework provides a more complex benchmark against FT, in which two
 25 KPIs - the GJT and the Generalized Costs (GC) - are calculated and compared for DRT and FT.

26 Following the workflow described in FIGURE 2, the GJT is calculated for the DRT trips
 27 and, if available, for the declined trips. The GJT of DRT are compared with the GJT that the
 28 passengers would have experienced if they had travelled using FT. Three parameters are used to
 29 calculate the GJT of the FT alternatives: booking time (as the desired start time), and origin and
 30 destination locations. Automatic Vehicle Location (AVL) data can be used for this purpose. If
 31 this information is unavailable, scheduled information from FT journey planners can be used.
 32 The GJT Ratio of each trip is expressed as:

$$33 \quad GJTR = \frac{GJT^{DRT}}{GJT^{FT}}$$

34
 35
 36



1
2 **FIGURE 2 DRT accessibility performance benchmarks against FT.**
3

4 The GJTR indicator is analyzed by considering its distribution, and performed and
5 declined trips are to be assessed separately. It is important to note that the median (or the
6 quartiles for a more detailed representation) should be used to assess the distribution rather than
7 rely on the mean due to the asymmetry caused by the ratio calculation.

8 The GJTR can be further evaluated both spatially and temporally. An aggregated
9 representation of this KPI can identify Origin-Destination (O-D) connections for which the DRT
10 service has mostly improved the transit provision. A comparison between the number of
11 performed and declined trips for the different O-D pairs can identify if rejections are more
12 prevalent in certain areas. Moreover, a disaggregated representation can identify connections
13 which are underserved by conventional transit. If significant temporal differences exist (either
14 daily or weekly), the spatial analysis can be performed for different time intervals.

15 The last step of the comparison between DRT and FT is based on the GC where the GJT
16 values are multiplied by the corresponding value of time (VoT) (see Wardman et al. (21) for a
17 recent meta-analysis on European VoT). The monetarized value of the GC Ratio indicator is
18 expressed, similarly to the GJTR as:

$$GCR = \frac{GC^{DRT}}{GC^{FT}}$$

19 Whenever the focus is set on the total monetary cost of the passenger instead on the
20 temporal convenience of both modes, this GC indicator can be used.
21

1 APPLICATION

2 Case Study Description

3 The assessment framework described in the previous section was applied to the DRT pilot
4 'Brenge flex' which operates in the Arnhem-Nijmegen region in the east of the Netherlands. In
5 the following, the Brenge flex service in Nijmegen is analyzed. The pilot started in December
6 2016 and it offers stop-to-stop connection with a total of 255 stops. The service area includes the
7 city of Nijmegen and the neighboring municipalities of Wijchen, Berg en Dal and Oosterhout,
8 with a total of approximately 200,000 inhabitants. Brenge flex is run by Brenge, the incumbent
9 local bus operator. Simultaneously with its introduction, two bus lines that linked the
10 municipality of Wijchen, traversed the central parts of Nijmegen and terminated at the northern
11 part of Nijmegen, were cancelled. The Brenge flex service has a fixed price of € 3.50 per person
12 and operates from 6:30 to 24:00 during the weekdays, 8:00 to 24:00 on Saturdays and 9:00 to
13 24:00 on Sundays. The fleet comprises of five minibuses (maximum of five seats for passengers
14 and two wheelchairs) and four electric cars (maximum of three seats for passengers). Rides can
15 be booked in real-time via a mobile app or a telephone number, and no advance booking option
16 is available. Maximum waiting time is set to 20 minutes, rides that cannot be served within this
17 time window will not be accepted.

18 The analyzed data includes the pick-up and drop-off locations for all registered ride
19 requests - both performed and declined trips - between the 16th December 2016 and 18th May
20 2017. Booking times and expected in-vehicle times were available for the declined trips. Data for
21 the performed trips also included actual in-vehicle time and waiting time. Rides with unrealistic
22 average travel speed - lower than 10km/h (6.21 mph) or higher than 70km/h (43.48 mph) - were
23 not considered in the analysis. For declined trips, requests with the same spatial characteristics
24 that differed by less than 5 minutes were included only once in the analysis to prevent multiple
25 counts. A total of 4719 performed trips and 130 declined trips (2.7 % of all requests) were
26 considered valid for the analysis.

27 Results

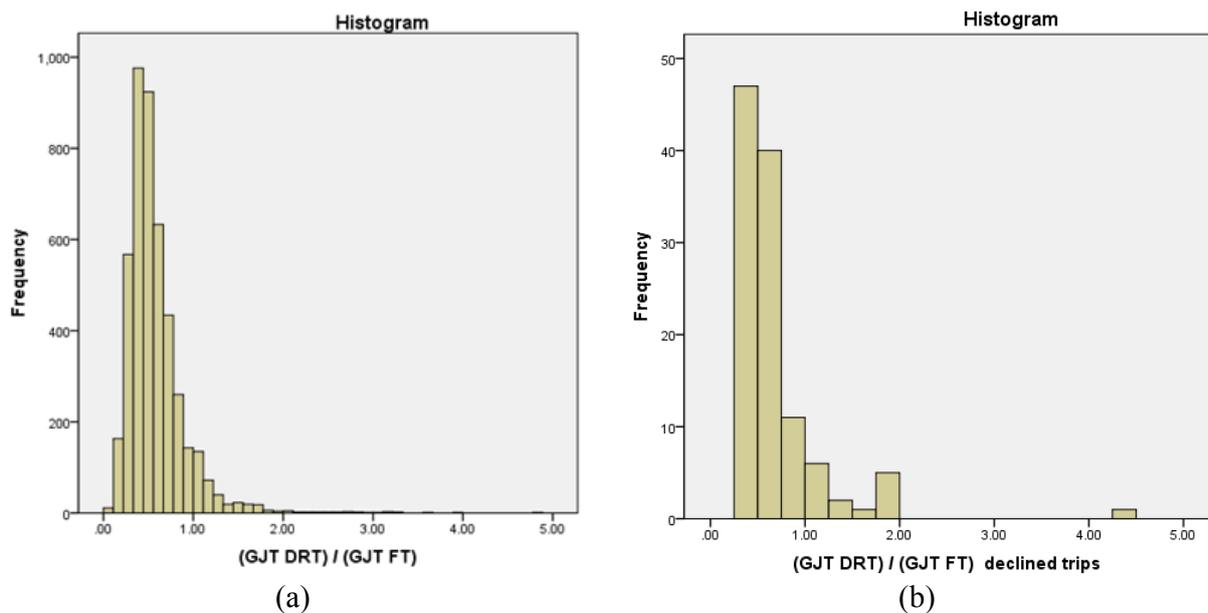
28 The average distance of the served DRT trips is 7.05 km (4.38 mi). Since no sociodemographic
29 data of the DRT users is available, the average walking and cycling distances in the Netherlands
30 were used as thresholds for these modes- i.e., 1.2 km (0.75 mi) for walking trips (19) and 3.6 km
31 (2.24 mi) for cycling trips (22). In total, 0.1% and 16.5% of the DRT trips could have been
32 performed on foot and by bike respectively, with the large majority of the rides covering a longer
33 distance than the average active mode trips.

34 The obtained data does not allow identifying DRT trips that constitute a part of a longer
35 transit trip. In order to have an approximation of the number of trips that could have used Brenge
36 flex as access or egress leg, we identified the number of DRT trips that had one of the six train
37 stations within the case study area as pick-up point (12.3% of the rides) or drop-off point (8.3%).
38 These numbers are upper bounds and suggest that up to 20 % of the rides could have been used
39 to access or egress one of the train stations.

40 The other indicators compare the DRT rides to FT rides. The characteristics of the FT
41 rides that could have substituted the performed and declined DRT rides were obtained
42 introducing the booking time and the start location and end locations of the DRT rides in the
43 transit Google Maps Directions API (23). The API provides scheduled rather than actual transit
44 data, hence possible deviations from plans in FT operations are not accounted for. As retrieval

1 criterion, we selected the FT trip with ‘the earliest time at the destination’. However, using this
 2 criterion, the option shown for 5 % of the performed trips and for 13% of the declined trips (242
 3 and 17 respectively) did not involve any transit, only walking. This is arguably an indication that
 4 the existing FT connection for these origins and destination is inadequate, or that the distance
 5 covered is rather short. To allow for a fair comparison where FT values can be attained, these
 6 trips are not included in the subsequent comparison of DRT and FT.

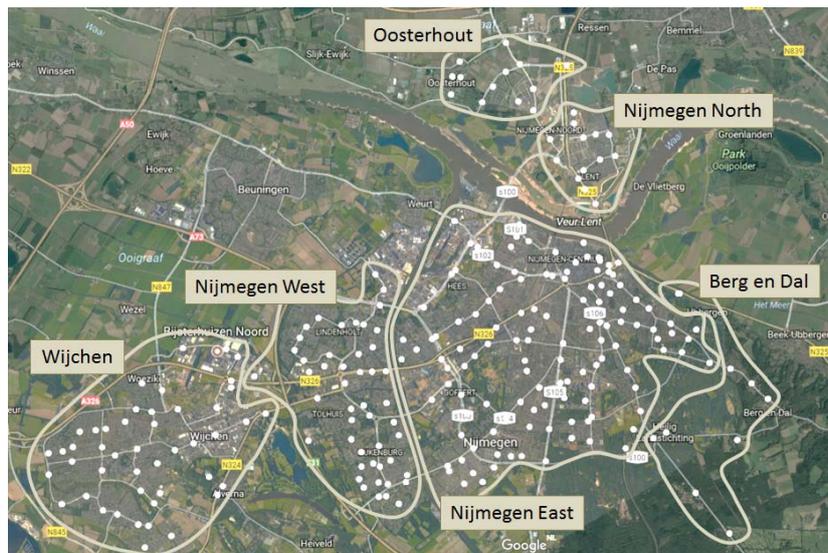
7 For the previous trips, the GJT for the performed and declined trips were calculated (the
 8 factors used being $\alpha_f = \alpha_w = 2$ and $\alpha_t = 10$ (17)). The average waiting time of the performed
 9 trips (9.4 min) is taken as the estimated waiting time for the declined trips. The distribution of
 10 the GJTR is illustrated in FIGURE 3 for both served trips (a) and declined trips (b). The median
 11 for the performed trips is 0.50 (0.38 for the 25 percentile and 0.68 for the 75 percentile). In other
 12 words, for 50% of the performed trips, the FT alternative is perceived by the passengers over
 13 twice as long as the DRT alternative. For the declined trips, the median is 0.54 (0.45 for the 25
 14 percentile and 0.71 for the 75 percentile). These results attest to how the DRT alternative
 15 considerably improves the accessibility of the performed trips in comparison to the FT
 16 alternative.



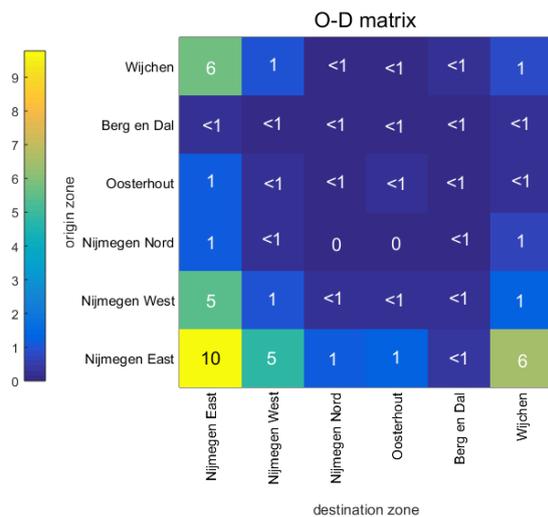
18 **FIGURE 3 Distribution of the GJTR for DRT in comparison to PT: (a) for the performed**
 19 **trips (N = 4477) and (b) for the declined trips (N = 113).**

21 The distribution of the GJTR is now analyzed spatially, both in an aggregated and in a
 22 disaggregated manner. FIGURE 4 presents the aggregated spatial analysis of the performed trips,
 23 with (a) the zonal delimitations used (in which Nijmegen has been divided in three parts by
 24 following natural water barriers), (b) the O-D matrix in hundreds, and (c) the median of the
 25 GJTR corresponding to each of the O-D pairs. The difference in the number of rides for each of
 26 the O-D pairs is partly due to the difference in the population size of the different areas.
 27 Moreover, part of the demand between Wijchen and the different areas of Nijmegen may be
 28 attributed to users of the two bus lines that were eliminated with the introduction of Breng flex.

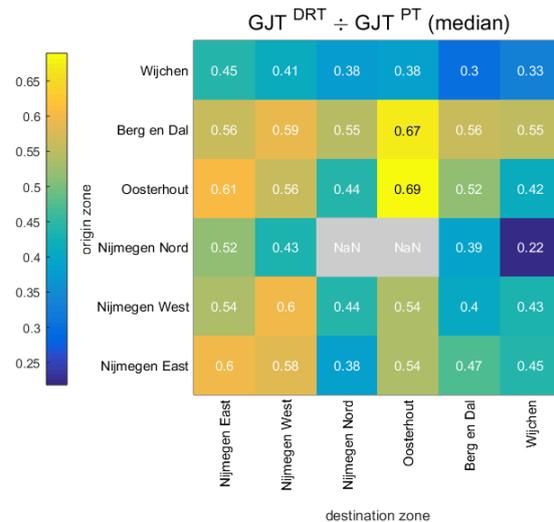
1 This fact also explains that trips from Nijmegen North to Wijchen have the lowest median for the
 2 GJTR indicator (the median DRT GJT is 22% of the FT GJT value). Conversely, the O-D pair
 3 for which the increases of accessibility provided by DRT in comparison to FT are the lowest is
 4 Oosterhout-Oosterhout (GJTR = 0.69). Regarding the declined trips, the low number of
 5 occurrences (with no occurrence at all for many of the O-D pairs) do not provide a representative
 6 sample to analyze if there are statistical differences between both trip groups and is therefore not
 7 included in the shown figures. Importantly, the number of declined trips for each O-D pair
 8 correlates with the number of served trip. Thus, there are no spatial disparities in the DRT
 9 service availability.
 10



(a)



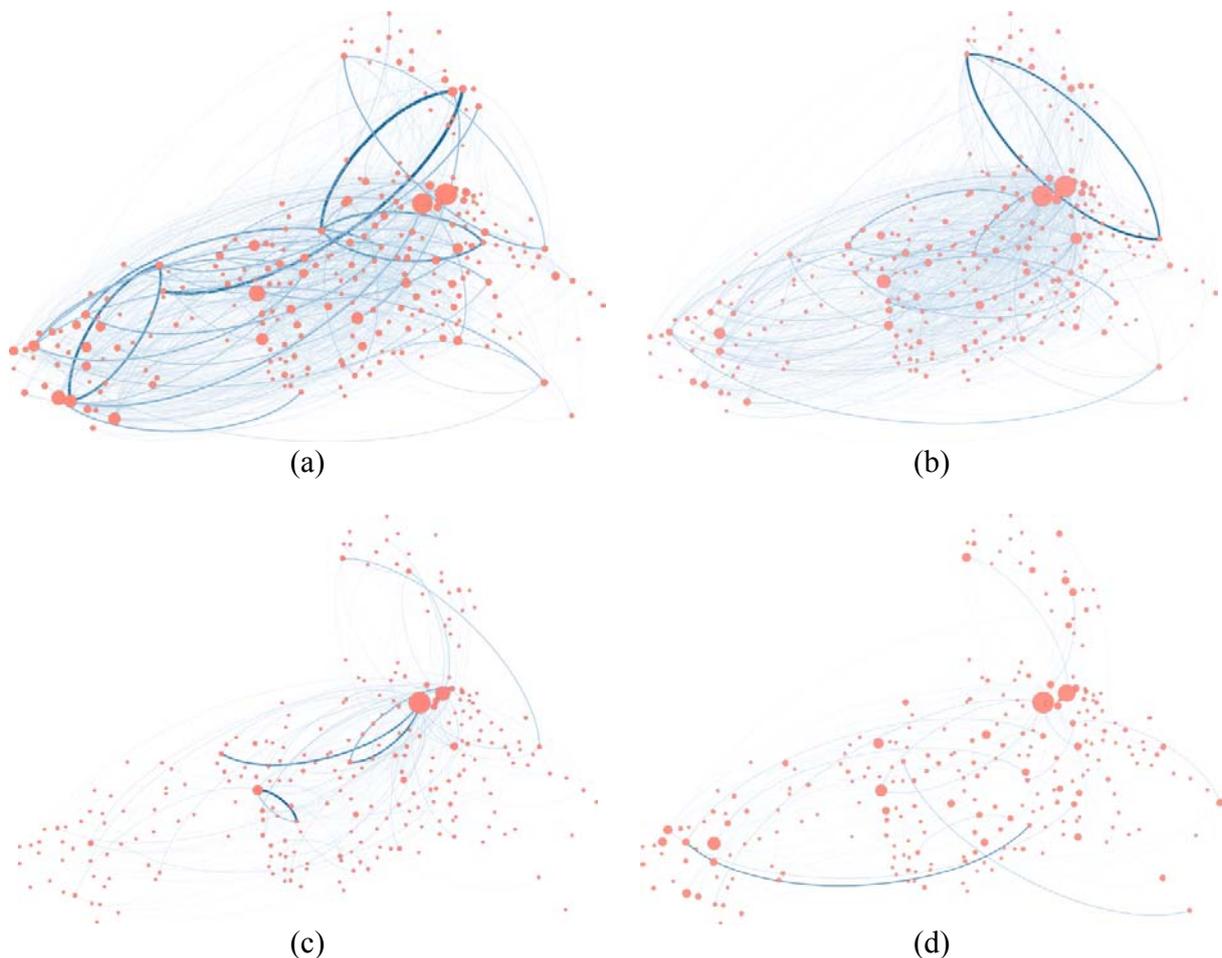
(b)



(c)

1 **FIGURE 4 Aggregated spatial analysis of DRT: (a) Zonal delimitation, (b) O-D matrix (in**
 2 **hundreds) and (c) median of the GJTR for each O-D pair.**

3
 4 The disaggregated spatial analysis is presented geocoded in FIGURE 5. The performed
 5 rides have been distributed in three graphs according to their GJT Ratios (a), (b), (c), while
 6 declined rides are illustrated in (d). Node size is consistent with the use frequency, as well as link
 7 size and link color intensity. The direction of the trips is represented clockwise. The large
 8 majority of the trips for which FT outperformed DRT ($GJTR > 1$) were radial trips with an end in
 9 the center of Nijmegen, while recurrent links with a distinctive DRT benefit have a more
 10 tangential nature. No distinctive pattern can be observed between performed and declined trips.
 11 The large majority of the 255 DRT stops has been utilized during the study period, and the stop
 12 at the 'Nijmegen central railway station' was one of the two most recurrently used stops.
 13



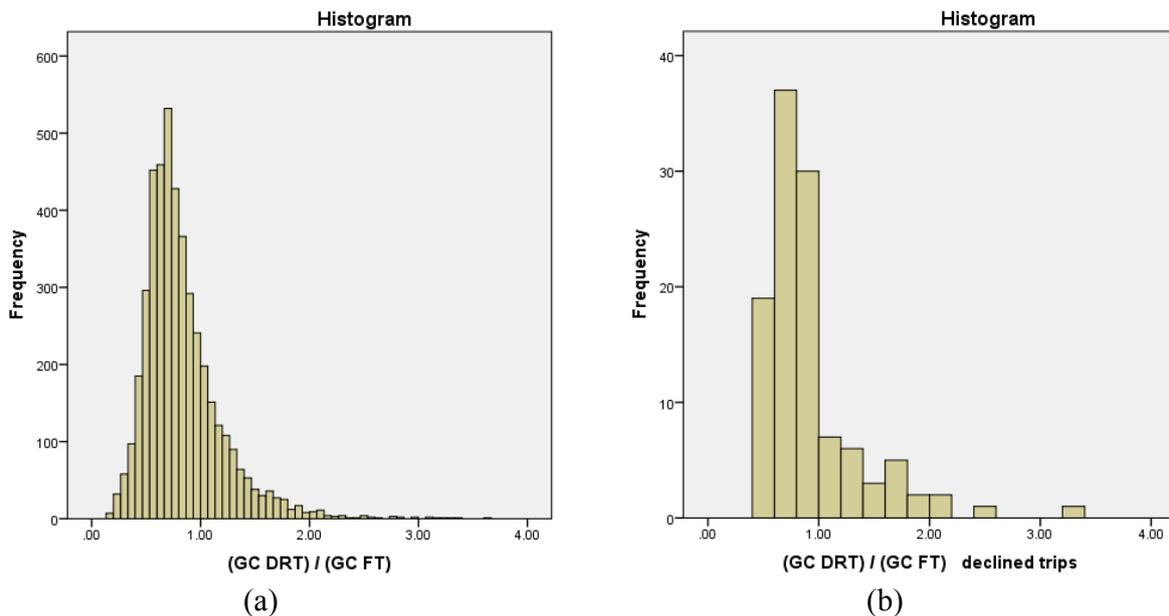
14 **FIGURE 5 Disaggregated spatial analysis of DRT: (a) performed rides with $GJTR < 0.5$**
 15 **(2206 rides), (b) performed rides with $0.5 < GJTR < 1$ (1905 rides), (c) performed rides with**
 16 **$GJTR > 1$ (366 rides), and (d) declined rides (113 rides). Plotted in Gephi (24).**

17
 18 The analysis of the evolution of the demand for Breng flex services shows a constant
 19 increase in the number of rides since the implementation of the DRT service. The number of

1 trips in the last week quadruple the trips in the first weeks to its introduction. Due to this large
 2 variation in demand volumes, only the data from the last 10 weeks is considered in the search for
 3 daily and weekly variations in the demand levels. No statistically significant differences were
 4 found in the demand on different days of the week ($p=0.113$ for one-way ANOVA) but
 5 differences in demand levels at different hours of the day are statistically significant ($p=0.001$ for
 6 one-way ANOVA studying the hourly demand between 9 and 21 h). The hourly DRT demand
 7 does not show strong commuting peaks as in the case for FT, but smaller peaks still do exist,
 8 with the highest demand observed in the afternoon (around 15:00). A spatial representation of
 9 the peak period could identify the highest demand areas during this timeslot. Due to space limits,
 10 it is not presented in this paper.

11 The last step described in the assessment framework involves the calculation of the GC of
 12 both performed and declined trips. A future modal shift from FT to DRT can arguably be
 13 expected if the GCR distribution favors DRT to a large extent. The VoT used for this study (both
 14 for DRT and FT) is the VoT calculated in Kouwenhoven et al. (25) for bus/tram/metro for all trip
 15 purposes in the Netherlands, which is 7.39 Euro per hour per person in 2016 terms. The
 16 distribution of the GCR is represented in FIGURE 6. The median for the performed trips is 0.75
 17 (0.60 for the 25 percentile and 0.97 for the 75 percentile). For the declined trips, the median is
 18 0.80 (0.63 for the 25 percentile and 0.99 for the 75 percentile). These results show that while
 19 DRT outperforms FT for the trips for which passengers opted for DRT, the distributions of the
 20 GC are closer to 1 than those of the GJT (FIGURE 3). This shift is caused by the higher fixed
 21 price for DRT than the distance-based FT fare, resulting with a smaller discrepancy in passenger
 22 disutility between the services when accounting for the price difference.

23



24 **FIGURE 6 Distribution of the GC for DRT in comparison to PT: (a) for the performed**
 25 **trips (N = 4477) and (b) for the declined trips (N = 113).**

1 **DISCUSSION**

2 Until recently, the main reasons for introducing DRT services were to substitute FT in low
3 demand areas or to fulfill the needs of specific sectors of the population (mainly the elderly and
4 the disabled). Also the case study service is partly introduced based on these grounds (it offers a
5 barrier-free service and two fix bus lines were eliminated in conjunction with its introduction).
6 Notwithstanding, it also offers a complementing service to FT, with the objective of improving
7 the mobility offered in the area and to better address passengers' needs. This additional role of
8 DRT is in line with the Mobility as a Service paradigm, in which "mobility services [are bought]
9 as packages based on consumers' needs instead of buying the means of transport" (26), and for
10 which different mobility services complement FT.

11 Results of the case study show that for half of the performed rides, the DRT GJT were
12 half or less than with FT, showing that large improvements in mobility can be attributed to DRT.
13 Rayle et al. (27) compared the times that performed ridesourcing trips (i.e. trips provided by
14 Transportation Network Companies (TNCs) such as Uber and Lyft) would have taken with FT.
15 In line with the results of this study, they found that "the majority of ridesourcing trips would
16 have taken more than twice as long if made by public transport". Both results show that, even if
17 these services may be competitors of FT, they improve the offered mobility, with the subsequent
18 economic and social benefits.

19 Despite the opportunities that DRT provides as complement to FT, its implementation
20 also brings a series of risks that should not be overlooked. Three main risks are identified.
21 Firstly, for a DRT system to achieve a high degree of efficiency, a relative large fleet is
22 necessary, as stressed in Kutsuplus final report (8). As a result, the offered DRT service can
23 become a (possibly heavily subsidized) individual taxi service. Secondly, if DRT provides a
24 lower GC than FT, more users may shift from FT to DRT, with the FT revenue seeing a decrease
25 and in extreme cases a possible increase in road congestion. An analysis of the incurred GC of
26 both DRT and FT (as performed in this study) can help identify large differences in the costs that
27 passengers incur with both services. Furthermore, FT revenue decrease can lead to the
28 deterioration (or elimination) of the offered FT service, even if DRT may not be capable of
29 absorbing the entire passenger demand. This second risk is elevated by recent research which has
30 found that FT users are more prone to use DRT than non FT users (28). Finally, DRT services in
31 their current regulatory framework do not guarantee a certain level of service. As a result, the
32 risk of not obtaining the desired ride exists, the importance of which increases if no other
33 alternative service (such as FT) is available. The share of declined trips could vary for different
34 O-D pairs, with rides for less convenient/profitable locations being more likely to be declined.
35 Thus, a spatial analysis of the declined rides should be performed together with the spatial
36 analysis of the performed rides, as described in the suggested framework.

37 The above mentioned risks can be reduced with an integrated FT-DRT approach. In an
38 integrated FT-DRT network, the ride fee for DRT can be modified so as to obtain the desired
39 split between the demand for DRT and FT. This price adjustment can be regulated based on
40 different attributes. When striving for an equal urban accessibility, DRT price can be calculated
41 as a function of FT accessibility. This will imply that price for DRT would be higher when a
42 competitive FT alternative exists, and lower otherwise. The accessibility indicators proposed in
43 this study can be used to adjust the DRT price function if this approach is adopted. An alternative
44 price adjustment approach can be based on comfort considerations since more exclusive (and
45 less collective) mobility services provide a higher utility to the passenger. This approach, which
46 is used in the Flexible Mobility on Demand system presented in Atasoy et al. (5), implies that

1 passengers should pay a higher fee for using a premium service which is less capacity-efficient.
2 Whatever the adjusting function is, an integrated FT-DRT approach can increase the
3 opportunities that DRT can bring as a complement to FT and decrease the collateral risks.

4 **CONCLUSIONS**

5 There are a wide range of innovative transportation services that have recently appeared in urban
6 areas. However, they are often considered in isolation, and the impacts of their interactions and
7 implications for other modes are largely ignored (29). This paper presents an assessment
8 framework for evaluating the usage of DRT. A generalized travel cost comparison is proposed as
9 an indicator of changes in accessibility related to the introduction of DRT in relation to the FT
10 alternatives. Moreover, the usage of DRT as first or last leg in longer FT journeys, and the
11 suitability of the performed rides for walking and cycling are also considered in this assessment.
12 To the authors' knowledge, this is the first study that measures the increase in accessibility that
13 the implementation of DRT has granted DRT passengers, in comparison to the FT alternative.
14 An empirical analysis is performed by applying the proposed framework to an urban DRT
15 system in the Netherlands. Results indicate a reduction of over half of the generalized journey
16 times for half the rides that were performed using the DRT service, in comparison to the FT
17 alternatives. Results also identified areas for which this reduction is the highest, highlighting
18 connections for which FT offers a poor alternative.

19 Public transport authorities can use the proposed framework for one or more of the
20 following purposes: 1) evaluate real performance of DRT for the different areas, including the
21 distribution of declined rides; 2) identify whether DRT is used as a complement of FT, due to
22 poor FT connections, or as a substitute of FT, due to the higher comfort DRT provides, and 3)
23 assess the impacts of DRT on improving mobility.

24 Other than DRT, recent studies have shown that other flexible modes, such as
25 ridesourcing and car-sharing, may also complement public transit (30). However, even if a series
26 of partnerships between them and transit are already in place, data concerning their usage is
27 necessary to enhance transit planning (31). The assessment framework provided in this study can
28 be extended to analyze the usage of other flexible modes and better identify opportunities for
29 synergies as opposed to symbiotic relations where new services gain the most lucrative markets.

30 In the absence of information on individual characteristics, the shortcomings of this study
31 pertain to the unobserved drivers of user behavior. The analysis of travel behavior under
32 different conditions will allow estimating demand elasticities, the socioeconomic characteristics
33 of DRT riders or differences in perceived times for DRT with respect to FT values. Future
34 studies could include these aspects in their evaluation by incorporating travel survey data. Also,
35 further research is needed to analyze how urban development characteristics and transit-related
36 factors influence DRT usage, as already researched for taxi ridership (32).

37 **ACKNOWLEDGMENT**

38 This work was funded by NWO (The Organisation for Scientific Research from the
39 Netherlands), as part of the SCRIPTS (Smart Cities Responsive Intelligent Public Transport
40 Services) research project. The authors thank Breng and Arjen van Weert from HAN University
41 for providing the data used for the case study.

42 **REFERENCES**

43 1. Cole, L. M. *Tomorrow's Transportation: New Systems For The Urban Future*. 1968.

- 1 2. Markovic, N., M. E. Kim, and P. Schonfeld. Statistical and Machine Learning Approach
2 for Planning Dial-a-Ride Systems. *Transportation Research Part A: Policy and Practice*,
3 Vol. 89, 2016, pp. 41–55. <https://doi.org/10.1016/j.tra.2016.05.006>.
- 4 3. Kalpakcı, A., and N. Karataş Ünverdi. Integration of Paratransit Systems with Inner-City
5 Bus Transport: The Case of Izmir. *Public Transport*, Vol. 8, No. 3, 2016, pp. 405–426.
6 <https://doi.org/10.1007/s12469-016-0136-9>.
- 7 4. Li, X., and L. Quadrifoglio. Feeder Transit Services: Choosing between Fixed and
8 Demand Responsive Policy. *Transportation Research Part C: Emerging Technologies*,
9 Vol. 18, No. 5, 2010, pp. 770–780. <https://doi.org/10.1016/j.trc.2009.05.015>.
- 10 5. Atasoy, B., T. Ikeda, X. Song, and M. E. Ben-Akiva. The Concept and Impact Analysis of
11 a Flexible Mobility on Demand System. *Transportation Research Part C: Emerging*
12 *Technologies*, Vol. 56, 2015, pp. 373–392. <https://doi.org/10.1016/j.trc.2015.04.009>.
- 13 6. Martinez, L. M., G. H. A. Correia, and J. M. Viegas. An Agent-Based Simulation Model
14 to Assess the Impacts of Introducing a Shared-Taxi System: An Application to Lisbon
15 (Portugal). *Journal of Advanced Transportation*, Vol. 49, No. 3, 2015, pp. 475–495.
16 <https://doi.org/10.1002/atr.1283>.
- 17 7. Alonso-Mora, J., S. Samaranayake, A. Wallar, E. Frazzoli, and D. Rus. On-Demand High-
18 Capacity Ride-Sharing via Dynamic Trip-Vehicle Assignment. *Proceedings of the*
19 *National Academy of Sciences*, Vol. 114, No. 3, 2017.
20 <https://doi.org/10.1073/pnas.1611675114>.
- 21 8. Helsinki Regional Transport Authority. *Kutsuplus - Final Report*. 2016.
- 22 9. Ferreira, L., P. Charles, and C. Tether. Evaluating Flexible Transport Solutions,
23 Transportation Planning and Technology. *Transportation Planning and Technology*, Vol.
24 30, No. 2–3, 2007, pp. 249–269. <https://doi.org/10.1080/03081060701395501>.
- 25 10. Morse, L., M. Trompet, A. Barron, and D. J. Graham. Development of a Key Performance
26 Indicator System to Benchmark Relative Paratransit Performance. *Transportation*
27 *Research Record: Journal of the Transportation Research Board*, No. 2650, 2017, pp. 1–
28 8. <https://doi.org/10.3141/2650-01>.
- 29 11. Yigitcanlar, T., N. Sipe, R. Evans, and M. Pitot. A GIS-Based Land Use and Public
30 Transport Accessibility Indexing Model. *Australian Planner*, Vol. 44, No. 3, 2007, pp.
31 30–37. <https://doi.org/10.1080/07293682.2007.9982586>.
- 32 12. Khattak, A. J., and Y. Yim. Traveler Response to Innovative Personalized Demand-
33 Responsive Transit in the San Francisco Bay Area. *Journal of Urban Planning and*
34 *Development*, Vol. 130, No. 1, 2004, pp. 42–55. <https://doi.org/10.1061/ASCE0733-94882004130:142>.
- 35 13. Lerman, S. R., M. Flusberg, W. M. Pecknold, R. E. Nestle, and N. H. M. Wilson. A
36 Model System for Forecasting Patronage on Demand Responsive Transportation Systems.
37 *Transportation Research Part A: General*, Vol. 14, No. 1, 1980, pp. 13–23.
38 [https://doi.org/10.1016/0191-2607\(80\)90090-4](https://doi.org/10.1016/0191-2607(80)90090-4).
- 39 14. Jain, S., N. Ronald, R. Thompson, and S. Winter. Predicting Susceptibility to Use Demand
40 Responsive Transport Using Demographic and Trip Characteristics of the Population.
41 *Travel Behaviour and Society*, Vol. 6, 2017, pp. 44–56.
42 <https://doi.org/10.1016/j.tbs.2016.06.001>.
- 43 15. Balcombe, R., R. Mackett, N. Paulley, J. Preston, J. Shires, H. Titheridge, M. Wardman,
44 and P. White. *The Demand for Public Transport: A Practical Guide*. 2004.
45 <https://doi.org/10.1016/j.tranpol.2005.12.004>.
- 46

- 1 16. Wardman, M. Public Transport Values of Time. *Transport Policy*, Vol. 11, No. 4, 2004,
2 pp. 363–377. <https://doi.org/10.1016/j.tranpol.2004.05.001>.
- 3 17. Booz Allen & Hamilton (NZ) Ltd. *Valuation of Public Transport Attributes*. 2000.
- 4 18. Currie, G., and I. Wallis. Effective Ways to Grow Urban Bus Markets - a Synthesis of
5 Evidence. *Journal of Transport Geography*, Vol. 16, No. 6, 2008, pp. 419–429.
6 <https://doi.org/10.1016/j.jtrangeo.2008.04.007>.
- 7 19. International Transport Forum. *Pedestrian Safety, Urban Space and Health*. OECD
8 Publishing, 2012.
- 9 20. Yang, Y., and A. V Diez-Roux. Walking Distance by Trip Purpose and Population
10 Subgroups. *American Journal of Preventive Medicine*, Vol. 43, No. 1, 2012, pp. 11–19.
11 <https://doi.org/10.1016/j.amepre.2012.03.015>.
- 12 21. Wardman, M., V. P. K. Chintakayala, and G. de Jong. Values of Travel Time in Europe:
13 Review and Meta-Analysis. *Transportation Research Part A: Policy and Practice*, Vol.
14 94, 2016, pp. 93–111. <https://doi.org/10.1016/j.tra.2016.08.019>.
- 15 22. KiM Netherlands Institute for Transport Policy Analysis. *Mobiliteitsbeeld 2016*. 2016.
- 16 23. Google Developers. Google Maps Directions API. *Google*.
17 <https://developers.google.com/maps/documentation/directions/>. Accessed Jul. 23, 2017.
- 18 24. Bastian, M., S. Heymann, and M. Jacomy. Gephi: An Open Source Software for
19 Exploring and Manipulating Networks. *Third International AAAI Conference on Weblogs
20 and Social Media*, 2009, pp. 361–362. <https://doi.org/10.1136/qshc.2004.010033>.
- 21 25. Kouwenhoven, M., G. C. de Jong, P. Koster, V. A. C. van den Berg, E. T. Verhoef, J.
22 Bates, and P. M. J. Warffemius. New Values of Time and Reliability in Passenger
23 Transport in The Netherlands. *Research in Transportation Economics*, Vol. 47, No. 1,
24 2014, pp. 37–49. <https://doi.org/10.1016/j.retrec.2014.09.017>.
- 25 26. Kamargianni, M., W. Li, M. Matyas, and A. Schäfer. A Critical Review of New Mobility
26 Services for Urban Transport. *Transportation Research Procedia*, Vol. 14, No. 14, 2016,
27 pp. 3294–3303. <https://doi.org/10.1016/j.trpro.2016.05.277>.
- 28 27. Rayle, L., D. Dai, N. Chan, R. Cervero, and S. Shaheen. Just a Better Taxi? A Survey-
29 Based Comparison of Taxis, Transit, and Ridesourcing Services in San Francisco.
30 *Transport Policy*, Vol. 45, 2016, pp. 168–178.
31 <https://doi.org/10.1016/j.tranpol.2015.10.004>.
- 32 28. Alonso-González, M. J., N. Van Oort, O. Cats, and S. Hoogendoorn. Urban Demand
33 Responsive Transport in the Mobility as a Service Ecosystem: Its Role and Potential
34 Market Share. Presented at Thredbo 15 Conference, Stockholm, 2017.
- 35 29. Ciari, F., and H. Becker. How Disruptive Can Shared Mobility Be ? A Scenario-Based
36 Evaluation of Shared Mobility Systems Implemented at Large Scale. In *Disrupting
37 Mobility*, Springer International Publishing, pp. 51–63.
- 38 30. Feigon, S., and C. Murphy. *Shared Mobility and the Transformation of Public Transit*.
39 Transportation Research Board, Washington, D.C., 2016.
- 40 31. New York Public Transit Association. *NYPTA White Paper on Transportation Network
41 Company (TNC) Issues*. 2017.
- 42 32. Nam, D., K. (Kate) Hyun, H. Kim, K. Ahn, and R. Jayakrishnan. Analysis of Grid Cell
43 Based Taxi Ridership with Large Scale GPS Data. *Transportation Research Record:
44 Journal of the Transportation Research Board*, Vol. 2544, No. 2544, 2016, pp. 131–140.
45 <https://doi.org/10.3141/2544-15>.
- 46