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Impacts of replacing a fixed public transport line by a demand responsive transport system: Case study of a rural area in Amsterdam

Felipe Mariz Coutinho [a], Niels van Oort [a,*], Zoi Christoforou [b], María J. Alonso-González [a], Oded Cats [a], Serge Hoogendoorn [a]

[a] *Delft University of Technology, the Netherlands*
[b] *Université Gustave Eiffel, Paris, France*

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ABSTRACT

The diffusion of the smartphone and the urban sprawl is pushing both private and public actors to revisit the concept of demand-responsive transport (DRT). This paper provides a historical overview of DRT experiences, understanding their pros and cons. In addition, it presents the case study of Mokumflex, a 12-month DRT pilot program that replaced the regular bus service in low-density areas of Amsterdam, the Netherlands. Based on a close collaboration with the private enterprise that operated the service and also with the local bus operator, we performed an empirical before and after comparison. These insights help to understand the impacts of DRT systems and support (future) design of DRT and public transport. A set of indicators was chosen for the inter-modal comparison: travel distances, ridership, costs, Greenhouse Gases (GHG), emissions and population's perception. Ridership dropped from 78.1 passengers/day to 15.9 passengers/day, however, for being "demand-tailored", passenger-km reduced even more, going from 1252.8 km/day to 136.6 km/day, hence reducing the costs and GHG emissions per passenger. In regards to population's perception, the system enjoyed a good evaluation.

1. Introduction

Urbanization is not a recent trend and neither are the challenges it raises. In 1968, the "first truly comprehensive official look at urban transportation in the light of modern technological capabilities to deal with modern urban problems" was published. It pointed out the problems that urban planners had to deal with including equality, accessibility, quality of service, congestion, efficient use of assets, pollution and unadapted institutional framework (Cole, 1968).

Nowadays, the spread of cities is still facing similar challenges but they are all aggregated under the concept of sustainability and transport is seen as one major tool to address them (Feigon et al., 2018; Laws et al., 2009). The 5E framework, proposed by Van Oort et al. (2017), for example, considers the value of public transport by its economic, environmental and social impacts, but also regarding its effectiveness (transporting people reliably, safely and reducing congestion) and its efficiency (good usage of (limited) space).

When it comes to the analysis of mobility and urbanization, a classical problem is how to serve low-density and dispersed settled areas, where regular public transport is usually not feasible on financial grounds. Demand-responsive transport (DRT) is a possible solution, helping the population to satisfy their mobility needs (Ellis & McCollom, 2009; MOG, 2014). DRT, as understood in this article, is a form of privately or publicly operated transport, with fixed or dynamically allocated routes and schedules that offers a service that relies on trip pooling (MaRS, 2016; Westervelt et al., 2018). New (mobile) technologies have led to a resurgence of DRT services. In some occasions, fixed public transport services are transformed to DRT services. However, there is still limited knowledge regarding the impacts of such changes.

This study aims to evaluate the impacts coming from the transformation of a fixed bus line into a demand-responsive system, helping urban planners and operators in their decision-making process. It is based on data from a Dutch DRT pilot called Mokumflex.

In the next section, both a literature review of the development of DRT and recent related experiences are presented. Next, we provide an explanation of the local context and the system of Mokumflex itself.

* Corresponding author. Dep. Transport and Planning, Faculty of Civil Engineering and Geosciences, Delft University of Technology, 2600, GA Delft, the Netherlands.

E-mail address: N.vanOort@tudelft.nl (N. van Oort).

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Then, we analyse the outcomes by evaluating a series of performance indicators. This paper concludes with a summary of both previous and current systems, demonstrating the weaknesses and strengths of each.

2. Origins and current experiences of DRT

DRT is not an innovation of the twenty-first century, as the first somehow formal and documented experiment was realized in 1916, in Atlantic City. This first DRT was a jitney service open to the general public operated in a fixed route picking-up and discharging passengers according to their requests (O'Leary, 1974; Strobel, 1987).

The following decades saw only a shy dissemination of these type of projects with only two more operations being documented until the 60's. In the end of this decade and the beginning of the 70's, however, a more rapid expansion of these transport systems took place, starting in North America and followed by Europe (Strobel, 1987). It is important to note that DRT was also spread in developing countries (Cervero & Golub, 2007) but this literature review focused on developed countries. Fig. 1 illustrates the technologic developments and the context that helped DRT systems in their spread worldwide until today.

The rise of low-density areas that generally did not dispose of the same financial resources as consolidated urban areas, in the US, was the main reason behind the diffusion of demand-responsive bus-based systems during the 60's (Cole, 1968). At the time, researchers worked on the development of a "many-to-many" origins and destinations algorithm to assign efficiently demand, making a door-to-door public transport affordable: the most notorious of those was the CARS project of the Massachusetts Institute of Technology (Wilson et al., 1969). During the 70's, the first automated operations with automated dispatch were put into practice: first in Haddonfield, New Jersey, in 1972, followed by Rochester, New York, in 1975 (Strobel, 1987).

The inaugural European experiences date from the end of the 60's and beginning of the 70's and were mainly influenced by North-American initiatives and different travel comportment, income level, telephone and car ownership (Webster, 1974).

The 80's and 90's saw the improvement of different technologies that enhanced communication and data collection. During these decades, the replacement of regular services by shared taxis and dial-a-ride bus options was stimulated by the limited budget context in the USA (Casey et al., 1991). Further in the 2000's, the internet enabled important cost and time savings as a result of a shift from inefficient telephone communication (Lasdon et al., 2000).

Despite its development, this concept did not meet great acceptance as a substitute for regular public transport in situations where the last was not economically viable (Davison et al., 2014). One of the reasons is the nature and objectives of DRT systems: usually, the main motivation for their implementation is to serve low demand areas and/or periods in a more efficient and effective way. However, to reduce subsidies, the systems have to raise the ridership, but this raise often indicates the necessity of a regular line, therefore limiting their application (Vuchic et al., 1981, pp. 83–86).

The second decade of the 21st century, however, due to the ubiquity of smartphones and significant budget cuts to public transport subsidies, is inviting urban planners to reconsider DRT (Currie & Fournier, 2019; Davison et al., 2014; Westervelt et al., 2018). The private sector is pioneering the DRT rediscovery and the so-called Transportation Network Companies (TNCs), which started operating in 2009, have played an important role in this development of contemporary DRT systems. Their evolution made them use their platform to pool multiple trips in the same vehicle, offering a "new" service to their customers and inspiring the development of current DRT services (Westervelt et al., 2018).

Some examples of recent DRT solutions that emerged between 2012 and 2016 are Via + ViaVan, Kutsuplus, Bridj, Chariot, Padam, Leap, Loup, UberPool, Lyft Lines and Shuttle. All of them offer shared trips that situates between a taxi and a public transport trip and currently, both private and public stakeholders are taking part in the DRT development. We outline some characteristics of some DRT services in Fig. 2.

Both private and public stakeholders are taking part into this development, operating under a "stop-to-stop" modality, in opposition of the "door-to-door": instead of picking-up and dropping users at the doors of their houses, operators optimize routes and offer a solution that displaces between bus stops.

Even if ultimately all of these services propose a final and ideal offer,

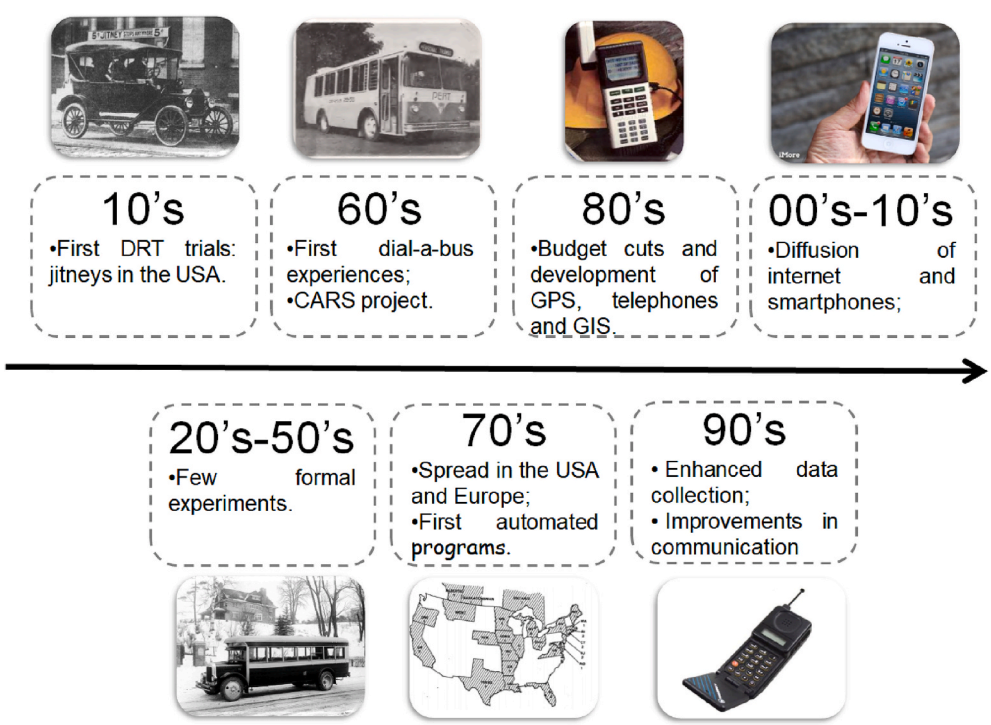

Fig. 1. Important technological facilitators for DRT deployment.

	Starting year	Type	Platform	Modality	Scheduling	Routing	Geographic coverage	Place of origin
HSL HRT kutsuplus	2012	Public	Website-based	Stop-to-stop	Flexible	Flexible	Area-based	Helsinki, Finland
VIA VAN	2013	Private	App-based	Stop-to-stop	Flexible	Flexible	Area-based	New York, USA
BRIDJ	2014	Private	App-based	Stop-to-stop	Flexible	Flexible	Area-based	Boston, USA
CHARIOT	2014	Private	App-based	Stop-to-stop	Fixed	Fixed	Line-based	San Francisco, USA
brengflex	2016	Public	App-based	Stop-to-stop	Flexible	Flexible	Area-based	Arnhem-Nijmegen, Netherlands

Fig. 2. Characteristics of some contemporary DRT services.

being a shared trip, with prices and level of comfort that are situated somewhere between regular public transport and TNC/taxis, their business models vary considerably between enterprises and, within the same organization, between cities where they operate.

Nonetheless, a sustainable business model is still to be found and the reasons are unclear to the large public as enterprises hardly share their data (McCoy et al., 2018). However, some general characteristics of their product support this statement (Feigon et al., 2018):

- Cost-intensive nature: when compared to individual-trip offerings, DRT experiences includes renting vehicles and paying drivers as employees, which raises its costs;
- Similar service compared to public transport but in low-demand areas and usually not publicly subsidized;
- Low patronage attraction: the system is well understood and accepted by a few users only.

The next section presents some description of recent DRT experiences.

2.1. Kutsuplus

Kutsuplus was a publicly operated DRT pilot program in the Helsinki metropolitan region that opened in April 2013 (HSL, 2016). Trips were provided by high-comfort 8-passenger vans and could be booked up to 30 min in advance. Users paid a distance-based fare that varied according to the level of service and number of passengers booking the displacement (Weckstrom et al., 2018).

The system did not make use of a smartphone application and requests were to be made via internet, which impacted the ridership. Scaling the system, which was considered fundamental for enhancing the economic performance, was not possible due to the constrained financial environment of the municipalities, leading to the cease of operations in the end of 2015 (HSL, 2016).

2.2. Via and ViaVan

Via launched its first operation in New York in September 2013 (Observer, 2015). The system ran during rush-hours and under a flat-fare regime. It asked users to go to “virtual stops” a few blocks away from their departing point to be picked up (Crains, 2015). Via services are area-based, allowing people to go anywhere within any of the virtual stops in the served zone. The company uses a crowd-sourcing strategy to expand to new areas and time-frames (CityLab, 2017).

The company expanded to different countries in Europe, Asia and Oceania and these new operations highlighted another important feature of the current business models: flexibility. In the case of Via, three main features justify the last affirmation:

- Different market products: ranging from private to public shuttles, offering only the technology/algorithms to managing both fleet and drivers, or even independent contracted drivers, in partnership or not with the local public transport authority or operator.
- Differentiated levels of service: for each single trip, Via gives the final client the option for a more direct but costly service, Via Express.
- Different environments: the operational contexts vary from suburban and/or areas poorly served by public transport systems, (such as the operations in Orange County and in Kent Science Park/Sittinbourne) to dense urban centres (such as New York).

2.3. Bridj

Bridj is one of the first for-profit smartphone-based DRT enterprise. It launched the first operations in the metropolitan area of Boston, Massachusetts, in 2014. It offered non-stop fixed routes trips in premium buses (Gizmodo, 2014).

The initial routes were established using passengers’ preferences during the trial period, government information and social media (Next City, 2014). During the following months, the company went through important changes: (1) the distance-dependent fare was replaced by a flat one; (2) the 50-seats buses were substituted for 14-passenger vehicles; (3) it launched the app that allowed clients to book trips and track the vehicles, and (4) it stopped offering a monthly subscription (Beta Boston, 2015a, 2015b; Xconomy, 2015).

In 2015, the system expanded to Washington D.C., where it operated with a flat-fare (Americaninno, 2015). In 2016, Bridj started in Kasas City, in a pilot program partnered by the local public transport authority and car manufacturer Ford, serving large employment areas during peak hours, offering displacements for a flat-fare equal to the current regular system (Peterangelo & Henken, 2017). This project did not meet the initial ridership expectations, mainly due to insufficient marketing, the inadequate times (the pilot just ran during peak hours) and served areas (which did not meet the population’s commuting needs) (Shaheen et al., 2016; Westervelt et al., 2018).

In April 2017, Bridj terminated its operations due to a deal that felt through with Toyota (Boston Globe, 2017). It was afterwards acquired by an Australian transport operator and relaunched in Sydney (Americaninno, 2017). In this new context, the system is being used as a feeder service to train stations, under a non-subsidized, flat-fare regime (Perera et al., 2019). The initial results demonstrate a growing ridership that could be justified by a better travel experience and/or by time savings, which seem to outweigh its higher fares when compared to the regular system (Perera et al., 2019).

2.4. Chariot

The operations began in April 2014 in San Francisco in corridors already served by public transport lines (Walker, 2017). Chariot is a fixed-route, fixed-schedule DRT system, in contrast to the other mentioned examples. The main "demand-responsive" aspect of this service was the crowdsourcing and crowdfunding technique used to create new routes: if 120 users vote for a certain route and would buy a monthly pass upfront, the enterprise would launch the line in a few days, making the process of creating new routes bottom-up and thus much more economic and faster (TechCrunch, 2014).

2.5. Brengflex and other Dutch experiences

Brengflex started operation in 2016 in the Dutch region of Arnhem-Nijmegen. The Brengflex pilot offered stop-to-stop connections between 255 bus stops, serving 200,000 inhabitants. The system replaced two pre-existing bus lines and charged passengers with a fee of € 3.50 and a detailed analysis showed that the users benefited from lower generalized journey times - i.e. the perceived journey times– in comparison to the public transport alternative (Alonso-González et al., 2018).

Following Brengflex, other DRT services started in the Netherlands afterwards. In December 2017, Helmond and its surroundings started Bravoflex. Prebooked Bravoflex rides costed €3.00 in a stop-to-stop regime (Hermes, 2019). Also in 2017, Mokumflex started operating in Amsterdam, operated by RMC, a private company. RMC also started another DRT system in Rotterdam in partnership with the public transport operator of Rotterdam, RET. This last pilot was named RET STOPenGo (RET, 2019).

3. Case study of the replacement of a fixed line by DRT

In the case of Amsterdam, the municipality launched a pilot program called Mokumflex, which operated between December 2017 and December 2018. The pilot motivation was to reduce costs, while maintaining accessibility in a low-demand area, investigating demand-responsive transport and evaluating the integration of paratransit and non-paratransit demands (Gemeente Amsterdam, 2018).

Two areas were chosen for the test, based on their limited public transport offer and low efficiency.The project was executed differently in each one:

- In Amsterdam Zuidoost and Weesp, Mokumflex was added to the existing public transport offer (provided by line 49) and ran between December 2017 and December 2018;
- In Amsterdam Noord, Mokumflex completely replaced the public transport (previously provided by lines 30 and 31) and ran between February 2018 and December 2018.

As the objective of this study is to evaluate the impacts of the replacement of fixed bus lines for DRT, only the outcomes of Amsterdam Noord will be presented. For further information about the impacts in Amsterdam Zuidoost and Weesp, other indicators and comparisons, please refer to Coutinho (2019). The area served by the lines 30 and 31 is shown in Fig. 3.

While the original fixed bus lines were operated by GVB (the local public transport operator) and regulated by Vervoerregio Amsterdam (the transport authority), Mokumflex was operated by RMC, a private enterprise, which also operated the paratransit of the region. Since the paratransit is regulated by the municipality of Amsterdam, the project was regulated by the municipality, not by GVB. It is important to say that the fleet of Mokumflex was not dedicated, as RMC used these vehicles to provide paratransit as well. Fig. 4 summarizes the main operational features (number of vehicles, operational time-frame, headway, number of stops and fare) of both the before (fixed) and after (flexible) services.

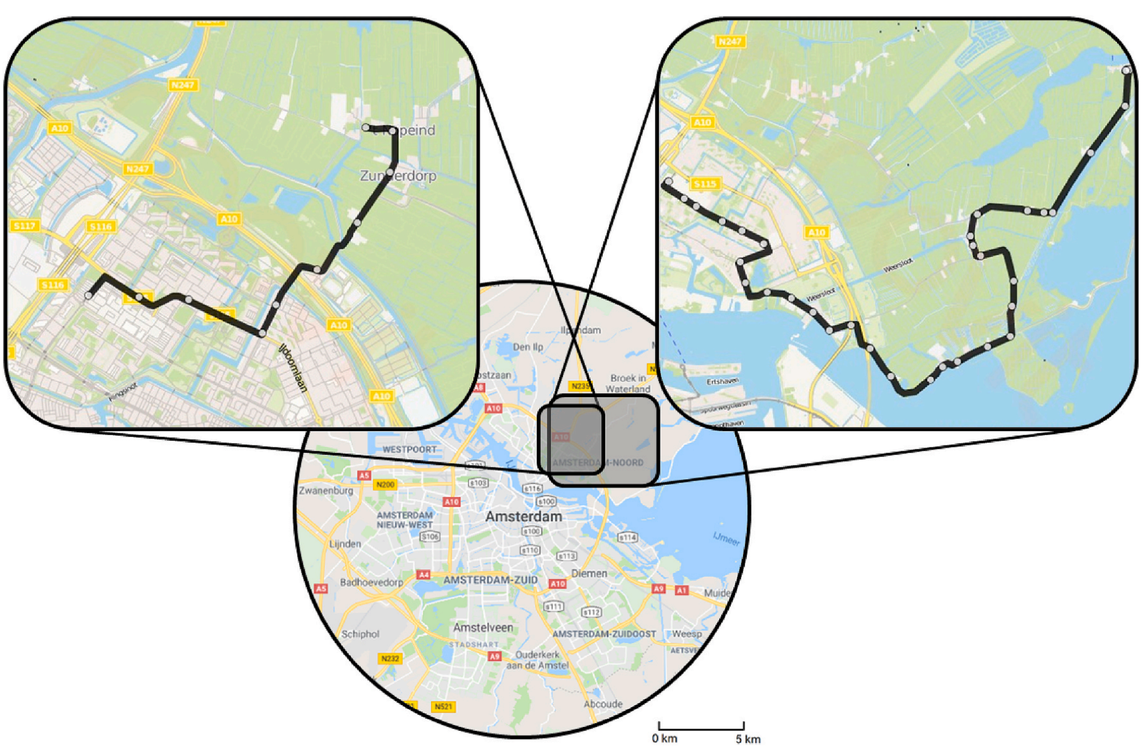

Fig. 3. Fixed bus lines in the 'before' state of the case study (top left, line 31, top right, line 30).
Source: Google Maps (2018) and Moovit (2018).

	GVB	Mokumflex
Fleet	30: 2 vans; 31: 1 van	2 vehicles
Operating frame	30/31: 6:00 - 24:00, Mo-Fr	6:00 - 24:00, Mo-Mo
Headway	30/31: 60 min	N/A
Stops	30/31: 43 stops	45 stops
Fare	0,155 €/ km	Free

Fig. 4. Before and after service characteristics.

This comparison demonstrates that the structure for Mokumflex was leaner: 2 vehicles were capable of serving the areas that previously required 3 vans (without considering reserve fleet). However, as will be presented later, the transformation caused a drop in ridership, making this comparison unfair. Also, it is important to note that the pilot extended the operating time-frame as well as the number of stops.

With regard to the large headway of 60 min, it was replaced by a demand-based system: the user had to book a trip up to 1 h before and the vehicle was supposed to arrive in a 15-min time-frame around the desired departure time. Finally, while the previous system was charged at 0.155 €/km (GVB, 2018), the pilot was free of charge.

4. Data analysis

As previously mentioned, public transport has the capacity to help urban planners to surmount some of the main issues of urban sprawl on the ongoing context. However, not all the impacts regarding the implementation of mobility projects are considered, when designing new transport policies and plans. And despite the technical capacity that humanity currently dispose of, the main indicators used for evaluations are still traditional metrics, such as costs and time savings, as illustrated for the instance (Van Oort et al., 2017). This work incorporated, then, a broader set of indicators to compare a regular public transport line with a DRT taking into consideration some indicators pertaining to sustainability.

4.1. Data sources

Diverse sources were consulted to consolidate the metrics used in the comparisons as this information was not readily available. The first dataset was the one provided by RMC, containing information such as displacing, request and drop-off times, request and drop-off stops, user's opinion, the ID of the car allocated for each displacement and scrambled client's ID, for the whole duration of the pilot program, as shown in Table 1:

For the service in Amsterdam Noord, between February 2017 and December 2018, 5980 requests were recorded, 95% were properly registered (different pick-up and drop-off stops, times and distance travelled superior to 50 m) and 83% of the displacements were completed (for the rest, the passenger did not show up).

The second most important source was provided by the local public transport operator, GVB, containing information about the demands for the regular bus lines via smartcard data, containing tap-in and tap-out information.To find more details of the Dutch Smartcard system, refer to Van Oort et al. (2015). Finally, other sources of data were the socio-demographic and territorial facts provided by the Dutch Bureau of Statistics, CBS (CBS, 2012), and the national car database, which keeps a detailed description about each car registered in the Netherlands and is available via the website of RDW, the Dutch Vehicle Authority (RDW, 2019).

4.2. Comparison between the fixed system and the DRT system

Considering that the objective of this work is to evaluate a DRT project going beyond the traditional operational metrics (such as mileage, ridership and costs), a broader set of indicators was selected to compare the regular public transport and the demand responsive offer, considering also environmental and social impacts, following the 5E framework proposed by Van Oort et al. (2017).

In the comparison between systems we considered: ridership (passengers/month), distances (vehicular kilometres/month), costs (€/month, €/passenger and €/kilometre), GHG emissions (measured in gCO2Eq/veh km) and user's satisfaction obtained from surveys with the users of both systems).

For the DRT, the first two indicators were extracted from the dataset provided by RMC, the operator. While the ridership was straightforward, the mileage required considerable calculation, as the distance travelled from the place where the vehicle received the request up to the pick-up stop was unknown. To address this issue, the time when the vehicle started displacing for the pick-up point combined with the average speed of the displacement (represented by 1 in Fig. 5), allowed the estimation of the distance travelled between the request and the pick-up stop. By summing this displacing distance ("1" in Fig. 5) with the tripping distance ("2" in Fig. 5) and the one to and from the depot, it was possible to obtain the total mileage.

Another important feature that deserves explanation is the fleet dimensioning of the DRT. As previously mentioned, since RMC used vehicles from the paratransit system for the displacements of Mokumflex, the "fleet dimensioning" was based on the "analysis of simultaneity of vehicles" operating in Mokumflex: for every minute of the pilot, it was checked how many vehicles were providing trips for Mokumflex. The results are demonstrated in Fig. 6.

Table 1
Example of the dataset provided by RMC.

Date	Passengers	Realized/No-show	Displacing time (sec)	Pick-up time	Drop-off time	Pick-up stop	Drop-off stop	Trip rating	Vehicle ID	Client ID
180511	1	Realized	1195	08:13	08:27	17	3	Satisfied	1	
180511	2	No-show	356	08:35	08:49	3	18	-	2	
180511	2	Realized	897	09:45	10:15	9	2	Dissatisfied	3	
180511	1	Realized	218	09:49	10:15	10	2	Satisfied	3	

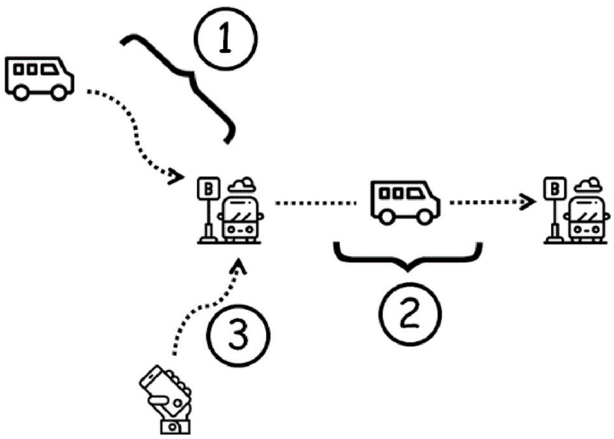

Fig. 5. Displacing and trip distances.

The average values in Fig. 6 show that the paratransit vehicles operated 192 min per day for Mokumflex. In 168.5 of those, there was only one car, while in 20.6 min, there were 2 and the remaining 2.9 min saw the presence of 3 or more vehicles. Based on the fact that for more than 98% of the operating minutes there was one or two cars, it was assumed that 2 were sufficient to provide the displacements (implying additional waiting time for passengers during the mentioned 2.9 min).

When it comes to the demand of the previous public transport offer, this was provided by the local bus operator, GVB and it contained the ridership for the line, per month, per stop, between February 2018 and January 2019. In regards to the mileage, it was calculated based on the headways, line length and distances to and from the depot, as shown in the following equation:

$$Dtot = Ddfs + Ddls + Llen*Ndisp$$

where:

- "Dtot" is the total distance travelled by a bus on a given day;
- "Ddfs" is the distance depot-first stop;
- "Ddls" is the distance depot-last stop;
- "Llen" is the line length, i.e. the distance between the first and the last stops;
- "Ndisp" is the number of displacements, i.e. number of times that a bus runs throughout the line.

Concerning the costs, they were divided into components studied for each vehicle model:

- Depreciation;
- Energy (fuel and, for electric vehicles, battery packs);
- Insurance;
- Interest of the depreciation;
- Maintenance;
- Own risk damage;
- Staff (direct and indirect);
- Storage;
- Taxes.

For Mokumflex, since the vehicles also alse were involved in paratransit operations, the costs were divided among the systems.Partial GPS data availability allowed the estimation of the total distance displaced daily by the cars, namely 243.0 km, out of which 56.2% was for Mokumflex trips and the remaining 43.8% for paratransit trips. This proportion was applied to divide the distance-based costs. Finally, no opportunity costs nor estimations for the future were considered.

For the GHG emissions, a Well-to-Wheel (WTW) analysis, comparing three different vehicular models, was made, being wo models that were used during the pilot and one being the van used for former lines 30 and 31. For the population's perception, the data came from the evaluation of users (after they completed each trip), where they could evaluate the displacement as "very satisfied", "satisfied", "reasonable", "dissatisfied" and "very dissatisfied".

5. Analysis of the case study Mokumflex

This section presents the main findings with regard to the indicators analysed. It starts with traditional metrics (distance, ridership and costs) and is followed by GHG emissions and population's perception.

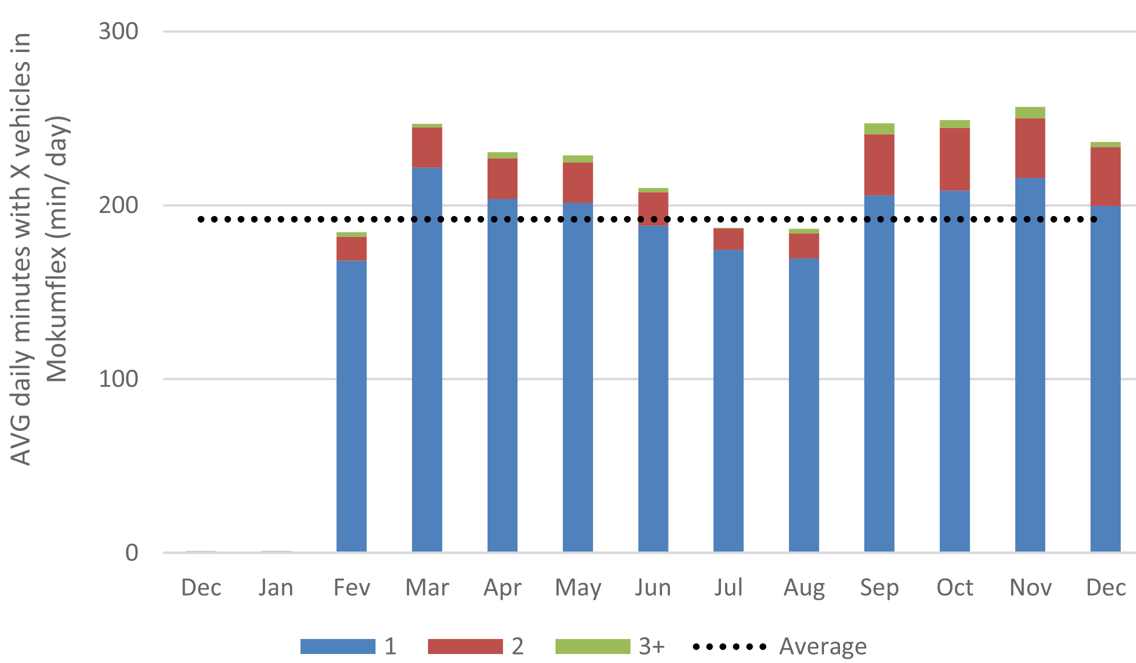

Fig. 6. Necessary fleet to run Mokumflex.

5.1. Ridership and distances

When comparing different public transport systems, the most traditional indicator is ridership. In addition, since this work incorporates other indicators that depend on the distances (such as operational cost and GHG emissions), the mileage travelled by the vehicles was calculated, following the method presented in Section 3. A summary of both is proposed in Table 2.

From this table, the low-demand character of the region is latent: the ridership of lines 30 and 31 combined was only 78 people per day. For Mokumflex, this number was even lower, about 16 users daily, despite the fact that it was free of charge. This drop is possibly linked to the large time-frame of 15 min around the desired departure time, that required customers to organize their schedules for a 30-min basis (as will be discussed in Section 5.4), but also due to the necessity of interacting with a system, instead of simply showing up in the stop. On the other hand, Mokumflex was more efficient in terms of vehicular mileage per passenger, as the distance reduced more than 46%, from 16 km/passenger to 8.6 km/passenger.

Since some of the chosen indicators of this analysis are directly influenced by the number of passengers and mileage, the occupancy (given by passenger kilometres/vehicular kilometres), is a suggestive metric to evaluate the performance of public transport systems. A compilation for different systems is shown in Table 3:

From a public transport perspective, disposing of a high occupancy is positive, as less vehicle-kilometers are necessary to transport passengers. The numbers for Mokumflex show an operation incapable of bringing positive effects to congestion, with the ratio being far lower than the local public transport system and even lower than the private Dutch car. However, congestion is not an issue for the low-density areas that Mokumflex serves.

When comparing the numbers of Mokumflex with those of Via, in 2016, which is also a DRT provider whose main operations are situated in consolidated urban centres, an inferior outcome is evident. However, since Mokumflex operates in a low-demand area, direct comparison with Via is not fair. Another interesting observation is about the daily distribution of the demand, shown in Fig. 7.

While the previous system had peaks around 8 A.M., 12 A.M. and 2:30 P.M, the demand for Mokumflex was more evenly distributed. Besides that, the substantial decrease in ridership is also evident.

5.2. Operational costs

The second most traditional indicator is the cost and it relies on mainly four aspects of a public transport system: the time-frame of the operation, the number of cars used, the vehicle model, and the mileage. The number of vehicles and the mileages were already discussed, but regarding the models, the previous lines were operated by a Mercedes-Benz Sprinter City (Traminfo, 2019), while Mokumflex used a set of different cars to provide the displacements. A CNG Combi, however, was used in more than 20% of the trips and was one of the models chosen for this evaluation. Moreover, an electric e-Crafter was introduced to check the impacts of electrification. The cars studied in this comparison are shown in Fig. 8.

The financial analysis demanded inputs that came both from Mokumflex, GVB and literature. The total cost of ownership (TCO) was calculated on a monthly basis, considering different mileage, daily time operations and type of fuel. A detailed explanation of each component of the operational costs can be found in Coutinho (2019). The summary of the costs is shown in Table 4 (the numbers are per vehicle while the information per system can be found in the conclusion section).

Table 2
Mileage and ridership.

	Fixed, Line 30	Fixed, Line 31	Fixed, Total	Mokumflex
Mileage (vehicular km/day)	1085.9	166.8	1252.8	136.6
Demand (pass/day)	64.7	13.4	78.1	15.9
Veh km/passenger	16.8	12.5	16.0	8.6

Table 3
Occupancy of different modes.

Public Transport Mode	Occupancy (passenger km/vehicular km)
Mokumflex, 2018	0.630
Netherlands Car, 2016	1.415
Amsterdam Bus, 2017	12.200
Amsterdam Tramway, 2017	28.164
Amsterdam Metro, 2017	83.449
USA Via, 2018	1.136
USA Uber, 2016	0.592
USA Bus, 2016	9.865
USA Light rail, 2016	22.226
USA Commuter rail, 2016	31.634
USA DRT, 2016	1.032
USA Taxi, 2012	0.527
USA Car, 2017	0.649

Source: KiM (2018), Gemeente Amsterdam (2017), Gemeente Amsterdam (2018b), Golde et al. (2017), Henao (2017), BTS (2020a), BTS (2020b), Schaller (2015), Energy (2018).

The regular line was less cost-performing than the demand-responsive offer in all the "total" indicators, showing that, despite the drop in demand, Mokumflex was more efficient. This is due to two reasons: the higher daily mileage (that caused more expenditure regarding fuel and other distance-dependent indicators, such as maintenance), but also due to the larger number of working hours per week: while the previous system operated 90 h/week with 3 cars (thus implying 270 h of direct and indirect staff per week and an average of 391h per car, per month), the demand-responsive ran an average of 192 min per day requiring, then, 44.8h per week and an average of 97.3h per vehicle, per month. This is fundamental when it comes to the analysis of these indicators as they will have a larger denominator and consequently, lower numbers making them "apparently more time and distance effective".

When it comes to the comparison of the energy disbursements between the CNG Combi and the e-Crafter, the e-Crafter was more expensive, mainly due to the depreciation of the battery pack, that accounted for about 62% of the total expenses with energy. A cost composition is depicted in Fig. 9.

This cost composition demonstrates that workforce is indeed highly impacting the total costs of the previous lines, but still accounts for an important part of the costs of Mokumflex, demonstrating the potential for automation. In regards to depreciation, the absolute disbursements were equivalent in absolute terms before and after but, given that after the transformation the total monthly expenditure diminished, it grew in percentage.

5.3. GHG emissions

Since this work considers a broader set of indicators than simply cost and ridership, an analysis of GHG emission was performed. The choice for a Well-to-Wheel (WTW) analysis evaluated more precisely the numbers and allowed the estimation of the impact of electric cars. It is important to say that for Tank-to-Wheel (TTW) emissions, the CO2 emissions were considered numerically by an equivalent to the total CO2 emissions, as other GHG accounts for small fractions of the total (Becker et al., 1999; Nam et al., 2004). The values are summarized in Table 5.

The lower emissions of the DRT were obtained by the cleaner fuel technology (higher efficiency), but the majority of the difference is due to the higher mileage of the regular offer. This raises the total emissions, making the previous system less performing than the demand-responsive one. Special attention should be given to the Well-to-Tank

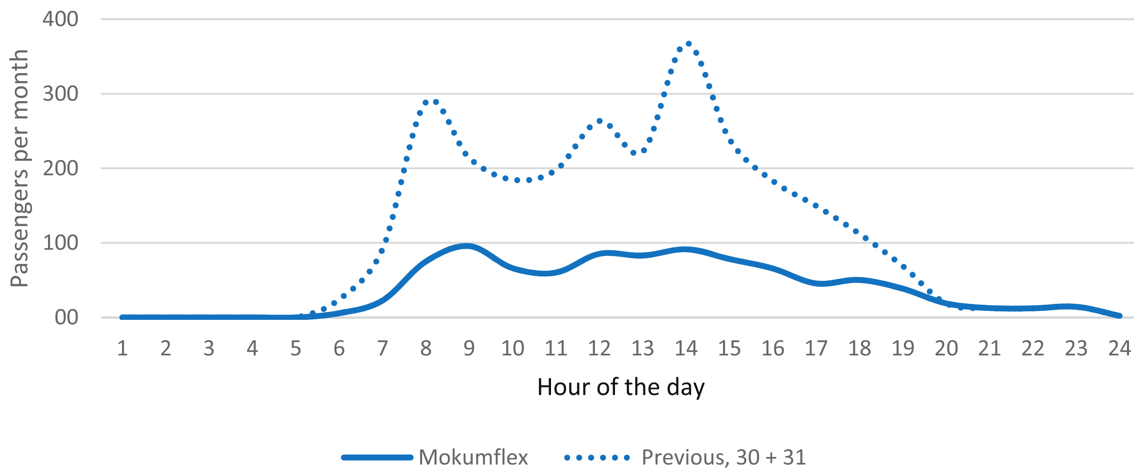

Fig. 7. Daily distribution of the demand.

Fig. 8. Vehicle models used for the financial analysis (from the left to the right: Combi, e-Crafter and Sprinter).
Source: Autowereld (2018), Green car reports (2017) and Busphoto (2019).

Table 4
Operational cost analysis.

	Fixed, Line 30 Sprinter	Fixed, Line 31 Sprinter	Mokumflex Combi	Mokumflex e-Crafter
Lifetime (years)	3.6	8.3	3.2	3.2
Lifetime (km)	504,000	360,000	288,000	288,000
Operating hours (hours/month)	391	391	97	97
Catalog price ($/vehicle)	$41,000	$41,000	$54,293	$54,184
Total ($/month)	$15,360	$13,567	$4775	$4951
Veh costs (%)	24%	14%	39%	41%
Workforce (%)	76%	86%	61%	59%
Total ($/km)	$1.30	$3.74	$1.15	$1.19
Total ($/pass)	$21.63	$50.06	$6.42	$6.65
Total ($/op. hours)	$39.28	$34.69	$49.06	$50.87

(WTT) emissions, that are a considerable part of the total: in the case of the e-Crafter, the carbon-intensity of the electrical Dutch matrix negatively impacted its performance, being even more pollutant than the manufacturing of the diesel.

5.4. Population's perception

The last indicator investigated was the population's perception. As the punctuality was a major issue for Mokumflex, the following numbers were split in two sub-groups: "on-time" and "not on-time" trips. Trips were considered to be "on-time" if the pick-up time was contained the 15-min frame around the requested pick-up hour. In total, 3892 completed trips were "on-time" and 329 were evaluated, while the "not on-time" accounted for 1082 completed trips and 64 evaluations. In regards to the previous system, it was measured differently: GVB's bus system had a satisfaction of 7.6 in 2016, in a 0–10 scale (GVB, 2018). The results for Mokumflex are summarized in Fig. 10.

The system enjoyed a good perception, with almost 94% of the "on-time" trips being evaluated as "very satisfying" or "satisfying". On the other hand, when it came to the judgement of the "Not on-time" trips, "very satisfying" reduce its representativity, giving space to the other opinions. Unfortunately, there was no similar data available for the previous fixed lines, which would allow further analyses.

6. Discussion and conclusions

This paper investigated the differences in terms of distances, ridership, costs, GHG emissions and population's perception of a DRT system compared to a regular bus line, based on an actual case study in Amsterdam. The results showed that the reduced mileage and operating time-frame contributed to a better overall efficiency of the on-demand system, when compared to the previous fixed service, despite the drop in the ridership. It was demonstrated that the transformation considerably impacted the ridership, which dropped to less than 28% of the previous level. However, as the mileage reduced to less than 11% the previous, the resources were rationalized. The number of vehicular kilometres per passenger, operational costs per passenger and GHG emissions per passenger were smaller. The system was also well positively vperceived by the users and punctuality was proven to be an important determinant of satisfaction with the DRT system. A summary of the used indicators along with their values are given in Table 6.

However, questions such as the proper context for DRT implementation, are still lacking answers. In low-demand areas, cars are usually more performing, since public transport requires large mileages to serve displacements, and they should be used for comparison in the moment of the decision-making process for these situations (Coutinho, 2019).

Furthermore, smartphone-based services require a level of digital literacy that usually population do not dispose of, especially for the

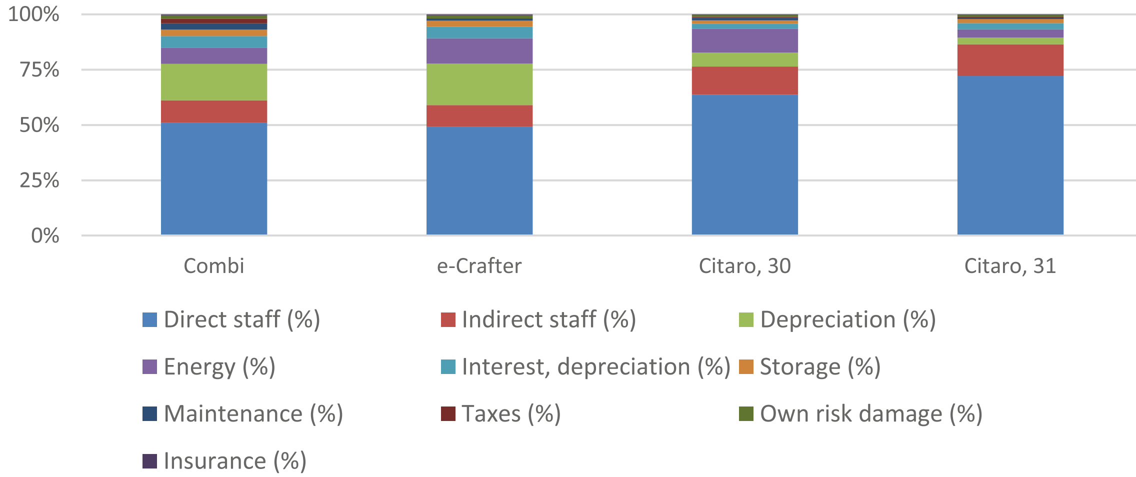

Fig. 9. Cost composition.

Table 5
Comparison between systems.

	Fixed, Total[a] Sprinter	DRT[b] Combi	DRT[b] e-Crafter
Fuel	Diesel	CNG	Electricity
Consumption (Lt, m^3 or kwh/100 km)	39	7	22
WTT emissions (gCO2eq/km)	103.5	49.7	115.1
TTW emissions (gCO2eq/km)	233.0	195.4	0.0
Mileage (veh[a]km/day)	1252.8	136.6	136.6
Emissions (kgCO2eq/month)	9275[b]	1004[a]	472[a]
Emissions (kgCO2eq/pass)	5.4	2.1	1.0

[a] 22-days month.
[b] 30-days month.

elders, which are a vulnerable group in terms of mobility and tend to live in rural areas (Ellis & McCollom, 2009).

From a public interest perspective, regulating the private sector is fundamental. Besides the fact that these systems may compete with regular public transport, capturing users, funnelling revenues and affecting mainly low-income communities (Maher, 2015), there are two other social issues with the free development of DRT. The first of one is the necessity of analysing what is already in place. In NYC, Chariot had social frictions due to the competition with the dollar-vans, which is a pre-existing informal and demand-responsive system (Brookelyn, 2017). The second one is that the ease to crowdfund and create new routes also works in the other sense as companies do not hesitate to eliminate under-performing routes or stops (TechCrunch, 2015).

In regard to the pricing policy, even if higher fares were found by Perera et al. (2019) as one of the main barriers for users to make DRT a daily option. The case study of Mokumflex demonstrated that other factors, such as punctuality, can have large impacts on this process.

Finally, Mokumflex was a pilot program whose objectives were to reduce costs and keep the provision of a public transport system in a low-demand area, to study demand-responsive public transport and to evaluate the integration of paratransit and non-paratransit demands (Gemeente Amsterdam, 2018a). From the data made available by the

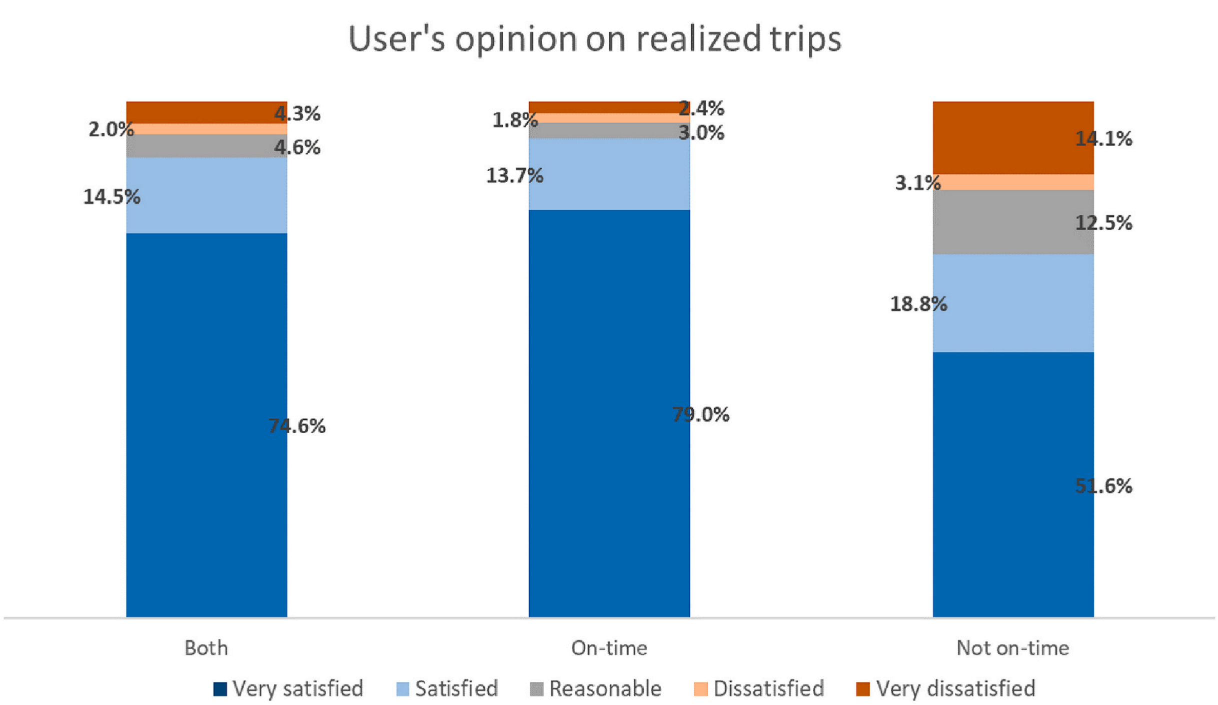

Fig. 10. Population's perception.

Table 6
Summary of the comparison.

	Fixed, 30 + 31[a] Sprinter	DRT[b] Combi	DRT[b] e-Crafter
Mileage (vehicular km/month)	27,561	4098	4098
Ridership (passengers/month)	1718	478	478
Vehicles	3	2	2
Operational costs (€/month)	$44,288	$9551	$9903
% vs Fixed line	100%	22%	22%
CO2 emissions (kgCO2Eq/month)	9275	1004	472
Population's perception	7.6/10	89,1% "very satisfied" or "satisfied"	

[a] 22-days month.
[b] 30-days month.

enterprises, only the last of these was not evaluated, but Mokumflex fulfilled the other goals since the first year of operations.

CRediT authorship contribution statement

Felipe Mariz Coutinho: Conceptualization, Data curation, Formal analysis, Methodology, Writing - original draft. **Niels van Oort:** Conceptualization, Data curation, Methodology, Project administration, Supervision, Writing - original draft, Writing - review & editing. **Zoi Christoforou:** Conceptualization, Methodology, Supervision, Writing - original draft, Writing - review & editing. **María J. Alonso-González:** Supervision, Writing - original draft, Writing - review & editing. **Oded Cats:** Data curation, Writing - review & editing. **Serge Hoogendoorn:** Writing - review & editing.

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