Evaluation of the impacts coming from the transformation of fixed bus lines into demand-responsive systems

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**ABstract = résumé**

Mokumflex is a demand-responsive transit (DRT) pilot that replaced/complemented the regular bus service in two low-density areas of Amsterdam for 12 months. This work aimed to evaluate the impacts of this changing, analyzing indicators such as ridership, costs, level of service, population’s perception, CO2 emissions, pollutants, accidents and tax revenue. Due to the lower mileages and lower fuel consumption, this DRT program presented better results when compared to the previous offer, allowing the Municipality of Amsterdam to optimize its economical resource in a more sustainable way.
Acknowledgement

This thesis is the result of 8 years of study in four different universities in 3 different countries. Hanging from the Brazilian technical perspective, passing through the socially implicated French culture and refined by the performance-based Dutch mindset, I tried to incorporate most of my learnings to make this work the most pragmatic possible.

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My sincerely thank you,

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List of abbreviations

AOV – Transit for disabled passengers;
DRT – Demand responsive transit;
GHG – Greenhouse Gases;
LR – Lost ridership;
SRT – Shared-ride taxi;
TTW – Tank to wheel;
VOV – Transit for non-disabled passengers;
WTT – Well to tank;
WTW – Well to wheel.
Executive summary

Three of the most important characteristics of the current context humanity is going through are the expansion of urban centers, the internalization of sustainability goals and the diffusion of the new communication technologies, such as smartphone and tablets (UN, 2012, and GS Statcounter, 2018). Yet, knowing the inherent negative externalities of private transportation and the new possibilities offered by this environment, urban planners are being forced to rethink mobility, favoring innovative and more sustainable modes of transportation.

The “converging forces” transforming the future of mobility include electrification, new materials, connected, autonomous vehicles and the reduction of the ownership (Deloitte, 2015). The last of these brings, as direct solution, shared and on-time transportation systems and this is core behind the concept of the demand-responsive transit, DRT. Even if they have been around since the beginning of the last century, the inexistence of the smartphones burdened their development and is exactly this gadget that is making possible the redesign of these type of businesses (Westervelt et al., 2018).

Considering that these new mobility offers are being dominated by startups that normally do not publicize data, partnering with a private enterprise responsible for the operation of a DRT experiment in Amsterdam willingness to understand this “new” solution gave this thesis a deep understanding of the subject.

The main objective of this study is, then, to evaluate the impacts coming from the implementation of a demand responsive transit service based on real data from a pilot program called Mokumflex which was implemented in two different areas of Amsterdam between December, 2017, and December, 2018.

The methodology is composed of different kind of studies: the first one is a literature review about the beginning of DRT, where an investigation of historical documents of conferences, reports and thesis about DRT experiences during the 60’s and 70’s, followed by an analysis about current experiences, where diverse websites, reports and blogs were consulted.

The following consists of data analytics: using diverse datasets, different investigations were realized. Starting with an overview of the transit offer before and after the implementation of Mokumflex, the next steps are the spatial characterization, ridership analysis, population’s perception, network effects, operationnal costs, societal costs and sensitivity analysis. A more detailed explanation of the methodology is offered in the next chapter.

Back to the pilot, as previously mentioned, it was implemented in two areas but differently: while in Amsterdam Noord the conventional bus lines 30 and 31 were completely replaced by the demand responsive system – which will be referred as the line 301 of Mokumflex -, in Amsterdam Zuidoost and Weesp the offer was added to the regular service, which is provided exclusively by the regular bus line 49 – and will be referred as the line 490 of Mokumflex.

Initially, the reader is brought to the beginning of the XIX century, when the first demand-responsive systems appeared in the North-America. Then he is taken to the 60’s and 70’s, where they started their
spread worldwide: main features of iconic examples, such as Bay Ridges (Ontario), Regina (Saskatchewan), Columbus (Ohio), Ann Arbor (Michigan), Batavia (New York), Haddonfield (New Jersey) and Rochester (New York) are presented. Furthermore, a special regard is made to the two last of these experiences, Haddonfield and Rochester, since they were the first ones with automated dispatching. The next table summarizes the developments during each decade:

- **10’s**
  - First DRT trials: jitneys in the USA.

- **60’s**
  - First dial-a-bus experiences;
  - CARS project.

- **80’s**
  - Budget cuts and development of GPS, telephones and GIS.

- **00’s - 10’s**
  - Diffusion of internet and smartphones;

- **20’s-50’s**
  - Few formal experiments.

- **70’s**
  - Spread of DRT in the USA and Europe;
  - First automated programs.

- **90’s**
  - Enhanced data collection;
  - Improvements in communication solutions.

Figure 1: Context of the development of DRT


The continuity of the report contains the explanation of some modern DRT experiences: startups like Bridj, Chariot, Via and Kutsuplus are presented, but also rural DRT, Dutch projects and initiatives in developing countries. A critical analysis of the main issues is proposed in the end, containing discussions about driver’s remuneration, social issues, partnership with local transit authorities and fares.

The next section is dedicated to the description of the context where Mokumflex was introduced. Spatial, social and economic indicators of Amsterdam and a more specific look at the catchment areas of the stops of Mokumflex is proposed. The user will see that the system runs in very different contexts, hanging from a dense and poor suburban occupation to a rich and low-density rural core. Still, an overview about the main features from both the previous and the Mokumflex’s offer is made, as following:
From this figure, it is possible to see that, despite the extended time-frame and intricacy, Mokumflex had lower monthly riderships than the previous regular transit demonstrating the difficulty coming from the introduction of inedit transit solutions.

The continuity is dedicated to the data analytics of the private datasets. Starting with the demand analysis, the user will be shown, for example, the drop on the ridership of the line 301 - 30% of the previous, different from the good patronage for the 490 - considering that the regular system kept the same ridership, the current usage of transit is 272% of the previous. Then, the potential of the increased intricacy is analyzed: even if only a few stops were added to the line 490, they were origin or/and destination of 70% of the trips. The following puts in evidence the low occupancy of the system: the ratio $\text{veh*km/ pass*km}$ of 1,588 is smaller than Uber in the USA but much larger than personal car and the other local buses and metros of Amsterdam.

In addition, the fleet dimensioning is presented: while the previous offer demanded at least 5 buses, Mokumflex – even if it could use any of the more than 300 cars used for the transit for people with disabilities - needed only 2 cars to provide the service with the current level of service, ensuring considerable economic and environmental advantages even if the total ridership during Mokumflex – 870 pass/month - was 46% of the previous transit and that these riders were possibly relying on private car to displace.

Nonetheless, before passing to the economic and environmental investigations, the perception of the local population and the network effects is highlighted. The discussion about the local opinion was based in two different sources, that had different results: while the survey made by the Municipality of Amsterdam demonstrated a weak satisfaction, the evaluation of the trips made through the smartphone application showed encouraging numbers about local population’s contentment.

In regards to the network effects, a regression analysis for trip length and occupancy levels versus demand were plotted, demonstrating considerable impacts: for the line 490, for a daily demand of 1 pass/day the average passenger’s trip length is 26.3km and the occupancy, 7,333 $\text{veh*km/ pass*km}$, while for 10 pass/
day these numbers are respectively 11.6 km and 3,206 veh*km/ pass*km, and for 50 pass/day, they drop 6.6 km and 1,798 veh*km/ pass*km: the gains of scale are put in evidence and discussed.

The following being dedicated to the total cost of ownership, TCO, analysis. It was broken down in 9 main components - depreciation, interest of depreciation, insurance, own risk damage, taxes, storage, maintenance, energy, direct staff and indirect staff - which were carefully analyzed for 7 different vehicle models – Combi, e-Crafter, Caddy, Rapid, Golf, e-Golf and Citaro bus – that ran in 4 different fuels – CNG, diesel, gasoline and electricity.

The reader will see that a traditional regular bus line is much more expensive than a demand-responsive one: a CNG Combi operating for Mokumflex had a monthly cost of € 7,089, while a diesel Citaro bus of the line 49 required € 19,414 per month to run. The following table with the contribution of each portion of the TCO to the total cost gives the reader an idea of the content of this section:

From this table, the user can see that workforce is the most important cost for all systems, demonstrating the potential of vehicular automation. Also, despite the Rapid, the depreciation costs are much more important for car-based systems than for bus-based operations.

The last part of the data analytics evaluated the societal costs. Composed of three externalities, GHG, pollutants and accidents plus the impacts on the tax revenues, this section highlights the consequences of the usage of the 7 different models of vehicles presented before.

The first part is the GHG emissions, which was studied in a Well-to-Wheel analysis, WTW. The reader will discover that the previous bus-based system had much higher emissions than the demand-responsive one due to the fuel consumption of the buses as well as the larger mileages: a CNG Combi-based Mokumflex emitted 245.1 g/km and ran for 6,362 km/month – plus 138.3 g/km and 3,744 km/month for the lost ridership –, while the previous bus-based system emitted 1397.7 g/km and travelled 28,082 km/month.

Another interesting point is the comparison with electric cars: due to the carbon intensity of the Dutch energy matrix, their numbers are still surprising as the e-Golf expel 91 gCO2Eq/km, while a similar gasoline version, 138.3 gCO2Eq/km.
Afterwards, the pollution is evaluated: since PM and NOx are heavily impacting, large diesel vehicles are disadvantaged and, again, the previous system has the worst performance: while a CNG Combi-based Mokumflex has a pollution cost of 0,30 €/ month, the previous Citaro-based line 31 had a monthly impact of 830,63€.

The third externality are the costs coming from accidents, a number that relies on the type of vehicle and the mileage. Another time, the previous system has the worst performance due to the higher mileages: the line 31 is almost 10 times more expensive than a passenger-car based Mokumflex.

Finally, the revenues coming from taxes. As 4 different fuels were studied, 4 different taxations were then applied. In the end, the most performing – due to the highest fuel consumption – was the previous system, with a monthly tax collection of 8.456 € against 111 € coming from a e-Golf Mokumflex. This example shows how weakly taxed is electricity when compared to fossil fuels, raising a real economic issue when into the electrification of these fleets.

With these cost components, it was possible to evaluate the final costs of each model, demonstrating that the previous system was much more expensive than the DRT option and the electric versions still costlier than similar fossil models. The final result is presented below:

The last section is dedicated to the sensitivity analysis: how does the variation of the demand impact the trip length, occupancy and other indicators? The analysis demonstrated, as expected, that considerable economic savings could be made by scaling the system: even if in a simplified way, for a monthly demand of 30 passengers to 4500 passengers per month, the cost per passenger goes from 26,81 € to 6,06 €.

The conclusions and recommendations come with a set of practical improvements to allow enhance the performance of similar projects in the Netherlands and abroad: studying the daily and spatial distribution of the demand, introducing variable remuneration on the contract and investing some resources in marketing are examples of recommendations. For the conclusions, the motivation for the continuity of the project is summarized, due to how it addressed the objectives initally proposed by the Municipality of Amsterdam, its social value and the inherent potential.
1. Introduction

The humanity took thousands of years to expand and control the emerging lands of the world and relatively a few decades to develop an instantaneous and effective system of communication between them: this “notional environment in which communication over computer networks occurs” is what we call “the cyberspace” (Oxford, 2018).

In general, this promising context characterized by the diffusion of computer, internet, smartphone and data management allowed us to develop new solutions as well as to revisit older ones, trying to recreate them in a more effective way. In the transportation sector, this can be exemplified by the vehicular automation and electrification.

Yet, adding the persistent explosive urbanization rates and the diffusion of the sustainability ideals to this new environment, radical changes are naturally expected on the urban morphology. Considering the negative externalities inherent to transportation in metropolitan centers and the ability of transit to overcome them and still promote business growth, accessibility and public health (van Oort et al., 2017), urban planners are naturally pushed to design an economically performing, socially equitable and environmentally acceptable transportation network.

This scenario spontaneously brings us to more flexible and dynamic modes, where one can easily arbitrate among a set of options reachable in his surroundings to satisfy its needs: transit, car, bikes, Uber, Lyft, ViaVan and ZipCar are just the tip of the iceberg. It is in this effervescent ambiance that Demand Responsive Transit (DRT) is gaining more and more attention from both public and private stakeholders as an option to answer mobility challenges (Weckstrom et al., 2017).

The term DRT generally refers to different modalities of transportation in the specter between regular fixed schedule, fixed route transit and private cars. Also, another characteristics is that commonly disaggregated interests of travelers are taken into consideration to better tailor the design and/or operation of the service to the existing demand. In the broader sense of the term, taxis, TNC, shared-taxis and dial-a-vehicle systems are concepts included in this definition. For this study, however, the focus will be road dial-a-vehicle projects because this term better suits the system studied in this document, Mokumflex.

Even if the first experiences date from the beginning of the twentieth century, the first massive wave of dial-a-vehicle operations arose during the 60’s and 70’s in the United States, motivated by the incapacity of regular offers to provide adequate and economically reasonable supply to low-density areas (HUD, 1968). During the following years, the development of computational capacity, data collection, communication and localization technologies improved the performance of these solutions and nowadays, they are being used not only in sparsely populated areas but also in urban cores offering usually an option with intermediate fare and level of service between regular transit and private cars.

1.1 Problem definition

Over the last decades, sustainability has evolved from a marginal concept to one of the bases of the urban planning. In the field of the transport systems, this idea is translated into the creation of stronger
communities, support of economic development, promotion of equitable social participation, environmental health and formulation of appropriate institutional arrangements (Ryley et al., 2014).

On the other hand, the new technologies enabled alternative forms of transportation. However, the private sector is taking the lead in developing and deploying them but due to its economic nature, it is not necessarily focused on promoting public policy goals such as accessibility, equity and mobility as public stakeholders are. This situation highlights the necessity of regulation to maximize collective surplus but before creating the proper control, policy makers must get acquainted to the subject, assembling the necessary information for doing so (Westervelt et al, 2018).

1.2 Research gap

After an analysis of the available sources about these schemes, the author concluded that the absence of practical information about DRT operations worldwide as well as their impacts was a gap in literature. There are no studies comparing previous and current situation of regions that implemented DRT: most of the information is diffused into reports that approach only traditional metrics, not approaching the problematic of transportation into the sustainability framework. Some recent studies were preferred:

Shaheen et al., (2016) evaluated the implementation of Bridj, a private DRT provider, in Kansas City. The authors concluded that the failure of this pilot was linked to the absence of a solid marketing strategy as well as an unadapted time-frame operation and service area. However, this post-pilot evaluation was diffusely structured, not offering the reader a broader and unified overview of Ride-KC.

HSL (2016) published a very interesting report about the Finish context: a DRT experience in Helsinki called Kutsuplus. This project lasted for 3 years and the initial idea was to create a complete DRT network in the city but, despite the good results, it had to be abandoned due to the costs for scaling it.

Henao (2017) worked as a VTC driver in Colorado for 6 months, offering a practical evaluation of the business model: user’s profiles, mileages and costs were clearly exposed based on his experience. In one hand, the author demonstrated that, in terms of pass*km/ veh*km VTC was not very efficient as the dead miles accounted for almost 50% of the total, but on the other, the social impact of these services in reducing drinking and driving travels.

Gemeente Amsterdam (2018a) published a first report about Mokumflex, giving interesting insights and its perception about the pilot. Besides problems with punctuality and the drop of the ridership, positive impacts of Mokumflex were highlighted, such as the lower costs.

In brief, all of these literatures are based into traditional metrics despite the necessity of evaluating these systems based on the ideas behind the 5E framework proposed by van Oort et al. (2017).

1.2.1 Research questions

The rediscovery of DRT inserts into this mutating context, where society takes profit of the technological developments to promote sustainability. Given the speed with which technology and business models are evolving and the growing number of DRT experiences driven around the world, it seems pertinent to develop a research project whose main objective is to investigate the impacts of implementing DRT operations to help the decision-making process of transit stakeholders.

Taking into consideration the ideas illustrated above, the main question of this project is:
• What are the impacts of replacing an existing fixed bus system for a DRT operation?
This is a wide question was sub-divided in more precise terms to clarify the research guideline:
• What are the changes on the ridership when implementing a dial-a-ride operation?
• What are the differences in terms of economic, environmental and social performance?
• What are the main challenges faced by a DRT from a social perspective?

For adequate answers, this work was divided in a few steps that will be explained in the next section.

1.3 Methodology

As previously mentioned, transit has the capacity to help urban planners to surmount some of the main issues they are facing in the ongoing context. However, not all of the impacts coming from its implementation are considered when designing new transport policies and options, and despite the technical capacity humanity dispose currently, the main indicators used for evaluations are still traditional metrics, such costs and time saving, for example (Van Oort et al., 2017).

This work incorporated a broader set of indicators – in a quantitative way, when possible, or qualitative, when not - to evaluate the implementation of a new transit offer, following the 5E framework proposed by Van Oort et al. (2017), which deposit in transit the following expectations:

• Effective mobility: capacity of moving large number of people in a fast a reliable manner;
• Efficient city: unlock certain areas and sustain urban development;
• Economy: improve the competitiveness of an area, since well served zones attract people and enterprises for its surroundings, presenting favourable conditions to local economic growth;
• Environment: keeping cities clean and liveable, favoring smaller urban footprints and healthier lifestyles;
• Equity: build a more equal and sustainable society, allowing people that cannot use private transport to have comparable access to education, employment and health services, for example.

Observing the objectives of this thesis, the methodology was divided into five steps:

1. The first step is dedicated to set the context and define DRT: an initial discussion about the concepts and the presentation of a brief timeline is proposed. For this section, a literature review of reports, congress proceedings from the 60’s and 70’s as well as websites, blogs and studies provided the necessary information;

2. The second step consists of a presentation of the case study: a description of the area where the system was implemented and the previous transit offer as well as the main features of the operation. Here, different sets of data coming from the local transit operator, GVB, information from CBS and the trip-per-trip database from RMC, the operator of Mokumflex, were exploited;

3. The third step is data analytics: all the data gathered from the stakeholders of this project as well as external sources was summarized, formulating and allowing the analysis of indicators that represent traditional metrics and sustainability goals. This part contains the heavy part of the data analytics of this
thesis to evaluate ridership indicators, population’s perception, network effect, economic and societal costs and a sensitivity analysis;

4. The final step is the recommendation and conclusion phase: after analyzing the outcomes of the previous phases, a final chapter dedicated to the advises for enhancing the performance of the system as well as conclusions about the pilot program.

1.4 Data sources

Another important aspect to be explained are the datasets. The most important was the one provided by the enterprise that operated Mokumflex, RMC. It is composed of an exhaustive set of information trip-per-trip from all requests made since the first day of Mokumflex - in 11/12/17 for the line 490, and 03/02/18 for the 301 - and the last one – in 09/12/18 for both. The data consists of displacing, request and drop-off times, request and drop-off stops, user’s opinion about the displacement and the ID of the car that made this trip.

The second most important was the dataset provided by the local transit operator, GVB, containing information about the demands for the lines 30 and 31 month per month, and aggregated values for the line 49.

The third most relevant was the survey made by the Municipality of Amsterdam, in May 2018, where inhabitants of the areas were demanded to answer some behavioral questions, such as satisfaction, trip induction effect and impacts on the usage of transit.

Finally, other sources of information were the socio-demographic and territorial information provided by the Dutch bureau of statistics, CBS, and the national car database, which contains info about the each car registered in the Netherlands, available in the site of RDW, the Dutch Vehicle Authority (https://ovi.rdw.nl/default.aspx).
2. Definition of DRT

Before going into a discussion about DRT, it is important to mention that concepts are becoming more and more tricky, due to the so called “identity crisis” humanity is going through, where new properties and functionalities can be easily added to existing objects making it difficult to clearly delineate them (Le Masson and McMahon, 2016).

However, for the present case, the chosen definition was the one stated by the MaRS (2016) that delineates DRT services as being all “shared public/private sector transportation offerings that offer fixed or dynamically allocated routes and schedules in response to individual or aggregate consumer demand”, including thus commuter shuttles (like Bridj, Chariot, Via, Brengflex and Mokumflex), ride-sharing services (such as UberPOOL and LyftLines) and rural systems. Still, in the current context, Shaheen (2018) highlighted that the biggest difference, when compared to similar systems from the 60’s and 70’s, is that modern experiences make “use of smartphone to avoid traditional costly methods of booking rides, such as call centers or booking websites”

It is important to add that micro transit, flexible micro transit and paratransit – this term is sometimes used for the service for people with disabilities - are employed in the current literature to describe similar means of transportation situated between the private cars and the fixed route and schedule transit. A deeper discussion about the concept is proposed in the Appendix A.
3. Timeline

The first formal DRT experience took place in 1916, in Atlantic City, New Jersey (O'Leary, 1974 and Strobel, 1982). However, it was only during the 60’s and 70’s that they started their spread worldwide, mainly motivated for the technological developments – the CARS project of the MIT resulted in a first “many-to-many” algorithm for transportation projects (Wilson et al., 1969, and UMTA, 1979a) - and concerns about environmental and social issues (HUD, 1968).

![Geographical distribution of 57 operating systems in North America in May, 1974](image)

*Source: O'Leary (1974)*

The first operations with automated dispatching happened in this decade and met a considerable success (Strobel, 1982) but due to high costs and low computational capacity, they were not diffused right away (Wilson and Higonnet, 1973, Aex, 1973 and Shackson et al., 1974).

The following technological developments, such as GPS, telephone, computers, communication and GIS improved the management of these kind of operations, helping to establish the main characteristics of the current experiences. However, it was not until the spread of the smartphone that the modern DRT experiments began: even if the first private for-profit formal DRT enterprise, Bridj, started in 2014 with no smartphone, it soon created its application (Beta Boston, 2015a).
However, this idea is not new as since the 60’s and 70’s this concept of transportation service was spread worldwide, with diverse initiatives happening in underdeveloped countries (Golub and Cervero, 2001) and in low-density areas (Davison et al., 2014).

A more detailed presentation of the beginning of DRT is proposed in the Appendix B, while for the current examples, Appendix C.
4. Case study - Mokumflex

Mokumflex is a demand-responsive transit that was firstly implemented as a pilot in two areas of Amsterdam in the Netherlands for 12 months, starting in December, 2017. The idea was to optimize the use of AOV – transit for disabled people - vehicles, utilizing them to additionally serve VOV – non-disabled people - passengers in low-demand areas offering demand-based trips between stops provided by cars, minivans and vans.

![Van used to provide trips for Mokumflex](image)

It was accessible between 6:00 and 24:00, seven days a week for free – an interesting feature when considering that the previous offer was a distance based that costed 0,155 €/ km (GVB, 2018b) - and the booking operation was straight: at least one hour in advance of the departure time, the user could request a trip via smartphone application, telephone or internet, by choosing pick-up and drop-off points, preferred time, accompanying persons and declaring if he wanted or not to receive a call providing information about times and localization few minutes before the arrival.

After the user had requested the trip, the application displayed the estimated pick-up and drop-off times in real time and 7 minutes before the pick-up, it was possible follow the driver's location. Also, for being considered “on-time” the van had to arrive at the pick-up point up to 15 minutes before or 15 minutes after the preferred pick-up time. The following images show the different steps of the booking process:
Figure 6: Interfaces when requesting a trip via the smartphone application

The request of a trip is very simple:

- The user has to initially select the date, time-frame, pick-up, drop-off, extra passengers and necessity of the call service;
- The confirmation of the trip and the estimated arrival times;
- A few minutes before the arrival, the user may follow the driver’s position;
- The arrival of the driver is displayed into the application.

In addition, a wheelchair accessible vehicle could be demanded and drivers were trained to help reduced-mobility users to board in the vehicle. The pilot program was not under the responsibility of the local transit operator, GVB, but it was rather managed by the Municipality of Amsterdam (dutch: Gemeente Amsterdam), which is responsible for the regulation of the AOV transport in the city. It had the following main objectives (Gemeente Amsterdam, 2018a):
- Evaluate if the Combination of AOV and VOV could propose users a better service or reduce costs;
- Investigate the potential to address the first and last mile problems;
- Help the Municipality to better understand demand-responsive transit to prepare the next tendering process;
- See how integrated VOV and AOV demands would behave;
- Study the impact of increased intricacy, i.e. creation of new stops in underserved areas.

N.b.: Since the information about the AOV system was limited, this objective was not studied in this thesis.

A first report made by the Municipality about the operation was published in August, 2018, concluding that in comparison with the regular system, Mokumflex should improve the punctuality and the Combination between VOV and AOV. On the other hand, the increased intricacy and extended time frames of operation were well seen by the local population (Gemeente Amsterdam, 2018a).

Moreover, this report explained the motivations for such a trial, which were to gain insights into this modality of transportation, to better plan the next tendering process and to enhance the integration between AOV and VOV transit. The report makes some analysis of ridership, social issues and economic performance proposing a the expansion of Mokumflex to two other areas of Amsterdam and instigating the transfer of responsibility over the trial from the Municipality to GVB.

Coming back to the spatial description, as previously mentioned, two areas were chosen for the pilot based on the limited transit offer and low efficiency: Amsterdam Zuidoost and Weesp which were served by the line 49, and Amsterdam Noord, that relied on lines 30 and 31 (Gemeente Amsterdam, 2018a).

This image shows the operating areas of the experiment: on the top left, line 31, on the top right, line 30, that served Amsterdam Noord, while on the bottom right, line 49, implemented in Amsterdam Zuidoost and Driemond.
The system was, however, introduced differently in these two zones: while the bus line 49 did not cease its operation, bus lines 30 and 31 stopped their service. The following table shows some main operational features of the lines before the beginning of the pilot in comparison to main indicators of Mokumflex:

<table>
<thead>
<tr>
<th></th>
<th>GVB (2016)</th>
<th>Mokumflex</th>
</tr>
</thead>
<tbody>
<tr>
<td>49: 200 pass/ month</td>
<td>490: 344 pass/ month</td>
<td></td>
</tr>
<tr>
<td>30/31: 1691 pass/ month</td>
<td>301: 526 pass/ month</td>
<td></td>
</tr>
<tr>
<td>5 buses</td>
<td>2 cars</td>
<td></td>
</tr>
<tr>
<td>49: 6:00 - 19:00, Mo-Fr</td>
<td>6:00 - 24:00, Mo-Mo</td>
<td></td>
</tr>
<tr>
<td>30/31: 6:00 - 24:00, Mo-Fr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>49: 30min headway</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>30/31: 60min headway</td>
<td></td>
<td></td>
</tr>
<tr>
<td>49: 17 stops</td>
<td>490: 21 stops</td>
<td></td>
</tr>
<tr>
<td>30/31: 43 stops</td>
<td>301: 45 stops</td>
<td></td>
</tr>
</tbody>
</table>

Figure 8: Operational features of the existing lines and Mokumflex


Firstly, the drop in terms of ridership: as will be explained later, the lower level of service – mainly given by the punctuality – when compared to the previous regular line was the cause of the lower ridership for the line 301. For the line 490, on the other hand, since most of the area served by Mokumflex did not dispose of a previous system, population was happy with its implementation and used considerably the new offer. In regards to the digital literacy, it also disfavoured the patronage.

As one can see, the headways were/ are large and the operating time-frame was limited when compared to Mokumflex: the line 49 did not serve late night demand and none of the lines operated during the weekends.

Besides the fact that it could give information about the impact on the existing line, the other motivation to keep the line 49 functioning during Mokumflex was due to its lower operational costs when compared to 30 and 31.

For this report, the service in Amsterdam Zuidoost and Weesp will be referred as 490 and the one in Amsterdam Noord, as 301 to make easier to differentiate information referring to the previous lines or to the new ones.
4.1 Spatial characterization

Amsterdam extends over an area of 212.8km² and is home for almost 850,000 people. It is divided territorially in 8 boroughs: Centrum, Nieuw-West, Noord, Oost, West, Westpoort, Zuid and Zuidoost. The following map shows this division, a more disaggregated apportionment in 4-digit postcodes and the stops of Mokumflex.

Figure 9: Boroughs and postcodes of Amsterdam

Source: CBS (2017a) and Google Maps (2018)

N.b.: Amsterdam Noord was subdivided in two regions: Amsterdam Noord Rural and Amsterdam Noord Suburban due to the different socio-economic characteristics of both regions. Moreover, a zoomed map of the stop distribution for both lines can be found in Appendix D.

The previous map also shows the new stops added to the system, in white. For the line 490, this was materialized by the addition of 5 stops, being 4 of them in Amsterdam Zuidoost – more specifically, in Driemond: Zandpad, Burgemester Kasteleinstraat, Match Zo and Volkstuinen Driemond - and the other one in Weesp - Gezondheidscentrum Weesp. It is important to state that some stops, such as Geinbruck in the line 49 for example, are not served anymore by the regular service and were not considered as added intricacy for Mokumflex even if they are served by Mokumflex.
Moreover, 2 stops were added to the itinerary of the line 301: one in a rural area, near a camping park – named Camping de Badhoeve - and the other one, near the local train station, Station Noord - named Station Noord Kiss & Ride.

In regards to line 490, it goes through a low density area and serves a considerably young and old population in a medium urbanity environment. On the other hand, line 301 serve very heterogeneous areas: while the rural zone has low density and high percentage of elder people, the suburban part of it has a high density and, besides a strong presence of old population, has also many young people living in.

Additionally, the households in the study zone are more populated and less educated – even if data is missing for 301 Rural. Also, the income has different standards: 490 has a medium income, while 301 has a rich rural zone, the suburban area can be considered poor.

Complete information for each borough and for the specific 4-digit postcodes served by Mokumflex can be found in the Appendix D.

## 4.2 Stakeholders

This project has 4 different enterprises. The first one, Vervorregio Amsterdam, which is the transit authority, responsible for regulating VOV transit, while the operation is made by GVB. In regards to the AOV transit, it is regulated by Gemeente Amsterdam, the Municipality of Amsterdam. Finally, RMC, which is the only private enterprise of these and is responsible for operating AOV transit and Mokumflex.

As previously mentioned, one of the objectives of Mokumflex was to optimize the usage of the AOV vans by including VOV passengers. This means that Mokumflex is a joint project between three public partners plus RMC.

![Figure 10: Stakeholders implicated into the project](image)

During the year of 2018 and 2017, Mokumflex was regulated by Gemeente Amsterdam. Nonetheless, the enterprise considered the possibility of passing this responsibility for the next year to GVB, since it was considered as having more capacity for doing so.
Demand analysis

App-based DRT systems are an emerging solution and few data is publicly available. In the case of Mokumflex, the cooperation with RMC granted a detailed dataset that permitted a deep analysis of the most important features of the system. The set was a trip-per-trip base from the first day of operation, 11/12/17, until the last one, 09/12/18, containing information about request, pick-up and drop-off times, pick-up and drop-off stops, number of passengers, ID of the car used for each displacement and the usage of telephone, internet or smartphone for the request.

Also, as recurrent in datasets, some of the trips were not properly registered, impeding their use for analysis. The data cleaning process assured that:

- Pick-up and drop-off times were registered and different from each other;
- Different pick-up and drop-off stop, both belonging to lines 490 or 301;
- Distance travelled superior to 50 meters.

While the total number of observations was 10,227, the valid ones were 9,567, 94%.

Moreover, besides the following proposed analysis, further information, such as daily distribution, trips per user and composition of fleet and emissions, can be found in Appendix E.

4.3 Requested and realized trips

Firstly, one must comprehend the classification of the trips. If a certain displacement was requested by a user but this person did not show up in the proper time at the pick-up point, this trip was considered as “No Show”. All other trips/passengers were considered as realized, REA. In the case of the passengers, the same logic can be applied: if a person requested a trip for two people and did not show-up, then it is considered 1 “No Show” trip and 2 “No Show” passengers. The distribution of total and realized trips during the pilot program is shown below:

![Graphic 3: Requested and realized trips](image)

N.B.: In December 2017 and in December 2018, the system operated only for 20 and 9 days, respectively, justifying lower total ridership.
In general, the line 490 showed a growing trend, losing some patronage in June. The 301 had a more inconsistent behavior, with a valley in August, probably related to the summer and school vacations. Both met good levels of ridership in the last “complete” month of operation, November.

Even if the line 49 was functioning, the 490 had a monthly average of 274 realized trips and 344 realized passengers, which is 172% of the previous ridership. Besides that, when asked about the impacts of Mokumflex on the patronage of the line 49, GVB declared that the line did not meet significant changes and for further analysis, the current demand of the line 49 was considered equal to the previous: 200 passengers per month.

In regard to 301, the numbers are respectively 408 and 526, which is 31% of the previous 1.691 monthly travelers, in spite of the extended time-frame, increased intricacy and reduced fare.

Finally, concerning no-show trips, they average 13% of the total for the line 490 and 12% for the line 301. These considerably high percentages are possibly linked to the non-existence of penalties for users that do not show-up for a booked trip.

### 4.4 Influence of the extended time-frame and new intricacy

Two of the most important added values for the inhabitants of both zones were the extended time-frame and the new stops. The following table shows all realized trips, as well as the ones made during the extended time-frame, the ones whose pick-up or drop-off point was one of the new stops and finally the number of trips going or coming from each area:

<table>
<thead>
<tr>
<th></th>
<th>490 (trips per month)</th>
<th>301 (trips per month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Realized trips</td>
<td>274</td>
<td>408</td>
</tr>
<tr>
<td>Realized passengers</td>
<td>344</td>
<td>526</td>
</tr>
<tr>
<td>Passengers per trip</td>
<td>1,26</td>
<td>1,29</td>
</tr>
<tr>
<td>Extended time-frame trips</td>
<td>164</td>
<td>53</td>
</tr>
<tr>
<td>% vs Realized</td>
<td>60%</td>
<td>13%</td>
</tr>
<tr>
<td>New stops trips</td>
<td>193</td>
<td>77</td>
</tr>
<tr>
<td>% vs Realized</td>
<td>70%</td>
<td>19%</td>
</tr>
<tr>
<td>Realized trips in Zuidoost</td>
<td>108</td>
<td>-</td>
</tr>
<tr>
<td>% vs Realized</td>
<td>40%</td>
<td>-</td>
</tr>
<tr>
<td>Realized trips in Weesp</td>
<td>27</td>
<td>-</td>
</tr>
<tr>
<td>% vs Realized</td>
<td>10%</td>
<td>-</td>
</tr>
<tr>
<td>Realized trips in Driemond</td>
<td>139</td>
<td>-</td>
</tr>
<tr>
<td>% vs Realized</td>
<td>51%</td>
<td>-</td>
</tr>
<tr>
<td>Realized trips in Noord Rural</td>
<td>-</td>
<td>249</td>
</tr>
<tr>
<td>% vs Realized</td>
<td>-</td>
<td>61%</td>
</tr>
<tr>
<td>Realized trips in Noord Suburban</td>
<td>-</td>
<td>159</td>
</tr>
<tr>
<td>% vs Realized</td>
<td>-</td>
<td>39%</td>
</tr>
</tbody>
</table>

*Table 1: General information about the passengers*

The impact of the new stops was different but relevant in both operations. While for the 490 the majority of the trips was executed in the new time-frame and between new stops – 60% and 70% respectively -, for the line 301 those numbers were smaller but far from being negligible – averaging 13% and 19%.
Furthermore, when it comes to the origins and destinations of the trips, even if Driemond has only 4 out of 21 stops of the line 490, 50% of the displacements realized in this line happened between one of these, proving the potential of transit to unlock repressed demand. This means that when in discussions about public transport offer, unlocking underserved areas or hours should be seen as a priority.

On the other hand, considering that the demand for this line 490 is mainly composed by new users, since no significant changes were related on the demand for the regular bus line 49, this elevated percentage can also be interpreted as the materialization of the old users’ resistance to disrupt their homeostasis as they probably kept using the fixed line even if its paid while Mokumflex is free.

4.5 Shared trips

Before passing to the data itself, some of the definitions used in this section must be explained.

For the shared trips, it was called “reference trip” the first one to be booked – i.e. the earliest pick-up time – in opposition to the “linked trips”, which are those having later pick-up times and due to spatial and temporal similarities, were chained to the “reference trip”. In practical terms, the “linked trips” are the detours made during the reference trip to pick-up other users, raising the occupancy of the system. The ensemble of a reference trip and its linked trips will be called the “tour”.

Some basic indicators are shown below: trips per month, tours per month and shared tours per month, i.e. tours that had at least 2 passengers partially or during the whole displacement, is shown below:

N.b.: Differently from the trips, the analysis of tours includes both realized and no-show trips. Moreover, “shared” is considered by more than one passenger, the driver does not count.

In regards to the occupancy, Mokumflex is not in a very good performance, as will be exposed later: besides the fact that the ratio trips/ tours is 1,1, the number of shared tours is also weak, 20%, the reader, however, must remember that Mokumflex is a system running in a low-demand area which burden considerably the occupancy of the system.
4.6 Tripping and displacing distances

To keep presenting other information about occupancy, the mileage travelled should be analyzed and for this study, distance was classified in two:

- Displacing distance: kilometers travelled from where the vehicle was when it received the request until the pick-up point, represented by 1 in the next image;
- Tripping distance: from the pick-up to the drop-off point, represented by 2;
- Other dead distance: mileage from the garage to the first stop.

Figure 11: Displacing and tripping distances

N.b.: in a situation where the vehicle displaced from one pick-up point to another pick-up point – case of some shared trips – this distance between two pick-up points was considered as tripping distance. Also, the software used for the dispatching function was provided by Trapeze.

The tripping distance was directly calculated, since the pick-up and drop-off stops were registered in the dataset. On the other hand, the displacing one had to be estimated, as the only information available about it was the time spent displacing. The calculation required then the displacing speed, which was estimated based on the tripping speed and the time of the day. The following table summarizes the most important information:

<table>
<thead>
<tr>
<th></th>
<th>490 (per month)</th>
<th>301 (per month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacing distance</td>
<td>933</td>
<td>1,990</td>
</tr>
<tr>
<td>Tripping distance</td>
<td>1,355</td>
<td>1,506</td>
</tr>
<tr>
<td>Other dead miles</td>
<td>229</td>
<td>350</td>
</tr>
<tr>
<td>Total distance</td>
<td>2,516</td>
<td>3,846</td>
</tr>
<tr>
<td>Tripping vs Total</td>
<td>54%</td>
<td>39%</td>
</tr>
<tr>
<td>Pass * km</td>
<td>1,251</td>
<td>2,755</td>
</tr>
<tr>
<td>Veh * km/ pas * km</td>
<td>2,01</td>
<td>1,40</td>
</tr>
<tr>
<td>Shared km</td>
<td>229</td>
<td>556</td>
</tr>
<tr>
<td>% vs Total distance</td>
<td>9%</td>
<td>14%</td>
</tr>
</tbody>
</table>

Table 2: Vehicular distances and passenger distance
Considering a 30 days-month, the most important outcome from the previous table is that, in average, a Mokumflex’s car runs daily 83.2 km for the line 490 and 127.1 km for the line 301. This demonstrates the difference in demands in both areas.

The low percentage of tripping distances versus the total, shared kilometers and ratio vehicle-km/passenger-km reinforce the low-occupancy of the system. It is important to note that the “Other dead miles” calculation was based on the information for the previous fixed lines: a percentage of 10% of the sum of the displacing and tripping distances was added. About the ratio vehicle-km/passenger-km, interesting comparisons can be made with other systems:

<table>
<thead>
<tr>
<th>Mode</th>
<th>Veh * miles/ Pass * miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mokumflex, 2018</td>
<td>1,588</td>
</tr>
<tr>
<td>Netherlands Car, 2014</td>
<td>0,714</td>
</tr>
<tr>
<td>Amsterdam Bus, 2017</td>
<td>0.082</td>
</tr>
<tr>
<td>Amsterdam Tramway, 2017</td>
<td>0.036</td>
</tr>
<tr>
<td>Amsterdam Metro, 2017</td>
<td>0.012</td>
</tr>
<tr>
<td>USA Via, 2016</td>
<td>0.880</td>
</tr>
<tr>
<td>USA Uber, 2016</td>
<td>1.690</td>
</tr>
<tr>
<td>USA Bus, 2016</td>
<td>0.101</td>
</tr>
<tr>
<td>USA Light rail, 2016</td>
<td>0.045</td>
</tr>
<tr>
<td>USA Commuter rail, 2016</td>
<td>0.032</td>
</tr>
<tr>
<td>USA DRT, 2016</td>
<td>0.969</td>
</tr>
<tr>
<td>USA Taxi, 2012</td>
<td>1.897</td>
</tr>
<tr>
<td>USA Car, 2017</td>
<td>0.649</td>
</tr>
</tbody>
</table>

*Table 3: Ratio vehicle kilometers/passenger * kilometers for different modes*


From a transit perspective, the lower is the ratio vehicle-miles/passenger-miles, the better it is, as less vehicle-km are necessary to transport passengers. The numbers for Mokumflex show an operation incapable of bringing positive effects on congestion, with the ratio being far higher than the local transit system and even from the private Dutch car.

Also, when comparing the numbers of Mokumflex with those of Via, which is also a DRT provider whose main operations are situated in consolidated urban centers, a less performing outcome is evident. However, since Mokumflex operates in a low-demand area, direct comparison with Via is not fair.

Finally, Uber and Taxi. They are both less performing than Via demonstrating that, despite the low-occupancy previously evoked, it still contributes more for traffic congestion than these two modes.

### 4.7 Smartphone penetration

One of the most important indicators for the smartphone-based DRT systems is the number of requests made via smartphone application. In the case of Mokumflex, the following table shows the numbers per trips:
The smartphone was highly used for the line 490, as the local population volunteered to teach other inhabitants to request trips via this gadget. For the 301, the cypher was lower but still important. In regards to the users, from the 169 people that used Mokumflex at least once for the line 490, 83% booked trips using the smartphone and again, from the 382 people that used the service of the 301 at least once, only 32% made reservations exclusively via website.

This table should be read as following: for the line 490, the total number of subscriptions that realized at least one trip was 169. 109 used only smartphones for requesting a displacement, while 28 booked it only through the telephone or the website, and 32 used both methods to ask for a car.

At this point, an important comment should be made: due to the fact that Driemond did not have a pre-existing line, the population welcomed the system and auto-mobilized themselves to spread it. On the other hand, in Amsterdam Noord, the population’s impression was mainly negative when comparing Mokumflex to the previous regular line.

4.8 Fleet dimensioning
The following graphic shows how many minutes per day there were 1, 2 or 3+ cars tripping or displacing for the system.
The most important outcome from this section is that Mokumflex is operated for 293 minutes per day, demanding 346 vehicle minutes daily. In 246 of these 293 minutes, there was only one vehicle, 84.0% of the total, while 40 minutes were shared between 2 vehicles at the same time, 13.7%, and the remaining 2.3%, 3 or more vehicles. The maximum registered was 7 vehicles at the same time.

This means that with 2 vehicles, the majority of the demand could be served for the current level of service, even if some critics arise about it, as will be discussed in the next section. For the simplification of the following analysis, it will be considered that from the 346 veh minutes daily, 296 minutes will be made by one car, 85.5% of the total, while the second car is responsible for the supplementary 50 minutes, 14.5%. Also, it will be considered that $1/0.855 = 1.17$ vehicles are necessary to run such a system.

For the sake of simplification, since the 85.5% of the daily veh minutes of Mokumflex were realized by one car, the application of this percentage for the daily mileage of 210.3km – see section “Tripping and displacing distances” - results in daily 179.8km daily for Mokumflex.
5. Population’s perception

During the month of May, 2018, the Municipality of Amsterdam made a survey with the inhabitants of both zones served by Mokumflex. A link to the survey was disposed on the local newspaper – Het Zwaantje – and could also be accessed via the the website of the community of Amsterdam Noord - centraledorpenraad.nl. In total, 12 users and 15 non-users answered the survey for the line 490, while for the 301, these numbers were respectively 21 and 8. Even if this is a small sample that could not be considered representative, one must remember that Mokumflex did not have much users as only 41 people made more than 50 trips. Consequently, the results of the survey cannot be conclusive but they were used as indication and will be compared with the outcomes of the Mokumflex’s evaluation from the smartphone application.

The respondents were demanded to write their accordance with affirmations in a scale from 1 to 5 and in the first question, they were asked to measure their accordance with the affirmation “I am satisfied with the services provided by Mokumflex (RMC)”: 5 means very satisfied, while 1 is very unsatisfied. For the line 490, the user satisfaction was 3,4, while for the 301, 2,7. It is important to notice that GVB’S bus system had a satisfaction of 7,6 in 2016, in a 0-10 scale (GVB, 2018a), which is 3,8 in a 0-5 scale, higher than the evaluation for Mokumflex for both lines.

The lower satisfaction from the line 301 is possibly linked to the fact that Mokumflex replaced a previously existing regular system, offering a non-punctual solution, that was not very well perceived among the population.

On the other hand, for the line 490, since it was added to an area that had no previous transit offer, the solution was very well received by the population with the inhabitants volunteering to teach others how to use the smartphone application, as previously mentioned.

Another source of satisfaction was the smartphone application, that gave the possibility of evaluating each ride after finishing it. From the 3380 realized trips for the line 490, 164 evaluations were obtained, while for the line 490, these numbers were 4974 and 393, respectively. Even if the metrics used are different, the results show some incongruency when compared to the survey:

![Graphic 7: User’s opinion about realized trips](image)
The majority of the users evaluated very positively the trip: 88% for the line 490 and 90% for the line 301. It is important to remember that the survey was applied in May, 2018, while the results coming from the opinions were gathered from December, 2017, to December, 2018. However, when analyzing the opinions from December, 2017, until May, 2018, the results are similar. The average satisfactory status coming from the app evaluation are different from the results of the survey. Naturally, it is possible that the survey was biased because of the low-number of respondents.

Since one of the most frequent complaints was the punctuality - for Mokumflex, a trip was considered “on-time” when the arrival at the pick-up stop happened in a 15-minutes frame – this frame was a convention between RMC and Gemeente Amsterdam - from the requested pick-up time - it was reasonable to compare how does the satisfaction change accordingly to it.

First of all, 82,1% of the trips made for the line 490 respected this time frame, while for the line 301, this number was 78,3%. The evaluation of the displacements accordingly to the punctuality is presented below:

![Graphic 8: User's satisfaction accordingly to the punctuality](image)

From these numbers, the reader can see that there is a correlation with punctuality and level of satisfaction. If, in one hand, for the trips on-time, the “very satisfied” or “satisfied” travelers are 91,6% for the line 490 and 92,7% for the line 301, on the other hand, the numbers for trips that were not on-time are still good: 73,5% and 70,4% respectively. In general, the “very satisfied” evaluations give place to “very dissatisfied” when a trip is not on-time.

Further information about the survey – motivation and purpose, car usage, inducted trips and usage of the line 49 - can be found in Appendix G.
6. Network effect

6.1 Trip length and demand

One of the most important information in this type of transit operation is the potential of scaling it, which passes by the so called "network effects", that are the improvements in terms of operational indicators – costs, trip length and occupancy, for example - coming from the growth of the demand. Higher levels of demand allow better matching of trips, reducing the average trip length per passenger, permitting better economic performance (HSL, 2016).

In the Mokumflex project, the data offered by RMC allowed a simple but efficient analysis of this phenomenon through the daily evaluation of the number of tours and realized passengers versus the average trip length per line.

For each single day of operation, the number of tours was obtained, as well as the total veh*km travelled that day, permitting the calculation of the daily averages veh*km per tour. By plotting the number of realized passengers – “Pas” - and/or the number of tours – “Tou” - on the X axis and the average tour length on the “Y” axis, it was possible to study three different types of linear regressions: linear – LIN -, logarithmic – LOG - and Cobb-Douglas – COB -, being these last two evaluated in their linearized forms, as presented below:

\[
(LIN) \ Y_i = \beta_1 + \beta_2 \times (\text{Pas or Tou}) \quad (1)
\]

\[
(EXP) \ \ln(Y_i) = \ln(\beta_1) + \beta_2 \times (\text{Pas or Tou}) \quad (2)
\]

\[
(COB) \ \ln(Y_i) = \beta_1 + \beta_2 \ln(\text{Pas or Tou}) \quad (3)
\]

The results for the trip length versus demand are the following:

<table>
<thead>
<tr>
<th></th>
<th>Lin Pas</th>
<th>Log Pas</th>
<th>Cob Pas</th>
<th>Lin Tou</th>
<th>Log Tou</th>
<th>Cob Tou</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope, ( \beta_2 )</td>
<td>-0,185</td>
<td>-0,018</td>
<td>-0,355</td>
<td>-0,156</td>
<td>-0,015</td>
<td>-0,219</td>
</tr>
<tr>
<td>Intercept, ( \beta_1 )</td>
<td>14,61</td>
<td>2,70</td>
<td>3,27</td>
<td>15,90</td>
<td>2,80</td>
<td>3,08</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>52,5%</td>
<td>75,2%</td>
<td>92,2%</td>
<td>39,3%</td>
<td>65,0%</td>
<td>54,2%</td>
</tr>
<tr>
<td>P-val slo</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
</tr>
<tr>
<td>P-val int</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
</tr>
<tr>
<td>Slope, ( \beta_2 )</td>
<td>-0,068</td>
<td>-0,007</td>
<td>-0,237</td>
<td>-0,108</td>
<td>-0,012</td>
<td>-0,268</td>
</tr>
<tr>
<td>Intercept, ( \beta_1 )</td>
<td>12,33</td>
<td>2,49</td>
<td>3,00</td>
<td>15,12</td>
<td>2,77</td>
<td>3,21</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>29,9%</td>
<td>46,2%</td>
<td>69,8%</td>
<td>71,4%</td>
<td>65,4%</td>
<td>53,8%</td>
</tr>
<tr>
<td>P-val slo</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
</tr>
<tr>
<td>P-val int</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
</tr>
</tbody>
</table>

Table 4: Linear regression models describing the effects of scale on trip length
N.b.: A more detailed investigation of these equations could be made, including the hypothesis tests – homoscedasticity, normality of residuals, autocorrelation of disturbances -, an evaluation of the confidence interval of the regressors and control groups analysis, for example.

From this table, one can see that for the line 490, the best model is the Cobb-Douglas whose independent variable is trip length per passenger. In the case of line 301, both Cobb-Douglas with trip length per passenger and linear model with trip length per tour had good results but preference was given for the first one since this was the best fit for line 490.

Plotting the previously mentioned linear regression in a graphic would give the lector a better visualization of the network effects:

![Graphic 9: Average trip length of Mokumflex according to the number of passengers per day](image)

N.b.: The maximum daily demand from Mokumflex was 73 passengers per day for the line 490 and 147 for the line 301.

These lines have a great gain in terms of tour length for low-demands: from a daily demand of 1 passenger per day to a patronage of 10 passengers per day, there is a reduction of about 50% in the tour length per passenger. The following table shows the relative reduction – the base is the demand of 1 passenger per day – for each level of demand:

<table>
<thead>
<tr>
<th>Pass/day</th>
<th>490</th>
<th>301</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% vs 1 pass/day</td>
<td>Tour len (km)</td>
</tr>
<tr>
<td>1</td>
<td>100%</td>
<td>26.3</td>
</tr>
<tr>
<td>5</td>
<td>57%</td>
<td>14.9</td>
</tr>
<tr>
<td>10</td>
<td>44%</td>
<td>11.6</td>
</tr>
<tr>
<td>25</td>
<td>32%</td>
<td>8.4</td>
</tr>
<tr>
<td>50</td>
<td>25%</td>
<td>6.6</td>
</tr>
<tr>
<td>100</td>
<td>20%</td>
<td>5.1</td>
</tr>
<tr>
<td>150</td>
<td>17%</td>
<td>4.5</td>
</tr>
</tbody>
</table>

*Table 5: Demand and trip length*
This table demonstrates more pragmatically the network effects and the necessity of ensuring levels of demand higher than 25 passengers per day in order to reduce the kilometers per passenger.

### 6.2 Occupancy and demand

It is naturally also expected that raising the demand, the occupancy of the operation would also improve.

For this analysis, the indicator chosen to represent occupancy was the ratio \( \text{veh} \cdot \text{km}/\text{pass} \cdot \text{km} \), since this number also provide an idea not only of the shared kilometers but also the occupancy.

A similar regression analysis was made: in the X axis, the number of passengers per day while the Y axis represented the occupancy. The results are as following:

<table>
<thead>
<tr>
<th></th>
<th>Slope, ( \beta_1 )</th>
<th>Intercept, ( \beta_1 )</th>
<th>( R^2 )</th>
<th>( P )-val slo</th>
<th>( P )-val int</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lin</td>
<td>-0.054</td>
<td>4.12</td>
<td>46.9%</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Log</td>
<td>-0.019</td>
<td>1.43</td>
<td>72.1%</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Cob</td>
<td>-0.369</td>
<td>2.02</td>
<td>89.1%</td>
<td>-0.04</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>-0.045</td>
<td>3.89</td>
<td>53.1%</td>
<td>-0.01</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>-0.017</td>
<td>1.39</td>
<td>77.2%</td>
<td>-0.28</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>-0.282</td>
<td>1.79</td>
<td>83.9%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>490</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lin</td>
<td>0.00</td>
<td>0.00</td>
<td>54.7%</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Log</td>
<td>0.00</td>
<td>0.00</td>
<td>78.3%</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Cob</td>
<td>0.00</td>
<td>0.00</td>
<td>80.3%</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>0.00</td>
<td>0.00</td>
<td>6.1%</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>0.00</td>
<td>0.00</td>
<td>13.3%</td>
<td>0.00</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>0.066</td>
<td>0.98</td>
<td>28.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>301</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 6: Linear regression models describing the effects of scale on occupancy*

Again, the Cobb-Douglas presented the best result for both lines. Similar to the previous section, the graphic plot is offered:

*Graphic 10: Occupancy of Mokumflex accordingly to the number of passengers per day*
As one can see, the smallest is the tour length per passenger, higher is the occupancy, implying in lesser veh*km required to provide one pass*km. This graphic reinforces the necessity of raising the demand since first it reduces the trip length and secondly raises the occupancy of the system.

Table 7: Demand and occupancy

<table>
<thead>
<tr>
<th>Pass/ day</th>
<th>% vs 1 pass/day</th>
<th>Occupancy</th>
<th>% vs 1 pass/day</th>
<th>Occupancy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%</td>
<td>7,333</td>
<td>100%</td>
<td>4,282</td>
</tr>
<tr>
<td>5</td>
<td>56%</td>
<td>4,112</td>
<td>64%</td>
<td>2,756</td>
</tr>
<tr>
<td>10</td>
<td>44%</td>
<td>3,206</td>
<td>53%</td>
<td>2,280</td>
</tr>
<tr>
<td>25</td>
<td>31%</td>
<td>2,306</td>
<td>41%</td>
<td>1,774</td>
</tr>
<tr>
<td>50</td>
<td>25%</td>
<td>1,798</td>
<td>34%</td>
<td>1,467</td>
</tr>
<tr>
<td>100</td>
<td>19%</td>
<td>1,401</td>
<td>28%</td>
<td>1,214</td>
</tr>
<tr>
<td>150</td>
<td>17%</td>
<td>1,211</td>
<td>25%</td>
<td>1,086</td>
</tr>
</tbody>
</table>

From this table, one can see that for the current levels of demand of Mokumflex, none of the lines has an occupancy inferior to 1: even for higher demands, the system has a worst occupancy than the regular car. In addition, as typical in Cobb-Douglas regressions, for lower demands, the marginal gains of occupancy are very high, demonstrating the importance of including more users.

N.b.: According to the regression, a demand of about 250 passengers per day is necessary in order to make the ratio pass*km/ tour length (veh*km) equal to 1 for the line 490, while for the line 301, this number is about 200 passengers per day. This cypher was not presented since the maximum daily patronage registered during the pilot program is much inferior to these two numbers.

Finally, one must remember that Mokumflex operates in a rural context, meaning that these levels of occupancy are expected to present weak results. Again, in such a context, the transit offer should aim much more in the economic performance, i.e. providing a public option for those incapacitated of driving a car, rather than in occupancy metrics.
7. Economic analysis

Together with ridership analysis, the economics of a project is crucial and this section will present an overview of the operational costs of some of the cars used for the pilot program as well as for the bus used previously. Before passing to the analysis, a brief explanation of the categorization of its components is presented below:

- **Depreciation**: costs related to the value lost for the investment in a vehicle, comprised the residual value. The total new vehicle cost is composed of 3 parcels: the expenditures with T1 the catalog price and the BPM, which is a national tax.
  - The first one was considered 10,000 € for buses, the minimum value pointed by Crow (2015) and comprises expenditure with technological gadgets, such as the card reader. It is important to say that since the cars used for Mokumflex were not equipped with these gadgets as the costs were considered prohibitive, for this analysis, they were considered as 0 for cars;
  - New value and BPM were recovered from the site of the Netherlands Vehicle Authority, RDW (2018);
  - The residual value was calculated by consulting Dutch sites of second-hand car sales as will be presented on the “Residual value” section;
  - The distance travelled per day per Mokumflex’s car was calculated based on the average daily kilometrage – see the section “Fleet dimensioning” – and will be considered as 179,8 km;
- **Interest, depreciation**: according to the European Central Bank (ECB, 2018), the average inflation from October, 2017, until October, 2018, for the Netherlands was 0.57% per month;
- **Insurance**: a percentage of 1% of the catalog price, as proposed by Crow (2015), was used;
- **Own risk and damage**: disbursements coming from the usage of the vehicle that are not covered by insurance, such as transit fees. According to Crow (2015), a value of 1,500 € per year is reasonable;
- **Taxes**: the site of the Tax and Customs Administration of the Netherlands (Belastingdienst, 2018a) was consulted and gives a trimestral tax according to the type of vehicle, emissions, region, fuel and weight. Full-electric and hydrogen cars do not pay any value;
- **Storage**: the analysis made by Crow (2015) pointed an average value for buses of 3,000 € per year for storage, washing and refueling. However, this number varies substantially, depending, for example, on the land price (Crow, 2015). For simplification, it was considered the same for all vehicles;
- **Maintenance**: the numbers of Crow (2015) are for fuel buses and it was retained as vehicles for Mokumflex cars are admitted to similar kilometragas as transit buses. The base value of value is 0,025 €/km + 30% additional for being in urban areas. In regard to electric cars, Hoekstra et al. (2017) found that, in the Netherlands, maintenance costs one third in of that of an equivalent fuel car. For the Citaro, the value of 0,0125 €/km presented by Civitas (2014) for a Euro VI bus was used;
- **Energy**:
  - **Consumption**: for each model, individual values were used. For the gasoline cars - 2017 Skoda Rapid and 2017 Volkswagen Golf – the numbers were based on the Combined fuel consumption offered by RDW (2018). For the 2011 CNG Volkswagen Combi,
Combined value came from CNG Europe (2011). Finally, for the electric cars - 2017 Volkswagen e-Golf and 2012 Volkswagen e-Crafter – the average value between the summer and winter consumptions exposed in Mountox (2018a) and Mountox (2018b) was used. For the bus, values for a Citaro Euro VI bus presented by Mercedes-Benz (2014) was retained;

- Costs: for CNG and electricity, the prices came respectively from CNG Europe (2018) and Eurostat (2017). For the gasoline, the price from Amsterdam was taken from Numbeo (2018).
- Battery: in the case of electric vehicles, battery costs are relevant. The prices are steadily decreasing and VDMA (2016) pointed that for the current horizon, a value between 200 €/kWh and 250 €/kWh is reasonable. For this simulation, 225 €/kWh was adopted. This is reinforced by the fact that a 24 kWh Nissan Leaf’s battery pack can be bought for US$ 5,499, about US$ 230/kWh (Clean Technica, 2017) and that there is a convergence of estimates in industry for the same US$ 230/kWh for 2017-2018 (Nykvist and Nilsson, 2015);
- Lifetime of the battery: recent literature suggest that Li-ion batteries can handle up to 1000 cycles before reaching the 80% capacity – usual percentage used as threshold for batteries’ duration (Warner, 2015, appud IEA, 2018). Disposing of the battery capacity for each model as well as the performance in kWh/100km, one can easily estimate the lifetime mileage;
- Losses while charging: even if losses depends on the hour of the day, penetration of electric fleet, battery degradation, power and temperature and type of charge, it was decided to use a percentage of 1.9% for the energy loss, which is the average between summer and winter for peak-hours in a penetration scenario of 0% (Mies et al, 2018), since in May, 2018, the electric fleet in the Netherlands is only 1.4% of the total (CBS, 2018);

• Direct staff: driver’s wage was a fixed value of 25 €/hour, accordingly to RMC. This value already includes a value of 7% for absenteeism is usual in public transport (Crown, 2015) and the losses coming from the compatibilization of schedules and extra-times – i.e. the system is offered from 6:00 until 24:00 but usually there are trips finishing after midnight, recharging during the shift and brakes. In the case of Mokumflex, as demonstrated in the section “Fleet dimensioning”, there is a demand of 296 minutes per day;
• Indirect staff: 20% of the costs of the direct staff were considered, as proposed by Crow (2015);
• Opportunity costs: they were not taken into consideration;
• In the daily kilometrage, it was added 10% for dead-miles. This number calculated based on the numbers coming three previous lines. Even if for an electric fleet this number may be higher due to the more frequent charging operation, this was not considered;
• The expenditures with parking were considered 0 because the vehicles have proper garages for themselves and these costs were already included in “storage”.

7.1 Daily distances

Before passing to the TCO, it is important to present the inputs. In regard to the daily distances travelled by these vehicles, a GPS dataset containing locations every 15 for the vehicles of the AOV system allowed
the estimation of the average. 322 daily distances of different vehicles were analyzed, offering the following results:

<table>
<thead>
<tr>
<th></th>
<th>Weekday</th>
<th>Weekend</th>
<th>Both</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days analyzed</td>
<td>251</td>
<td>71</td>
<td>322,0</td>
</tr>
<tr>
<td>Daily distance (km)</td>
<td>239,8</td>
<td>255</td>
<td>243,0</td>
</tr>
<tr>
<td>Relative standard dev (%)</td>
<td>23,7%</td>
<td>27,1%</td>
<td>24,6%</td>
</tr>
</tbody>
</table>

Table 8: Daily distances for AOV cars

This data shows no big difference for daily distances when comparing weekdays to weekends and despite the considerable relative standard deviation, the daily distance retained for the following steps was 243 km/day. Furthermore, in the section “Fleet dimensioning” it was shown that Mokumflex runs for 179,8km daily.

7.2 Different cars

Since Mokumflex used the AOV cars to provide VOV trips, more than 300 different cars were used for Mokumflex. However, RMC gave the preferrence for the 2011 CNG Volkswagen Combi to serve Mokumflex and 2 of these vehicles were responsible for about 20% of the trips and that is the reason why the following section presents a more described TCO analysis for this model. Besides that, 6 other models used were submitted to a similar analysis:

- 2012 electric e-Crafter: a similar vehicle in terms of dimension to the Volkswagen Combi;
- 2017 gasoline Rapid: the cheapest car used in Mokumflex;
- 2012 diesel Caddy: a cheap diesel car;
- 2017 gasoline Golf and 2017 electric e-Golf: similar cars whose difference is the fuel;
- 2009 diesel Citaro O530: diesel bus used by GVB but it was the only vehicle not used by Mokumflex.

![Figure 12: Models analyzed for the TCO evaluation](image-url)
7.3 Residual value

As previously stated, the residual value was calculated by the consultation of Dutch second-hand car sales sites. Concerning the CNG Combi and the e-Crafter, due to the unavailability of data for them, similar diesel models were analyzed. The regressions that best fitted – R² analysis only – are summarized below:

<table>
<thead>
<tr>
<th>Model</th>
<th>Fuel</th>
<th>Samples</th>
<th>Equation</th>
<th>R²</th>
<th>Catalog price (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combi</td>
<td>Diesel</td>
<td>182</td>
<td>-7000*ln(D) + 102449</td>
<td>0.60</td>
<td>$41.856</td>
</tr>
<tr>
<td>Crafter</td>
<td>Diesel</td>
<td>79</td>
<td>-7592*ln(D) + 102840</td>
<td>0.69</td>
<td>$36.031</td>
</tr>
<tr>
<td>Rapid</td>
<td>Gasoline</td>
<td>52</td>
<td>-2946*ln(D) + 43746</td>
<td>0.59</td>
<td>$20.300</td>
</tr>
<tr>
<td>Caddy</td>
<td>Diesel</td>
<td>63</td>
<td>-2802*ln(D) + 40319</td>
<td>0.70</td>
<td>$33.029</td>
</tr>
<tr>
<td>Golf</td>
<td>Gasoline</td>
<td>70</td>
<td>-5614*ln(D) + 79769</td>
<td>0.77</td>
<td>$26.230</td>
</tr>
<tr>
<td>e-Golf</td>
<td>Electric</td>
<td>34</td>
<td>-7991*ln(D) + 112325</td>
<td>0.59</td>
<td>$40.050</td>
</tr>
<tr>
<td>Citaro 0530</td>
<td>Diesel</td>
<td>36</td>
<td>-10000*ln(D) + 200000</td>
<td>0.57</td>
<td>$220.000</td>
</tr>
</tbody>
</table>

Table 9: Main definitions for depreciation analysis


N.b.: For the Crafter and the Caddy, the exponential regression presented a R² slightly superior to the logarithmic one but for simplification, this last form was kept. It is important to say that the catalog price does not include nor the BPM nor the expenditures with TI. Finally, the prices for the Citaro 0530 were collected from the German market since data was not available for the Dutch commerce. A plot of the depreciation with travelled kilometers can be found in Appendix F

7.4 Detailed TCO 2011 CNG Volkswagen Combi

To make things clearer, the inputs for the 2011 CNG VW Combi are shown below:
For the current simulation, only fraction of the costs was allocated to Mokumflex as the daily minutes and kilometers of Mokumflex are a percentage of the total, as explained on the beginning of this chapter – for the minutes, 296 from the 1200 daily minutes that the AOV is operating, while for the mileage, 179,8km from the 243km. When analyzed for the whole lifetime, these values per car are as following:

<table>
<thead>
<tr>
<th><strong>Table 10: Input for the economic analysis</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Depreciation</strong></td>
</tr>
<tr>
<td>Number of vehicles: 1</td>
</tr>
<tr>
<td>Total new vehicle cost (€): 75,714</td>
</tr>
<tr>
<td>Residual value (% of the total new vehicle cost): 28%</td>
</tr>
<tr>
<td>Lifetime mileage (km): 250,000</td>
</tr>
<tr>
<td>Kilometrage per day (km/ day): 243,0</td>
</tr>
<tr>
<td>Kilometrage for Mokumflex per day (km/ day): 179,8</td>
</tr>
<tr>
<td>Working days per year: 365</td>
</tr>
<tr>
<td><strong>Interest, depreciation</strong></td>
</tr>
<tr>
<td>Interest rate (% of the new vehicle cost/ year): 1%</td>
</tr>
<tr>
<td><strong>Insurance</strong></td>
</tr>
<tr>
<td>Insurance cost (% of the total catalog price/ year): 1%</td>
</tr>
<tr>
<td><strong>Own risk damage</strong></td>
</tr>
<tr>
<td>Own risk damage (€/ vehicle/ year): 1,500</td>
</tr>
<tr>
<td><strong>Taxes</strong></td>
</tr>
<tr>
<td>Taxes (€/ vehicle/ year): 2,084</td>
</tr>
<tr>
<td><strong>Storage</strong></td>
</tr>
<tr>
<td>Storage/ washing costs (€/ vehicle/ year): 3,000</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
</tr>
<tr>
<td>Maintenance (€/ driven km): 0,025</td>
</tr>
<tr>
<td><strong>Energy</strong></td>
</tr>
<tr>
<td>Fuel consumption (lt, kg or kwh/100km): 7,3</td>
</tr>
<tr>
<td>Fuel price (€/ lt, kg or kwh): 1,13</td>
</tr>
<tr>
<td>Battery cost (€): 0,00</td>
</tr>
<tr>
<td>Battery lifetime (km): 0</td>
</tr>
<tr>
<td><strong>Direct staff</strong></td>
</tr>
<tr>
<td>Operating hours per day, Mokumflex (hours/ day): 4,93</td>
</tr>
<tr>
<td>Remuneration (€/ hour): 25,0</td>
</tr>
<tr>
<td>Absenteeism: 0%</td>
</tr>
<tr>
<td>Time loss (compatibilization of shifts, breaks, charging): 0%</td>
</tr>
<tr>
<td><strong>Indirect staff</strong></td>
</tr>
<tr>
<td>Indirect staff (% vs Direct staff): 20%</td>
</tr>
<tr>
<td><strong>Interest, other costs</strong></td>
</tr>
<tr>
<td>Interest rate (% of the total costs but depreciation/ year): 0%</td>
</tr>
</tbody>
</table>

For the current simulation, only fraction of the costs was allocated to Mokumflex as the daily minutes and kilometers of Mokumflex are a percentage of the total, as explained on the beginning of this chapter – for the minutes, 296 from the 1200 daily minutes that the AOV is operating, while for the mileage, 179,8km from the 243km. When analyzed for the whole lifetime, these values per car are as following:
N.b.: under the hypothesis of 250,000 km for the lifetime and 243,0 km per day, the vehicle lifetime span is 34 months.

Even if a reduced percentage of workforce could be expected when comparing to the first systems during the 70’s, this is not real when analyzing Mokumflex. As mentioned previously, labor accounted from 70% to 60% of the total back in that time (Arriaga and Medville, 1974), similar to nowadays. Together, direct and indirect staff accounts for more than 60% of the total TCO, while depreciation for 15.8% and energy, 6.1%. A more detailed cost analysis is presented below:

<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>All years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total (€/ month)</td>
<td>$7,567</td>
<td>$6,984</td>
<td>$6,640</td>
<td>$0</td>
<td>$7,089</td>
</tr>
<tr>
<td>Vehicular costs (€/ month)</td>
<td>$3,068</td>
<td>$2,486</td>
<td>$2,141</td>
<td>$0</td>
<td>$2,590</td>
</tr>
<tr>
<td>Workforce (€/ month)</td>
<td>$4,499</td>
<td>$4,499</td>
<td>$4,499</td>
<td>$0</td>
<td>$4,499</td>
</tr>
<tr>
<td>Total (€/ operating hour)</td>
<td>$50,46</td>
<td>$46,58</td>
<td>$44,28</td>
<td>$0,00</td>
<td>$47,27</td>
</tr>
<tr>
<td>Total (€/ km)</td>
<td>$1,38</td>
<td>$1,28</td>
<td>$1,21</td>
<td>$0,00</td>
<td>$1,30</td>
</tr>
</tbody>
</table>

The numbers per km, 1.30 €/km, is lower than the average fare for taxi system in Amsterdam, which is 2.40 €/km (Numbeo, 2018). Moreover, considering that 1,17 cars are responsible for the average demand of 1050 passengers and 909 for realized passengers, REA, and that this demand is the following numbers appear per car:

<table>
<thead>
<tr>
<th>Total (€/ month)</th>
<th>$7,088,51</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passengers per month</td>
<td>859</td>
</tr>
<tr>
<td>REA passengers per month</td>
<td>744</td>
</tr>
<tr>
<td>Total (€/ passenger)</td>
<td>$8,26</td>
</tr>
<tr>
<td>Total (€/ REA passenger)</td>
<td>$9,53</td>
</tr>
</tbody>
</table>

Table 11: Detailed cost analysis

Table 12: Costs per passenger
A comparison between Mokumflex costs and different offers is proposed in the end of this chapter but these cyphers demonstrate the potential of Mokumflex to compete with other private modes.

### 7.5 Economical costs for different vehicles

As expected, to summarize the previous analysis of TCO, the following table was made with the main indicators of costs:

<table>
<thead>
<tr>
<th>Veh costs (%)</th>
<th>Combi</th>
<th>e-Crafter</th>
<th>Rapid</th>
<th>Caddy</th>
<th>Golf</th>
<th>e-Golf</th>
<th>Citaro, 49</th>
<th>Citaro, 30</th>
<th>Citaro, 31</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifetime (years)</td>
<td>2,8</td>
<td>2,8</td>
<td>2,3</td>
<td>2,3</td>
<td>2,3</td>
<td>10,8</td>
<td>11,3</td>
<td>18,4</td>
<td></td>
</tr>
<tr>
<td>Lifetime (km)</td>
<td>250.000</td>
<td>250.000</td>
<td>200.000</td>
<td>200.000</td>
<td>200.000</td>
<td>800.000</td>
<td>800.000</td>
<td>800.000</td>
<td></td>
</tr>
<tr>
<td>Total (€/ month)</td>
<td>$7,089</td>
<td>$7,180</td>
<td>$5,898</td>
<td>$6,600</td>
<td>$5,998</td>
<td>$6,240</td>
<td>$19,414</td>
<td>$18,567</td>
<td>$18,328</td>
</tr>
<tr>
<td>Workforce (%)</td>
<td>63%</td>
<td>63%</td>
<td>76%</td>
<td>68%</td>
<td>75%</td>
<td>72%</td>
<td>66%</td>
<td>63%</td>
<td>64%</td>
</tr>
<tr>
<td>Total (€/ oper hour)</td>
<td>$47,27</td>
<td>$47,88</td>
<td>$39,33</td>
<td>$44,01</td>
<td>$40,00</td>
<td>$41,61</td>
<td>$45,72</td>
<td>$47,48</td>
<td>$46,87</td>
</tr>
<tr>
<td>Total (€/ km)</td>
<td>$1,30</td>
<td>$1,32</td>
<td>$1,08</td>
<td>$1,21</td>
<td>$1,10</td>
<td>$1,14</td>
<td>$3,23</td>
<td>$3,14</td>
<td>$5,05</td>
</tr>
<tr>
<td>Total (€/ pass)</td>
<td>$8,26</td>
<td>$8,36</td>
<td>$6,87</td>
<td>$7,69</td>
<td>$6,99</td>
<td>$7,27</td>
<td>$194,14</td>
<td>$26,15</td>
<td>$52,40</td>
</tr>
<tr>
<td>Total (€/ REA pass)</td>
<td>$9,53</td>
<td>$9,65</td>
<td>$7,93</td>
<td>$8,87</td>
<td>$8,06</td>
<td>$8,38</td>
<td>$194,14</td>
<td>$26,15</td>
<td>$52,40</td>
</tr>
</tbody>
</table>

Table 13: TCO for different vehicles

N.b.: REA passengers do not include the “No Show” trips. The ridership used for the Citaro was the patronage of the fixed route while the others it was used the numbers of both lines of Mokumflex. Also, one must remember that each column of the Citaros represents only one line of the previous system, while the columns of the other vehicles express the whole cost for running Mokumflex.

The workforce represents an important percentage for both car-based and bus-based operations. This demonstrate the potential of automated operations, that would possibly reduce this kind of expenditure. When comparing the costs per hour, both bus-based and car based are equivalent. However, in all other economical indicator, the car-based operations overcome the bus-based. Specifically about the costs per passenger, even if there was a drop in the demand, the economic savings were much more important.

In regards to electrification, there is no big difference when analyzing the costs of the e-Crafter and e-Golf with the equivalent fossil-fuel alternatives. However, even if it is not in the scope of this document, when analyzing long-term trends, the electric cars tend to be cheaper in the future due to the reduction of prices of the components (VDMA, 2016) and fossil-fuel technologies, more expensive, as, for example, the cost of the ton of CO2 will raise (Carbon Market Watch, 2018).

Finally, the lowest prices are still for the Rapid, the cheapest solution proposed, even if it is gasoline-based.

The following table gives an overview of the cost composition per vehicle for Mokumflex and the previous operation, represented by the Citaros:
From this graphic, it is possible to see that the energy represents a higher percentage for buses. Also, the cost composition of the electric cars is similar to the fossil fuel vehicles. Furthermore, for the Combi and e-Crafter, depreciation has a very important contribution for the total.

These costs already show that the previous operation was much more expensive. However, the last table is an analysis per vehicle, while in real terms, more than one is necessary – check the section “Fleet dimensioning” to see that one car was necessary for 85.5% of the time and mileage, resulting in 1.17 cars to offer the service. The next table shows the real economical differences of running a regular and a DRT system – remember that the previous costs were given by the sum of all “Citaro” lines:

<table>
<thead>
<tr>
<th>Number of cars/ drivers</th>
<th>Total (€/ month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combi 1.17</td>
<td>$8.291</td>
</tr>
<tr>
<td>e-Crafter 1.17</td>
<td>$8.398</td>
</tr>
<tr>
<td>Rapid 1.17</td>
<td>$6.898</td>
</tr>
<tr>
<td>Caddy 1.17</td>
<td>$7.719</td>
</tr>
<tr>
<td>Golf 1.17</td>
<td>$7.016</td>
</tr>
<tr>
<td>e-Golf 1.17</td>
<td>$7.298</td>
</tr>
<tr>
<td>Citaro, 49 2</td>
<td>$38.827</td>
</tr>
<tr>
<td>Citaro, 30 1</td>
<td>$18.567</td>
</tr>
<tr>
<td>Citaro, 31 2</td>
<td>$36.657</td>
</tr>
</tbody>
</table>

Table 14: Economic summary of running a DRT system and a conventional line

For Mokumflex, 1.17 cars are sufficient to serve the demand, for the current level of service. In the case of the previous lines the minimum number necessary, according to the headways, was 2 buses for line 30, 1 for line 31 and 2 for line 49. No reserve fleet was considered.

When comparing the previous bus system, whose costs were 94.051€ per month – remember that the total costs are the sum of the lines of the Citaros – much higher than any car-based demand-responsive system. This table summarizes in operational costs the advantages of better tailoring supply to demand, both in terms of mileage and size of the vehicle.
7.6 Price comparison with other modes

A price comparison is also valid to situate the different transit options a user has: for a displacement between two stops served by Mokumflex 490 – Geinbrug and Gaasperplas – with approximately 2.7km of length – the local GVB bus, Via, Via Private ride, Uber X, Uber Black and Uber Van were available and a comparison of these offers with the cost – in orange, in opposition to the offers, in blue - of providing such a trip via Mokumflex is shown:

Graphic 13: Price comparison with different offers

N.b.: The prices presented above were distance-based.

Even if a direct comparison is not well-suited – remember that the orange columns represent the costs of DRT, while the blue ones, the final price offered for the clients – it gives an idea of the economic performance of Mokumflex.

An important comparison should be made with Via, as it provides a similar service and is offered at a higher price than Mokumflex’s costs. Despite good economic performance, two issues should be highlighted: firstly, Via is in the market for more than 5 years and concentrate its knowledge in DRT operations, while this was Mokumflex’s first year and there are possibly adjustments that could be made to enhance even more its performance. Secondly, Via is focused in urban cores, not operating in areas like Weesp and the rural part of the line 301, which naturally reduces the efficiency of Mokumflex.

Finally, the comparison between the fare of the GVB Bus and the cost to provide such a displacement – Citaro, 49 – shows how subsidies can be costly for the public power: while the user pays 1,32 €, this displacement costs 10,09 €.
8. Societal costs

Some considerations should be made before passing to this analysis. For the purpose of this project, the vehicle disposal emissions were not considered. Also, similar to the “Economic analysis” section, while the previous system was shown in a disaggregated way, i.e. each column of the Citaros represent one line, for Mokumflex, each column represents the sum of both lines.

Furthermore, it is important to define a new term: lost ridership, LR. This expression makes reference to the travelers that previously used the regular transit system and that, after the introduction of Mokumflex, are not using it anymore and are probably relying on personal vehicles to displace. For the present research, these citizens were considered to be using 1.0 Golf gasoline, as this model is similar to the most popular car in the Netherlands, the Volkswagen Polo, and was already studied for the TCO evaluation (Autocar UK, 2018).

Moreover, as previously mentioned, GVB informed that one of the purposes of introducing Mokumflex and keep line 49 functioning was to see the impact of the DRT system into the regular line. Since the ridership almost did not change, for the calculation of the following indicators, it was considered equal to the previous.

Besides the number of LR, it was important to estimate the veh*km of the LR. This was made by using average tripping distance for each line multiplied by their respective LR. Even if this approach has clear limitations, it was found to be the most adapted for this analysis. Finally, it is important to remember that the occupancy for passenger cars in the Netherlands is 1.4 (Bleijenberg, 2014). The basic numbers are shown below:

<table>
<thead>
<tr>
<th>Ridership (pass/month)</th>
<th>AVG displacing distance (km)</th>
<th>LR (pass/month)</th>
<th>LR (veh*km/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>49 Previous 200 344 2.74</td>
<td>0 0</td>
<td>1.165 2.674</td>
<td></td>
</tr>
<tr>
<td>30 Current 200 526 3.21</td>
<td>1.165</td>
<td>2.674</td>
<td></td>
</tr>
<tr>
<td>31 Mokumflex 2.61</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

*Table 15: Basic features of the lost ridership*

From this table, the reader can see that the reduction on the demand coming from the implementation of Mokumflex in Amsterdam Noord will have considerable impacts, since these 1.165 passengers and 2.671 veh*km are probably being made by car: this number is almost 42% of the total 6.362 veh*km that Mokumflex made monthly – see section “Tripping and displacing distances”

8.1 Emissions

When it comes to emissions, both Green House Gas, GHG, and pollutants should be analyzed. Additionally, when measuring the emissions, the well-to-tank - WTT - and tank-to-wheel – TTW – steps of the fuel cycle are fundamental to better estimate the impacts. For the current project, only equivalent CO2 emissions WTT were studied while for the TTW, both pollutants and GHG were taken into consideration.
8.2 GHG

Before presenting the results, it is important to explain the limitations of the WTT analysis. Firstly, no emissions linked to construction nor decommissioning of plants and vehicles were included since the data to measure these impacts is limited and they are not very relevant (Edwards et al, 2013).

Basically, the WTT steps of CNG, gasoline and diesel follow a standard procedure: production and conditioning at source, crude oil transport to refineries, refining and distribution. For each of these, average values for Europe obtained by Edwards et al (2013) were used.

Since the emissions WTT are usually estimated in gCO2eq/ MJ of fuel produced available at the gas station, the “heating value”, which is a factor to convert from MJ to kg and the specific mass of the different fuel were necessary and they were obtained from CBS (2018b) and CNG Europe (2015).

In regard to the electric vehicles, the most important was the carbon intensity, which is a measure of the gCO2eq/ kWh of electricity produced and in the case of the Netherlands, this number is 513gEqCO2/ kWh (Electricity Map, 2018). Furthermore, losses when charging electric vehicles happens and a percentage of 2% was included, considering peak-hours and penetration of 0% for electric vehicles, as proposed by Mies et al (2017). It is important to note that in the Netherlands, the electric fleet is only 1.4% of the total (CBS, 2018a). These values were summarized in the table below:

<table>
<thead>
<tr>
<th></th>
<th>Gasoline</th>
<th>Diesel</th>
<th>CNG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions (gCO2eq/ MJ)</td>
<td>13,1</td>
<td>14,7</td>
<td>13,0</td>
</tr>
<tr>
<td>Heating value (MJ/ kg)</td>
<td>42,4</td>
<td>43,2</td>
<td>52,3</td>
</tr>
<tr>
<td>Specific mass (g/ cm3)</td>
<td>0,75</td>
<td>0,84</td>
<td>-</td>
</tr>
<tr>
<td>Emissions (gCO2eq/ kg)</td>
<td>555,2</td>
<td>635,0</td>
<td>680,4</td>
</tr>
<tr>
<td>Emissions (gCO2eq/ L)</td>
<td>740,2</td>
<td>759,5</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 16: WTT emissions


Furthermore, CO2 emissions can be monetized in order to materialize its impacts. The value is based in the national carbon floor price, i.e. the limit under with CO2 price cannot fall beneath, which is currently 18 €/ ton for the Netherlands and is intended to raise to 43 €/ ton by 2030 (Carbon Market Watch, 2018). However, the price used for this simulation will be 20,35 €/ ton, as of European commodities’ prices in 05/12/18 (Market Business Insider, 2018). Assembling both WTT and TTW CO2 emissions, the following results are obtained per vehicle, per model:
Table 17: Summarized emissions per model

<table>
<thead>
<tr>
<th>System</th>
<th>Cons (Lt, kg or kWh/100km)</th>
<th>Mileage (veh*km)</th>
<th>WTT (gCO2eq/ km)</th>
<th>TTW (gCO2eq/ km)</th>
<th>Mileage (veh*km)</th>
<th>WTT (gCO2eq/ km)</th>
<th>TTW (gCO2eq/ km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combi</td>
<td>7,3</td>
<td>6.362</td>
<td>49,7</td>
<td>195,4</td>
<td>3.744</td>
<td>33,3</td>
<td>105,0</td>
</tr>
<tr>
<td>e-Crafter</td>
<td>22</td>
<td>6.362</td>
<td>115,1</td>
<td>0</td>
<td>3.744</td>
<td>33,3</td>
<td>105,0</td>
</tr>
<tr>
<td>Rapid</td>
<td>4,6</td>
<td>6.362</td>
<td>34,0</td>
<td>107,0</td>
<td>3.744</td>
<td>33,3</td>
<td>105,0</td>
</tr>
<tr>
<td>Caddy</td>
<td>5,2</td>
<td>6.362</td>
<td>39,5</td>
<td>136,0</td>
<td>3.744</td>
<td>33,3</td>
<td>105,0</td>
</tr>
<tr>
<td>Golf</td>
<td>4,5</td>
<td>6.362</td>
<td>33,3</td>
<td>105,0</td>
<td>3.744</td>
<td>33,3</td>
<td>105,0</td>
</tr>
<tr>
<td>e-Golf</td>
<td>17,4</td>
<td>6.362</td>
<td>91,0</td>
<td>0</td>
<td>3.744</td>
<td>33,3</td>
<td>105,0</td>
</tr>
<tr>
<td>Citaro, 49a</td>
<td>38,7</td>
<td>11.945</td>
<td>293,9</td>
<td>1.084,0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Citaro, 30a</td>
<td>38,7</td>
<td>3.670</td>
<td>293,9</td>
<td>1.084,0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Citaro, 31a</td>
<td>38,7</td>
<td>12.467</td>
<td>293,9</td>
<td>1.084,0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

a: The TTW emissions came from Citaro Euro VI bus tested by TNO (2014) in a route containing both rural and urban parts


N.b.: For the WTT gCO2eq was used since similar data was not found for TTW nor LR. Moreover, “system” refers both to Mokumflex or the previous transit lines.

When comparing the CO2 costs of the Golf and the e-Golf, the electric still emits 65% of the CO2 estimated for the gasoline version, due to the high carbon intensity of the Dutch energetic matrix. Brief, this table shows the importance of both studying WTT emissions since they can hide important numbers and also to prioritize investments in in decarbonization of the national electric mix. Finally, the LR emissions cannot be neglected and represent an important part of the total, accounting for more than one third in the case of the e-Golf.

This previous table, however, contained information per car, but since the system needs more than one car to run – see section “Fleet dimensioning” – the monetization of the impacts of each option is proposed below:

Table 18: CO2 costs

<table>
<thead>
<tr>
<th>System</th>
<th>Mileage (veh*km/ month)</th>
<th>CO2 cost (€/ month)</th>
<th>Mileage (veh*km/ month)</th>
<th>CO2 cost (€/ month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combi</td>
<td>6.362</td>
<td>$31,73</td>
<td>2.674</td>
<td>$7,53</td>
</tr>
<tr>
<td>e-Crafter</td>
<td>6.362</td>
<td>$14,90</td>
<td>2.674</td>
<td>$7,53</td>
</tr>
<tr>
<td>Rapid</td>
<td>6.362</td>
<td>$18,26</td>
<td>2.674</td>
<td>$7,53</td>
</tr>
<tr>
<td>Caddy</td>
<td>6.362</td>
<td>$22,72</td>
<td>2.674</td>
<td>$7,53</td>
</tr>
<tr>
<td>Golf</td>
<td>6.362</td>
<td>$17,91</td>
<td>2.674</td>
<td>$7,53</td>
</tr>
<tr>
<td>e-Golf</td>
<td>6.362</td>
<td>$11,79</td>
<td>2.674</td>
<td>$7,53</td>
</tr>
<tr>
<td>Citaro, 49</td>
<td>11.945</td>
<td>$334,96</td>
<td>0</td>
<td>$0,00</td>
</tr>
<tr>
<td>Citaro, 30</td>
<td>3.670</td>
<td>$102,92</td>
<td>0</td>
<td>$0,00</td>
</tr>
<tr>
<td>Citaro, 31</td>
<td>12.467</td>
<td>$349,59</td>
<td>0</td>
<td>$0,00</td>
</tr>
</tbody>
</table>
N.B.: It is important to highlight that in the case of Mokumflex’s, 1,17 cars were necessary to run these veh*km, while for the buses, the fleet was estimated based on the headways and length of the line. For the previous offer, 5 were necessary: 2 for the line 49, 1 for the 30 and 2 for the 31.

The difference of GHG costs existing between the current and the previous service is considerable since the buses are much more polluting and had higher daily mileages. These costs, however, represent only a small fraction of the operational costs.

As mentioned before, the difference between running an electric fleet and a fossil-fuel fleet is not very relevant: the e-Golf saves 6,12€/ month. Also, there is no big difference when comparing diesel to gasoline vehicles. Finally, the lost ridership deserves attention since it is responsible for a large percentage of the total, representing more than 30%.

### 8.3 Pollutants

Pollutants should also be taken into consideration when analyzing a new mobility project as they have important social and economic consequences. When it comes to health impacts, for example, they are estimated to be responsible for 7 million premature deaths each year, costing 1.431 trillion dollars only in the WHO European area, in 2010 (WHO, 2015). Due to distinct chemical natures, they also have diverse impacts that are translated in different costs per ton:

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>€/ ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH4</td>
<td>$575,0</td>
</tr>
<tr>
<td>N2O</td>
<td>$7,400,0</td>
</tr>
<tr>
<td>CO</td>
<td>$3,2</td>
</tr>
<tr>
<td>PM10</td>
<td>$418,160,0</td>
</tr>
<tr>
<td>SO2</td>
<td>$14,921,0</td>
</tr>
<tr>
<td>NOX</td>
<td>$1,659,0</td>
</tr>
</tbody>
</table>

*Table 19: Costs per ton of main pollutants*

Source: timme et al. (2007) and Timmermans et al. (2006) appud Macharis (2011)

In Europe, vehicles are submitted to the “Euro standard”, which establishes pollutant thresholds for diesel, gasoline and gas cars, light trucks, buses and heavy-duty trucks based on their fuel and weight. For the current situation, restrictions for CO, Hydrocarbons (HC), NOx, Particulate Matter (PM), Particle Number (PN) and smoke are already in place but due to the unavailability of information for the two lasts, they were excluded from the analysis. The following table contains the classification and limits for each of the vehicles analyzed in g/ km:
Table 20: Euro thresholds accordingly to the classification for each vehicle

Source: Dieselnet (2018a), Dieselnet (2018b)

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Euro</th>
<th>CO</th>
<th>HC</th>
<th>NOx</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combi Transporter: Gasoline/ CNG(^a)</td>
<td>5, N1 C-III</td>
<td>2,27</td>
<td>0,16(^b)</td>
<td>0,082</td>
<td>0,005(^c)</td>
</tr>
<tr>
<td>Crafter</td>
<td>Electric</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rapid</td>
<td>Gasoline</td>
<td>6</td>
<td>1,00</td>
<td>0,1(^e)</td>
<td>0,06</td>
</tr>
<tr>
<td>Caddy</td>
<td>Diesel</td>
<td>5b</td>
<td>0,50</td>
<td></td>
<td>0,18</td>
</tr>
<tr>
<td>Golf Hatchback</td>
<td>Gasoline</td>
<td>6</td>
<td>1,00</td>
<td>0,1(^e)</td>
<td>0,06</td>
</tr>
<tr>
<td>e-Golf</td>
<td>Electric</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Citaro OS30</td>
<td>Diesel, V, Comp Ignition</td>
<td>6,20</td>
<td>1,90</td>
<td>8,26</td>
<td>0,12</td>
</tr>
</tbody>
</table>

a: for the CNG car, the standard for gasoline was applied  
b: and non-methane Hydrocarbons = 0,108 g/km  
c: applicable only to vehicles using DI engines  
d: 0,0045 g/km using the PMP measurement procedure  
e: and NMHC = 0,068 g/km

N.b.: For the heavy-duty trucks and buses, the Euro norms propose limits of emissions in g/ kWh and in the case of Citaro the factor of 4,13 kWh/ km was used, as mentioned by Civitas (2014).

In addition, data of emissions for each of the vehicles was obtained and was summarized in the following table – again, in g/ km:

Table 21: Emissions of pollutants per km for each vehicle


<table>
<thead>
<tr>
<th>Year</th>
<th>Year</th>
<th>CO</th>
<th>HC</th>
<th>Nox</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combi Transporter(^a)</td>
<td>1984 cc 85 kW 243 g/km MPV</td>
<td>2010</td>
<td>0,105</td>
<td>0,002</td>
<td>0,003</td>
</tr>
<tr>
<td>e-Crafter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rapid</td>
<td>1197 cc 66 kW 105 g/km Hatchback</td>
<td>2017</td>
<td>0,157</td>
<td>0,022</td>
<td>0,039</td>
</tr>
<tr>
<td>Caddy</td>
<td>1598 cc 75 kW 119 g/km MPV</td>
<td>2015</td>
<td>0,191</td>
<td></td>
<td>0,103</td>
</tr>
<tr>
<td>Golf</td>
<td>999 cc 81 kW 106 g/km Stationwagon</td>
<td>2018</td>
<td>0,356</td>
<td>0,063</td>
<td>0,033</td>
</tr>
<tr>
<td>Citaro OS30(^b)</td>
<td>6,195</td>
<td>1,900</td>
<td>8,260</td>
<td>0,124</td>
<td></td>
</tr>
</tbody>
</table>

a: The emissions for the CNG Combi Transporter were obtained based on the petrol model emissions  
b: The emissions for the Citaro were considered as being equal to a Euro V bus;

N.b.: In red, pollutant emissions that were superior to the limit of the norm.

Taking into consideration the previous tables, the following numbers are obtained in €/ month:
Table 22: Pollution costs in €/ month per pollutant per car

<table>
<thead>
<tr>
<th>System</th>
<th>Mileage (veh * km)</th>
<th>Pollution cost (€/ month)</th>
<th>Mileage (veh * km)</th>
<th>Pollution cost (€/ month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combi</td>
<td>6.362</td>
<td>$0.04</td>
<td>2.674</td>
<td>$0.26</td>
</tr>
<tr>
<td>e-Crafter</td>
<td>6.362</td>
<td>$0.00</td>
<td>2.674</td>
<td>$0.26</td>
</tr>
<tr>
<td>Rapid</td>
<td>6.362</td>
<td>$0.50</td>
<td>2.674</td>
<td>$0.26</td>
</tr>
<tr>
<td>Caddy</td>
<td>6.362</td>
<td>$1.09</td>
<td>2.674</td>
<td>$0.26</td>
</tr>
<tr>
<td>Golf</td>
<td>6.362</td>
<td>$0.59</td>
<td>2.674</td>
<td>$0.26</td>
</tr>
<tr>
<td>e-Golf</td>
<td>6.362</td>
<td>$0.00</td>
<td>2.674</td>
<td>$0.26</td>
</tr>
<tr>
<td>Citaro, 49</td>
<td>11.945</td>
<td>$795.85</td>
<td>0</td>
<td>$0.00</td>
</tr>
<tr>
<td>Citaro, 30</td>
<td>3.670</td>
<td>$244.54</td>
<td>0</td>
<td>$0.00</td>
</tr>
<tr>
<td>Citaro, 31</td>
<td>12.467</td>
<td>$830.63</td>
<td>0</td>
<td>$0.00</td>
</tr>
</tbody>
</table>

N.b.: For the HC, the price used per ton was the one for the CH4.

The main conclusion coming from this table is the high pollution costs for running a bus-based system, mainly due to the PM and NOX costs and the higher veh * km – in the Appendix F the detailed cost composition for the system’s emission is presented. The costs for a car-based DRT operation are negligible. Additionally, the importance of studying the LR is expressed through the final numbers where, again, it accounts for considerable percentages of the total.

Moreover, the Caddy, a diesel model, as expected, has a considerably higher costs than the gasoline and CNG versions.

8.4 Safety

For the analysis of safety and road accident costs, it was given preference to the numbers contained in TML (2017), which contain information for Belgium. The choice was motivated due to the cultural and territorial proximity of both cultures but also due to the similarities in costs in terms of road-crash contexts, evidenced in Ricardo-AEA (2014).

In this study made by TML (2017), different transport externalities are analyzed and in the case of road accident costs, car classifications and road types have impacts on the accident costs (measured in € per 1.000km):

- Combi and e-Crafter: “Light truck”, 28.5 € per 1.000km;
- Rapid, Caddy, Golf and e-Golf: “Passenger cars”, 4.10 € per 1.000km;
- Citaro: “Bus”, 20.6 € per 1.000km.

Furthermore, this study refers to the road classification and the “average road” values were used, since this line is serving an urban-suburban and rural areas. The lost ridership, LR, was analyzed and taken into account as if the vehicles-kilometers were made by Golf, passenger car, similarly to the emissions.
The higher costs for the previous system is due to the mileage, even if the cost per km of the light truck is smaller. The passenger cars have the best results, favoring their use. Again, this externality has no great impact when compared to the operational costs.

### 8.5 Tax revenue

The motivation for studying this subject is the possibility of changes in revenues for the public power coming from the growth of the electric automobile park, reducing the budget. Naturally, this evaluation should start with the information for the different taxations accordingly to the fuel:

<table>
<thead>
<tr>
<th>Tax</th>
<th>% vs TT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>57%</td>
</tr>
<tr>
<td>Gasoline</td>
<td>69%</td>
</tr>
<tr>
<td>CNG</td>
<td>24%</td>
</tr>
<tr>
<td>Electricity</td>
<td>0,1043 €/kWh + 21% VAT</td>
</tr>
</tbody>
</table>

Table 24: Taxations for each type of fuel in the Netherlands


The last column shows the percentage of the taxation in the final price offered to the customer. Gasoline is the most taxed. The next table shows the final numbers for the comparison between Mokumflex and the previous system:
As expected, the previous system generates much more revenues than the current offer. In addition, even if the expenditure with electricity is less than a half of the fossil fuel options, the revenue coming from them is much lower than this ratio, highlighting an unbalanced taxation. Also, gasoline versions are more taxed than diesel cars, what is counter intuitive from an environmental point of view, since diesel has similar CO2 emission levels TTW but expel much more pollutants.

Finally, even if in a very simplified way, this table elucidates a real economic issue: the loss of revenues coming from the diffusion of electric and on-demand transit have real impact on the public budget.

### 8.6 Consolidated information

As expected, all the previous tables can be consolidated in a last one, expressing the “real” costs of operating Mokumflex in € per month – the detailed analysis is in the Appendix C. It is always important to remember that this is a limited set of externalities, since parking spaces, congestion, GDP growth and accessibility, for example, were not included.
The most important from these numbers is to realize that the operating costs and the tax revenue are prominent in the cost analysis and all other analyzed externalities play a marginal role - as a rule of thumb, for the current situation, they account for:

- Light trucks: about 2.5% of the total, slightly less for electric;
- Passenger car: about 0.7% of the total, slightly less for electric;
- Heavy duty: between 2.4% and 4.2% depending on the mileage.

Even if the tax revenue for the bus systems is higher, operating the previous lines is much more expensive: even the cheapest line, 30, is costlier than any of the possibilities exposed for both lines of Mokumflex.

As already elucidated, the workforce still responds for the majority of the operational costs, suggesting the potential of automation to enhance its performance. However, this change could not be straightforward since unemployment could generate negative effects.

Finally, the lowest costs was obtained for a small gasoline car, the Rapid, followed by the Golf. For the current situation and analysis, it is better to have a Rapid fleet rather than a e-Golf fleet. However, considering that the natural trend of raising prices for non-environmental friend technologies, investing in electric fleets and decarbonization of the electric matrix would be recommended.
9. Sensitivity analysis

The sensitivity analysis consists of estimating indicators accordingly to different scenarios but for the present case, the “different scenarios” mean different levels of demand. The objective of this section was then to estimate how the different levels of patronage impacted the trip length and the occupancy – see section “Network effects” – and consequently, societal and operational costs. Before presenting the results from the different scenarios studied, however, a few considerations should be made. Moreover, another important aspect is the number of cars required and a simplified estimation was made as following:

- For the current levels of service and urban context, from the 346 minutes an AOV car is being used for Mokumflex, in 296 of them, there is only one car on the system, a percentage of 85.5% - See the section “Fleet dimensioning”;
- An AOV car runs for about 243km daily – even if for Mokumflex, each vehicle runs 179.8km, see section “Tripping and displacing distances” –, meaning that for every 243km, one extra car will be added to the system;
- The length of the average lost-ridership trip was calculated based on the weighted average of the trip lengths multiplied by the old-system’s ridership, resulting in 3.16km/trip.

P.s.: Taking into consideration the regressions studied in the “Network effect” section of this report, for the current situation, a daily demand of 31 passengers could be served with a daily mileage of 243km.

When comparing the performance of Mokumflex to the one of Uber, presented by Henao (2017) the kilometers per hour is weak: during 14.767 minutes as a chauffeur, the author travelled 7.971km, giving an average of 30.8km/h, much higher than the average of 4.2km/h of the AOV system – it operates 20h per day – but lower than the 36.8km/h presented by Mokumflex. It is important to note that while the AOV system operated for 16h per day, Henao (2017) was working 5h per day, allowing him to work in better time-frames. In regards to Mokumflex, one must remember that, in opposition to the AOV, the daily time and kilometers considered for the system were only those when it was being used – displacing or tripping.
Table 26: General info for the different scenarios presented

<table>
<thead>
<tr>
<th>Demand (pass/month)</th>
<th>Trip length (veh*km per pass)</th>
<th>Occupancy (veh<em>km/pass</em>km)</th>
<th>System (veh*km)</th>
<th>LR (veh*km)</th>
<th>Passenger*km</th>
<th>Cars</th>
<th>Daily hours for Mokumflex (hours per vehicle per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>23,2</td>
<td>4,17</td>
<td>696</td>
<td>5.936</td>
<td>167</td>
<td>1</td>
<td>0,47</td>
</tr>
<tr>
<td>150</td>
<td>14,3</td>
<td>2,33</td>
<td>2,142</td>
<td>5.553</td>
<td>918</td>
<td>1</td>
<td>1,45</td>
</tr>
<tr>
<td><strong>200,0</strong></td>
<td><strong>13,1</strong></td>
<td><strong>2,11</strong></td>
<td><strong>2,621</strong></td>
<td><strong>5.394</strong></td>
<td><strong>1,245</strong></td>
<td>1</td>
<td><strong>1,77</strong></td>
</tr>
<tr>
<td><strong>271,4</strong></td>
<td><strong>12,0</strong></td>
<td><strong>1,89</strong></td>
<td><strong>3,249</strong></td>
<td><strong>5.166</strong></td>
<td><strong>1,722</strong></td>
<td>1</td>
<td><strong>2,20</strong></td>
</tr>
<tr>
<td>300</td>
<td>11,6</td>
<td>1,82</td>
<td>3,486</td>
<td>5.075</td>
<td>1,915</td>
<td>1</td>
<td>2,36</td>
</tr>
<tr>
<td>600</td>
<td>9,5</td>
<td>1,42</td>
<td>5,683</td>
<td>4.118</td>
<td>4,001</td>
<td>1</td>
<td>3,85</td>
</tr>
<tr>
<td>750</td>
<td>8,9</td>
<td>1,31</td>
<td>6,654</td>
<td>3.639</td>
<td>5,074</td>
<td>2</td>
<td>2,25</td>
</tr>
<tr>
<td>900</td>
<td>8,4</td>
<td>1,23</td>
<td>7,570</td>
<td>3,161</td>
<td>6,161</td>
<td>2</td>
<td>2,56</td>
</tr>
<tr>
<td>1,200</td>
<td>7,7</td>
<td>1,11</td>
<td>9,280</td>
<td>2,204</td>
<td>8,370</td>
<td>2</td>
<td>3,14</td>
</tr>
<tr>
<td><strong>1,419,6</strong></td>
<td><strong>7,4</strong></td>
<td><strong>1,04</strong></td>
<td><strong>10,454</strong></td>
<td><strong>1,504</strong></td>
<td><strong>10,012</strong></td>
<td>2</td>
<td><strong>3,54</strong></td>
</tr>
<tr>
<td>1,500</td>
<td>7,2</td>
<td>1,02</td>
<td>10,871</td>
<td>1,247</td>
<td>10,618</td>
<td>2</td>
<td>3,68</td>
</tr>
<tr>
<td>1,800</td>
<td>6,9</td>
<td>0,96</td>
<td>12,372</td>
<td>2,90</td>
<td>12,897</td>
<td>2</td>
<td>4,19</td>
</tr>
<tr>
<td>2,100</td>
<td>6,6</td>
<td>0,91</td>
<td>13,804</td>
<td>0</td>
<td>15,203</td>
<td>3</td>
<td>3,11</td>
</tr>
<tr>
<td>2,250</td>
<td>6,4</td>
<td>0,89</td>
<td>14,497</td>
<td>0</td>
<td>16,364</td>
<td>3</td>
<td>3,27</td>
</tr>
<tr>
<td>2,400</td>
<td>6,3</td>
<td>0,87</td>
<td>15,178</td>
<td>0</td>
<td>17,531</td>
<td>3</td>
<td>3,42</td>
</tr>
<tr>
<td>2,700</td>
<td>6,1</td>
<td>0,83</td>
<td>16,504</td>
<td>0</td>
<td>19,880</td>
<td>3</td>
<td>3,72</td>
</tr>
<tr>
<td>3,000</td>
<td>5,9</td>
<td>0,80</td>
<td>17,789</td>
<td>0</td>
<td>22,427</td>
<td>3</td>
<td>4,01</td>
</tr>
<tr>
<td>3,300</td>
<td>5,8</td>
<td>0,77</td>
<td>19,038</td>
<td>0</td>
<td>24,631</td>
<td>3</td>
<td>4,29</td>
</tr>
<tr>
<td>3,600</td>
<td>5,6</td>
<td>0,75</td>
<td>20,255</td>
<td>0</td>
<td>27,030</td>
<td>4</td>
<td>3,43</td>
</tr>
<tr>
<td>3,750</td>
<td>5,6</td>
<td>0,74</td>
<td>20,852</td>
<td>0</td>
<td>28,235</td>
<td>4</td>
<td>3,53</td>
</tr>
<tr>
<td>3,900</td>
<td>5,5</td>
<td>0,73</td>
<td>21,443</td>
<td>0</td>
<td>29,444</td>
<td>4</td>
<td>3,63</td>
</tr>
<tr>
<td>4,200</td>
<td>5,4</td>
<td>0,71</td>
<td>22,606</td>
<td>0</td>
<td>31,870</td>
<td>4</td>
<td>3,82</td>
</tr>
<tr>
<td>4,500</td>
<td>5,3</td>
<td>0,69</td>
<td>23,746</td>
<td>0</td>
<td>34,309</td>
<td>4</td>
<td>4,02</td>
</tr>
</tbody>
</table>

N.b.: In bold the numbers of ridership for the previous lines: 200 for the line 49, 271,4 for the line 31 and 1419,6 for the line 30. The month was considered as having 30 days thus the maximum demand studied here was 150 passengers per vehicle, respecting the limits of the regressions for the section “Network effect”.

This table confirms expectations previewed earlier, at the “Network effects” chapter: even for higher demands, the system does not perform better than the private car and again, the argumentation of being a rural transit should be applied.

In regards to the costs, the CNG Combi was used, showing the following results - a more detailed analysis can be found in the Appendix F:
From this table, one can see that operational costs – workforce and vehicular – represent the majority of the expenditures. Furthermore, the tax revenue is not relevant. However, an analysis of final costs per REA passenger and per veh*km can help the reader better understanding the advantages of growing the ridership:

On the left axis, the scale for the costs per realized passenger, the blue curve, while on the right axis, the cost per month per pas*km. The two curves demonstrate a descending trend: the higher the demands, the better is the usage of the cars, the better is the matching process, the better is the economic
performance. Again, for lower demands the economic gains are much more important than for higher patronages. When it comes to the analysis of the supply, however, the trend is different:

On the left axis, the monthly cost per veh*km, while on the right axis, the cost per month per car. Again, the lower demands offer great gains but in opposition to the previously presented results, there is a stabilization independently of the fleet size: despite the ondulations whose valleys are caused by the addition of one car to the fleet, the values of both indicators tend to stabilize in values around 1,15 €/month/SYS veh*km and 6.500 €/month/car.
10. Conclusion and recommendations

10.1 Conclusion

10.1.1 General conclusions

DRT are seen as an offer that could provide a transit option for in an more economically performing way. This means that necessarily the ease of use of a fixed route and fixed schedule regular transit system – which causes high expenditures – is not a feature that this system will dispose since it requires more cars and more vehi*km travelled. Furthermore, even if there is a raise in demand accordingly to the level of service, the cost reduction is still much more important and a cost comparison in €/ month/ REA pass highlight these differences – see Appendix F:

Moreover, in these calculations are already included the societal costs. The operational costs account for the absolute majority of the total, meaning that even if there is a conscientization about environmental issues, their representativity on the total costs is still very limited. If sustainable development is to be effectively internalized into the decision making of transit, the costs associated with externalities should rise.

Further important comments should be made about social issues. Besides the unavailability of practical indicators nor studies about this subject that made hard estimating their societal costs, they are possibly one of the main motivations for keeping a transit system running in such an environment: as exposed before, as Mokumflex is less performing than the private car. As previously evocated, for the present case, the decision should be made not between serving or not an area with regular or on-demand transit but rather serving with on-demand transit or not serving at all. If all inhabitants had the capacity to drive a car, possibly the final recommendation of this report would be to suspend such a trial but this is not even close to the reality as both areas have a considerable percentage of vulnerable population, for example.

In regards to further studies, recommendations would be mainly around social issues, since this pillar of the sustainable development is probably the one facing more limitations in terms of data. In one hand, because this kind of information can be invasive, putting in question privacy issues, and secondly because it is naturally more complicated to assemble big datasets on human’s perception rather than operational indicators.

However, given the importance of the smartphones for the current mobility offers, realizing studies to assess how population is adapting to the gadget seems fundamental, addressing questions like: “how does the digital literacy and the body’s homeostasis impact mobility”.

Other subject that deserves better attention is to check the inclusion of vulnerable groups within this new context of mobility. Finally, as previously evocated, more should be done when analyzing the disturbances on the mobility chain coming from subsidizing transport offers.
10.1.2 Conclusions for Mokumflex

Transportation systems are very complex due to its importance on the core of the society as well as the challenges they face. In the case of Mokumflex, it ran in different environments: from a low-density rural area to a dense suburban core, crossing both rich and poor zones with a considerable percentage of old population. From this description, the user may already envisage some challenges: in a low-demand context, the metrics for transit operations will naturally be less performing than in urban cores thus comparisons with other modes and lines should be made with care.

When it comes to demographics, for being the only transit option available in the rural area of Amsterdam Noord and in Driemond, stopping the service would possibly impact very negatively vulnerable parts of the population thus being a hard decision from the political point of view. One must remember that being in a rich area where the car ownership is probably high does not exclude the necessity of transit nor the existence of vulnerable population.

When it comes to the demand analysis, there are two different conclusions. If the northern part of Amsterdam the difficulty of reducing the level of service of transit, reduce the ridership as the population judge negatively the system. On the other hand, the implementation of such an offer in an area lacking public transport offer proved to be a good investment, bringing more users to transit in an economically performing way.

Because of the low ridership and long distances travelled, Mokumflex is not very performing when compared to other urban modes in terms of occupancy. However, again, it is a first attempt for a rural system that had other objectives rather than only serving inhabitants of these areas, like learning about demand-responsive systems.

From a social point of view, challenges like the smartphone usage and population’s perception were also evaluated. In regards to the first one, more than 80% of the clients used a smartphone to book trips and even if data about age and income are missing, this can be considered a good numbe. Still, the local volunteers that spread the smartphone usage on the area of the line 490 had impacting results: the smartphone penetration impacted the patronage, which was much lot better – when compared to the previous situation – for the line 490 than for the 301.

The population’s perception also deserves deepening: the two sources exhibited different results about the opinion of locals towards Mokumflex. When it comes to induction effects or reduction of usage of cars, there is a difference in results between the two areas target of the pilot which may limit the quality of affirmations coming from these results. This is reinforced by the negative image of Mokumflex in the northern part of Amsterdam due to the already discussed drop in level of transit service, which may put in question the bias of the survey.

The network effects showed that despite larger demands, Mokumflex would still be less performing than a private car in terms of externalities. This reinforces the purpose of DRT operations in dispersed-demand zones, where it must be understood as a social tool that would allow vulnerable groups to access basic services.

The evaluation of the economic, social and environmental performances show that the system is more performing than the previous offer. Of course, the drop on the demand could not be neglected and, as
suggested earlier, understanding the impacts of digital literacy on mobility is a theme that deserves better attention.

Nonetheless, Mokumflex presented interesting economic performances, providing a transit offer in a financially optimized way, mainly due to the reduced mileage and type of vehicles used. This reduced mileage and vehicular size also favored reduced emissions and pollutants but it is important to remember that the comparisons of different models demonstrated that the current context in the Netherlands still makes fossil fuel options more viable than electric ones but this tends to change as environmentally friendly solutions to be cheaper in the future.

In regards to social issues, the lack of data limited the analysis and impeded, for example, an evaluation of vulnerable groups in a disaggregated manner. When studying the perception of the inhabitants about Mokumflex, two different scenarios appear: while in Amsterdam Noord some critics arose about the quality of service, in Amsterdam Zuidoost-Weesp, the system was well seen by the locals.

Also, the main challenges faced by a DRT operation were around the level of service, that could be solved by scaling the offer and better managing the fleet. Moreover, if the performance from an operational point of view is satisfactory, the punctuality, ease of information and integration to the local transit are priorities for further development.

Finally, from all the objectives expected by the Municipality of Amsterdam—see section “Case study – Mokumflex”—the pilot answered properly all four of them, since it had a good performance and provided insights about this type of offer.

10.2 Recommendations

Evaluating a transportation system is a complex activity due the diversity of the impacts on the society, that go far beyond ridership, costs and emissions. This thesis tried to frame DRT systems in a more sustainable approach. For the continuity of similar projects, a set of practical recommendations was made:

- Reduce the size of the cars accordingly to the demand as buses are more expensive: vehicular, GHG emissions, pollutants and accidents costs are considerably higher when compared to regular passenger car. In the case where preference was still given to buses, better using it through the day is recommended: instead of offering a whole day service for the studied areas, a peak-service is more suitable. During the other parts of the day, the vehicle could be used in other lines. This would optimize the workforce costs, which is the only cost studied here that is independent of the mileage – not even depreciation is distance-dependent since probably most of the transit vehicles reach the mileage threshold before the time;

- Changes on the contract: both the bidding between Gemeente Amsterdam and GVB should consider the new technologies and their impacts – for example, headways are not good indicators to define a served area since they are not important for on-demand systems – but also between GVB and RMC – since the contract is based on a standard remuneration per veh*min, a variable remuneration is recommended to align drivers to the main indicators of the system, such as punctuality;

- Electrifying the fleet: a deeper analysis considering future contexts and other externalities – such as the infrastructure costs – should be made to better evaluate the savings coming from investing
in this technology. It is important to mention that for the current operation and the information analyzed, the e-Golf is still more costly than the Rapid;

- Marketing: besides the bad integration with the local transit due to the absence of signs and other marketing tools, digital literacy is an issue that could be overcome with marketing campaigns aimed at teaching people on how to use the system, making local inhabitants conscious that this is the best solution – the previous system was too costly – and that showing that the more they use, the better is the performance are keys;
- Increase the demand: network effects are important and have the potential to impact the costs and performance of the system, notably through reduced trip lengths and increased occupancy. The question is: how to do it?
- Study the demand: for the operational issues evocated before but also to reduce the high percentage of “No-show” trips it is important to take a careful look on demand;
- Existing areas: reducing the 15 minutes frame, improving punctuality and reducing the time required before the departure to book a trip are fundamental. Ensuring that cars are near the request could address these issues. Besides having more cars in the system, studying the spatio-temporal patterns of the demand: knowing where and at what time usually users request Mokumflex would allow a better matching between demand and supply;
- Increased intricacy: people are eager for transit and this could attract car-users for public buses. However, to be more precise about this migration, a study about the inductive power of buses should be made, since only qualitative data coming from the survey was available;
- New areas and time-frames: low patronage lines and times of the day – such as night service – are usually more costly per passenger/ per veh*km than other situations and experimenting in these environments could boost even the performance in the oldest areas;
- Higher demands: even if a demand of 25 pass/ day/ vehicle would bring good results that are still worse than private cars, one must keep in mind that this is a low-demand transit solution which rarely would be profitable and present great indicators;
- No-transit: this is politically complicated even if GVB is not obliged to serve these areas. Additionally, studying other externalities, such as GDP growth, accessibility, infrastructure costs could help to boost the option for a transit system.

Finally, but not less important, the creation of standardized procedures of evaluation of DRT operations is fundamental to allow comparisons between different systems, permitting to evaluate, for example, the influence of the context on the behavior of the demand.
The elaboration of this work in the Netherlands allowed me to apply great part of the knowledge acquired in my formation as a Civil Engineer as well as new ideas coming from the master program. Developing a practical analysis for a project that has so many diverse stakeholders implicated gave me a transversal vision of the decision-making process. Moreover, being in a different country, living the Dutch philosophy of work and urbanism was a plus.

The Master TraDD offers us a broader vision of the problems of mobility: studying the strategic level of transportation planning gave me the necessary mindset to frame a such a small pilot program in a sustainable framework. As an engineer, this is very important, since we tend to analyze exclusively traditional metrics, neglecting, for example, the social mission of transportation.

The decision to follow a mixed specialization during the Master, combining subjects of Design of Mobility Services – that gave me a market-based vision - with concepts coming from Eco-conception of Infrastructures – which complemented my engineer background – was fundamental to better balance my analysis between practical information and more technical outcomes.

The most important ideas from the program that allowed the development of this report were:

- The major role played by transportation to tackle externalities and how to internalize the consequences of this phenomenon were ideas absolutely necessary to improve the quality of this work;
- The inclusion of a social analysis into a technical project, learning how to find interesting information – that is usually not available in traditional sources – and develop a critical mindset of the impacts of mobility into people’s day-to-day life;
- The transversal approach of transportation and its interactions with other economical sectors, such as energy, housing and general market itself.

Finally, as previously evoked, the multiculturality of the program and, in my personal case, my internship, made me ready to face not only the transportation market in Europe, but all types of business in almost every corner of the world.
As evoked on the “Definition od DRT”, the concept dispose of different operational features, being the most important the fact that they can be operated on a fixed or flexible route, by a preset or a non-demand schedule. From this, different possible business models are possible (Westervelt et al., 2018):

<table>
<thead>
<tr>
<th></th>
<th>Fixed route</th>
<th>Flexible route</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fixed schedule</strong></td>
<td>Users can “crowd-source” new lines, informing operators their preferences in terms of stops and the operator itself decide to implement or not a new line.</td>
<td>Users may request pick-up and drop-off points from a fixed schedule service.</td>
</tr>
<tr>
<td><strong>Flexible schedule</strong></td>
<td>Users may request shared vehicles in real-time along a predetermined route.</td>
<td>Users may request vehicles to deviate from their routes to somewhere within a near distance of the him in a non pre-determined schedule.</td>
</tr>
</tbody>
</table>

*Table 27: Different business models based on the scheduling and routing processes*

*Source: Westervelt et al., 2018*

Other interesting approach is to try to define a transit system by the classification of its characteristics:
<table>
<thead>
<tr>
<th>Nature</th>
<th>Description</th>
<th>Possibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand</td>
<td>Accept only private rides or is it open to public?</td>
<td>Private, Open</td>
</tr>
<tr>
<td>Demand</td>
<td>Accept disabled passengers?</td>
<td>Yes, No</td>
</tr>
<tr>
<td>Demand</td>
<td>Subscribe system with pre-booked rides or individual rides?</td>
<td>Pre-booked, Individual</td>
</tr>
<tr>
<td>Demand</td>
<td>Rural, semi-urban or urban context?</td>
<td>Rural, Semi-urban, Urban</td>
</tr>
<tr>
<td>Fare</td>
<td>Flat or variable fare?</td>
<td>Flat, Variable</td>
</tr>
<tr>
<td>Fare</td>
<td>Pre-payment or real time paying system?</td>
<td>Yes, No</td>
</tr>
<tr>
<td>Governance</td>
<td>Ownership of the company?</td>
<td>Private, PPP, Public</td>
</tr>
<tr>
<td>Governance</td>
<td>Internal subsidies?</td>
<td>Yes, No</td>
</tr>
<tr>
<td>Governance</td>
<td>To whom the cars and other supplies belong?</td>
<td>Driver, Private entreprise, PPP, Public Power</td>
</tr>
<tr>
<td>Governance</td>
<td>Drivers are hired by the company?</td>
<td>Yes, No, Independent</td>
</tr>
<tr>
<td>Governance</td>
<td>Formed system?</td>
<td>Yes, No</td>
</tr>
<tr>
<td>Governance</td>
<td>Replaced a previous line?</td>
<td>Yes, No</td>
</tr>
<tr>
<td>Service</td>
<td>Flexible routing?</td>
<td>Yes, No</td>
</tr>
<tr>
<td>Service</td>
<td>Dispatching and/or call-center?</td>
<td>Yes, No</td>
</tr>
<tr>
<td>Service</td>
<td>On board services (WiFi, water, newspapers...)</td>
<td>Yes, No</td>
</tr>
<tr>
<td>Service</td>
<td>Possibility of proposing new stops?</td>
<td>Yes, No</td>
</tr>
<tr>
<td>Service</td>
<td>Door-to-door, Door-to-Stop/ Stop-to-door or Stop-to-Stop</td>
<td>DtD, DtS/ StD, StS</td>
</tr>
<tr>
<td>Service</td>
<td>Area or line based?</td>
<td>Area, line</td>
</tr>
<tr>
<td>Service</td>
<td>Commuter or feeder?</td>
<td>Commuter, feeder</td>
</tr>
<tr>
<td>Service</td>
<td>Trip purpose?</td>
<td>Commuting, leisure/ events, health, school, other</td>
</tr>
<tr>
<td>Service</td>
<td>Indefinite number of stops or just selected stops?</td>
<td>Indefinite, selected</td>
</tr>
<tr>
<td>Service</td>
<td>Many-to-one/ One-to-many, many-to-few or many-to-many?</td>
<td>MtO/ OtM, MtF, MtM</td>
</tr>
<tr>
<td>Service</td>
<td>Short or long distance?</td>
<td>Short, Long</td>
</tr>
<tr>
<td>Time</td>
<td>Flexible schedule?</td>
<td>Yes, No</td>
</tr>
<tr>
<td>Time</td>
<td>Operates only in regular peak-hours or not?</td>
<td>Yes, No</td>
</tr>
<tr>
<td>Time</td>
<td>Operates as a night service?</td>
<td>Yes, No</td>
</tr>
</tbody>
</table>

Table 28: Characteristics of transit systems

Using this table, one can classify different features of different transit operations, making it clearer for the reader where does Mokumflex is situated:
Table 29: Classification of different transit systems

As one can see, the visualization of a certain transport offer can be easier using this classification.
13. Appendix B - Timeline

13.1 Context during the 60’s and 70’s
Taking a look at these two photos may give the lector an idea of the changes in these 50-60 years that separate the current days from the first wave of DRT operations.

![Figure 13: North-American households during the 60’s and 2020’s](image)

Source: Flickr (2012), Ramnimal (2013)

They show North-American households during these two different times. A detail that is usually unnoticed has changed drastically the way people move around: the smartphone - and mobile internet. This combination made the possibility for on-demand transportation latent and is redefining mobility in cities around the world (Ledwell, 2016).

To study DRT systems, one must go back to the beginning of the 20th century, when the first regular and documented experiment took place in 1916, in Atlantic City, New Jersey: a jitney service open to the general public that operated in a fixed route picking-up and discharging passengers accordingly to their demand (O’Leary, 1974).
The following decades, however, met only a shy diffusion of these type of projects with only two more operations being documented. It was only during the 60’s that the planet watched the expansion of these transportation systems: starting in North America and followed by Europe during the 70’s (Strobel, 1982).

Naturally, the first question that arises is what was the context during the 60’s that favored the “birth” of the DRT?

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 made and described the main urban challenges faced by society at that time. Among equality, accessibility, quality of service, congestion, efficient use of assets, pollution and urban development, the uncompromising and misfit institutional framework was seen as crucial to answer the already accelerated growth of suburban areas (HUD, 1968, and UMTA, 1979a).

Fortunately, a favorable mindset could be already outlined in those days: the technological developments were perceived as “the most striking opportunities for improvement in urban transportation” and main lines of this scientific progress were car automation - scheduling and operation - and sharing - car rental service for short trips -, solutions to reduce pollution - electric and hybrid motors - and tailored schedules and headways – better matching offer to demand (HUD, 1968). Buses were a promising mode due to its flexibility and low initial investment costs and were especially well seen to address the proliferation of low-density areas that generally did not enjoy the same economic power of metropolitan regions (HUD, 1968, EPM, 1973). It is important to say, however, that DRT operations were also implemented in high-density areas at that time.

In this specter, the “dial-a-bus” project was considered the basis of the solution for low-demand areas “picking up passengers at their doors or at a nearby bus stop shortly after they have telephoned for the
service” and was expected to soon become affordable due to improvements in automation and ridesharing (HUD, 1968). Another interesting fact is the already existing possibility of different levels of service according to the customer’s preference, hanging from unscheduled single-passenger door-to-door service to scheduled multi-passenger stop-to-stop service (HUD, 1968).

As one can see from the previous picture, even if there were many similarities to the current context, the operation of DRT systems in that time had some peculiarities: instead of smartphones, algorithms and internet, their operation was based in telephone calls, dispatchers and radio. Indeed, one of the main concerns to the deployment of these operations was the telephone ownership (Oxley, 1973). The following table shows the telephone subscriptions in different countries that had projects of DRT during the 60’s and 70’s.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>27,8</td>
<td>26,7</td>
<td>30,4</td>
<td>35,7</td>
</tr>
<tr>
<td>France</td>
<td>4,8</td>
<td>6,3</td>
<td>8,4</td>
<td>13,4</td>
</tr>
<tr>
<td>Germany</td>
<td>4,4</td>
<td>6,4</td>
<td>10,9</td>
<td>16,3</td>
</tr>
<tr>
<td>Netherlands</td>
<td>9,1</td>
<td>12,3</td>
<td>16,9</td>
<td>24,4</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>9,6</td>
<td>12,0</td>
<td>16,6</td>
<td>23,5</td>
</tr>
<tr>
<td>United States</td>
<td>26,4</td>
<td>29,2</td>
<td>32,9</td>
<td>36,7</td>
</tr>
<tr>
<td>Sweden</td>
<td>27,9</td>
<td>37,8</td>
<td>44,7</td>
<td>51,3</td>
</tr>
</tbody>
</table>

*Table 30: Telephone subscriptions per 100 people in different countries during the 60’s*
One can see how different telephone possession was in North-America and Europe: except for Sweden, the subscriptions in the first continent were much higher than the European average and this had an influence in the spread of DRT projects.

### 13.2 Cost composition

Focus on cost-optimization has always been an issue in no matter what business. In transit, this becomes even more urgent, as operations are rarely profitable. If one is to analyze the cost composition of operations back on the 70’s, he would already find why transit was considered a workforce-dependent activity: the expenditures with dispatchers and drivers accounted from 60% to 75% of the costs (Guenther, 1973, and UMTA, 1979a). One example is the cost composition for the system of Bay Ridges, during the 70’s:

<table>
<thead>
<tr>
<th>Type</th>
<th>Cost (US$ 1973)</th>
<th>% vs. total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed</td>
<td>2.000</td>
<td>2.4%</td>
</tr>
<tr>
<td>Semi variable</td>
<td>13.000</td>
<td>15.7%</td>
</tr>
<tr>
<td>Variable</td>
<td>68.000</td>
<td>81.9%</td>
</tr>
<tr>
<td>- Drivers</td>
<td>42.000</td>
<td>50.6%</td>
</tr>
<tr>
<td>- Dispatchers</td>
<td>18.000</td>
<td>21.7%</td>
</tr>
<tr>
<td>- Vehicles</td>
<td>8.000</td>
<td>9.6%</td>
</tr>
</tbody>
</table>

*Table 31: Annual costs of Bay Ridges system 70/71 and 71/72*

Source: Bonsall (1973)

N.b. the inflation in the USA between 1970 and 2018 is almost 550% thus US$ 100,00 in 1970 has the same purchasing power as US$ 650,00 in 2018 (Officialdata, 2018).

Furthermore, evidence from 13 DRT operations in the US and Canada reinforce this idea, showing that control centers accounted for 20% of the implementation and operational costs with telephonists, dispatchers and managers representing 75% of this total (Arrillaga and Medville, 1974).
13.3 The beginning of automation

During this period, computation science was giving its first steps and applications in transit were already studied but they still had a limited role. In the case of DRT, it was mainly focused in dispatching functions such as defining routes, schedules, payments and assigning trips (Shackson et al., 1974).

The beginning of automation for DRT operations could be considered the Computer Aided Routing System project, CARS, conducted by the Massachusetts Institute of Technology, MIT. It was launched in 1965 with the main objective to design a system to provide a door-to-door transit service at a cost comparable to existing fixed route bus lines (Wilson et al., 1969, and UMTA, 1979a). To accomplish this, it was fundamental the development of a “many-to-many” origins and destinations algorithm to assign efficiently demand, reducing the workforce necessary to provide the offer. This would naturally diminish expenditures, allowing a more affordable fare allowing these systems to scale (Wilson et al., 1969, Strobel, 1982).

The operation was simple: passengers would request their trips via telephone and the calls would be processed by a central where a routing algorithm would allocate vehicles to demand and communicates this to the vehicle drivers in real-time. The idea was to pick-up the passenger within 10-15 minutes of the initial call and the vehicle would make deviations to pick-up and deliver other travellers respecting a limit of 2,5-3 times the duration of the trip if it was made by car (Wilson et al., 1969).

As consequence of the CARS project, the Urban Mass Transportation Administration, UMTA, run a few pilots in Rhode Island, Florida and, California but the two largest experiments were made in Haddonfield,
New Jersey, launched in 1972, and in Rochester, New York, in 1975 whose main objective was exactly to assess the effectiveness of computer-controlled dial-a-ride systems (Strobel, 1982).

Naturally, one may think that a workforce intensive market whose tasks could be easily automated is a fertile field for the implementation of computer control but in the case of DRT, this change was not straightforward. Computers did not perform much better than manually dispatched operations due to the weak computational capacity, high costs of implementation, constant breakdowns and mismatch of calibration parameters (Strobel, 1982). Additionaly, the necessity of developing parallel technologies that could potentialize the manpower savings - such as digital communication between the dispatching center and vehicle – was another factor impeding the rapid diffusion (Wilson and Higonnet, 1973, Aex, 1973 and Shackson et al., 1974).

13.4 DRT, dial-a-bus, shared-taxis and jitneys

During the 60's and 70's, were considered DRT all those systems that “provided flexible, point-to-point service in response to individual travel requests, often without fixed schedules nor routes, using a dispatching center that received calls and assigned demand to vehicles whose objective was to provide efficient service, group them and reduce the price paid by each passenger” (Roos, 1973). When made by bus or van, DRT was called “dial-a-bus”, DAB – generally managed by public operators - and when made by taxis, “shared-ride taxis”, SRT – usually operated by private enterprises (UMTA, 1979a, and UMTA 1979b). Furthermore, “Jitneys” are a form of demand-responsive system that provides shared-ride in fixed routes generally available by hailing (UMTA, 1979b).

About the taxis, already at that time they were a popular form of transportation, carrying more than all rail systems and half of the bus system in 1979 (UMTA, 1979b) and faced the same “many-to-many” problems when operating in a SRT regime (TRB, 1974). Indeed, during the 80’s, the low productivity of DAB systems opened a possibility of transferring to the taxi industry, via SRT. The taxi industry, however, saw as a great challenge the management of large taxi fleets in a shared-ride regime, making operators reluctant to enter this market (Strobel, 1982)

13.5 First North-American DAB experiences

The first two formal experiments, in Bay Ridges, Ontario, and Regina, Saskatchewan, took place under similar conditions: both offered a many-to-few feeder service in areas with similar street patterns and high car ownership (École Polytechnique de Montréal, 1973, appud TRB, 1973, and Atkinson, 1973). They differed, however, in terms of existing transit offer: while in Bay Ridges there was no transit system in the moment of the implementation, in Regina the DRT integrated the current network (Bonsall, 1973, and Atkinson, 1973). Both had interesting initial results: growing ridership and vehicle productivity, i.e. trips per vehicle-mile, and gains of private automobile users were recurrent (École Polytechnique de Montréal, 1973, appud TRB, 1973).

A third notorious example was the operation of Columbus, Ohio. Differently from the previous, this one was implemented in an area of low car ownership with a previous existing fixed route service and in a high populational density area. The system was part of a local urbanistic program thus had to operate with low fares which incremented the subsidy levels (Habig, 1973).

Another example in US happened in Ann Arbor, Michigan. The local environment was characterized by high car dependency, falling transit ridership but a supportive community and public power. Even if the
population struggled to abandon their cars due to the facility and low marginal costs of use (Urbanik, 1973, and Berla, 1973), most of the patronage of this system was composed by people that previously commuted in private automobiles (Berla, 1974).

Also, the case of Batavia, New York, where DRT was implemented to tackle the car dependence in a context of falling patronage and poor transit offer. The growing ridership and successive expansions were a proof of the success of the system, that met also a good financial result (Aex, 1973).

When it comes to computerized operations, the two first large federally funded DAR experiences happened in Haddonfield, New Jersey, and in Rochester, New York (Strobel, 1982). The first one was Haddonfield, beginning effectively in May, 1972, and was initially manually dispatched (Gwynn and Simpson, 1972), becoming automatically dispatched in February, 1974 (UMTA, 1974b). The algorithm used was the one developed in the CARS project (Strobel, 1982). A comparison of performance of both dispatching options showed that they were similar but the computer better performing in terms of customer’s waiting time. However, this was a small system - 10 to 12 vehicles, receiving 40 to 60 requests per hour – and managers were already conscious that computing capacity could be easily developed and other improvements coming from its implementation, such as easier management of files and indicators, automatic billing and enhanced reliability, made the opinion towards automatic dispatching positive (Strobel, 1982). A negative point was the replicability to other cities, as it was estimated that 80% were non-recurring when translating from one city to another (Shackson et al., 1974).

One of the expansions of the system of Batavia was to Rochester, in 1973 (McDougall et al, 1974). The operation became computerized in 1975 and many learnings from Haddonfield were used (Strobel, 1982). One of the most interesting was the classification of users in three groups that were characterized by a utility function accordingly to the preference of the passenger in terms of displacement: those willingness to be picked-up and delivered as soon as possible, those desiring to transfer to a scheduled bus and those that booked in advance whose punctuality was highly evaluated (Strobel, 1982).

The utility function depended on wait, ride and pick-up deviation times. Besides minimizing the disutility for both new and current users, the algorithm also aimed at minimizing the expenditure of resources and assuring smooth transfers (Strobel, 1982).

The first evidences demonstrated problems to achieve good levels of economic performance for DRT experiences. This leaded to modifications, such as changing for a many-to-one system - which decreased the importance of computer to perform dispatching functions - and moving parts of the service to the taxi industry - via shared taxis (Strobel, 1982). Indeed, in spite of great attention being given to DAB systems, the SRT companies benefited a lot from computation, improving their dispatching, level of service and productivity (Shackson et al., 1974).

Even if automation brought benefits, the translation of its costs into additional fares exceeded any improved quality coming from it. The main conclusion was that computation was good for bigger and more complex operations, which was not the case of Rochester nor Haddonfield, where a dispatcher was more appropriated (Newman et al, 1981).
The following table show some main operational features of the first years of operations of the previously mentioned systems.

Table 6:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Start</th>
<th>Dispatching</th>
<th>Fleet</th>
<th>Service area (km²)</th>
<th>Served pop (háb)</th>
<th>Pop density (háb/ km²)</th>
<th>Daily patronage (weekday)</th>
<th>Average fare (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bay Ridges, Ontario</td>
<td>Jul-70</td>
<td>Manual</td>
<td>4</td>
<td>3,5</td>
<td>13,700</td>
<td>3,947,4</td>
<td>463</td>
<td>$0,25</td>
</tr>
<tr>
<td>Regina, Saskatchewan</td>
<td>Sep-71</td>
<td>Manual</td>
<td>6</td>
<td>7,1</td>
<td>18,000</td>
<td>2,527,2</td>
<td>1200</td>
<td>$0,32</td>
</tr>
<tr>
<td>Ann Arbor, Michigan</td>
<td>Sep-71</td>
<td>Manual</td>
<td>3</td>
<td>3,5</td>
<td>10,000</td>
<td>2,857,1</td>
<td>214</td>
<td>$0,50</td>
</tr>
<tr>
<td>Batavia, New York</td>
<td>Oct-71</td>
<td>Manual</td>
<td>5</td>
<td>12,3</td>
<td>17,300</td>
<td>1,406,2</td>
<td>455</td>
<td>$0,50</td>
</tr>
<tr>
<td>Columbus, Ohio</td>
<td>Oct-71</td>
<td>Manual</td>
<td>4</td>
<td>6,8</td>
<td>37,000</td>
<td>5,473,4</td>
<td>485</td>
<td>$0,20</td>
</tr>
<tr>
<td>Haddonfield, New Jersey</td>
<td>May-72</td>
<td>Both</td>
<td>10-12</td>
<td>21,0</td>
<td>27,481</td>
<td>1,310,0</td>
<td>333</td>
<td>$0,50</td>
</tr>
<tr>
<td>Rochester, New York</td>
<td>Aug-73</td>
<td>Both</td>
<td>7</td>
<td>25,0</td>
<td>30,000</td>
<td>1,201,9</td>
<td>230</td>
<td>$1,00</td>
</tr>
</tbody>
</table>

Table 32: Initial features of some North-American systems


It is important to note that it was usual that these operations were subsidized. The most performing farebox recovery rate at this time was Batavia – 80% - but still needed extra sources to approximate the break-even situation. This was one of the major issues for Ford and GM – that already participated actively in the diffusion of DRT – to keep investing (Guenther, 1973).

13.6 European experiences

The European opinion about transit is very different from the North-American. While in the US transit was seen as non-performing and played a secondary role in public transportation, in Europe it was already perceived as highly viable, playing central role in main cities and having a strong institutional support. The first experiences date from the 70’s mainly influenced by the North-American initiatives but also because their results could differ from Europeans due to different travel behavior, telephone and car ownership and disposable income (Webster, 1974). The first countries to study these systems were the UK, Netherlands, Germany, France and Sweden (UMTA, 1981). The following table shows the possession rates for USA and Great Britain/England.
In the UK, they were characterized by small systems lacking central government support, expensive and not aligned to the national priorities. They started to be implemented in 1972 but in the end of the decade just very few operations were still running mainly focused in serving rural areas at lower costs (UMTA, 1981).

In the Netherlands, a single DRT project called BUXI started in 1970, in Emmen. By 1972, due to the low usage, it was discontinued but in 1976-1977, the central government started other pilot programs focused in low-density areas (UMTA, 1981).

In Germany, the two main initiatives were RUFBUS and RETAX (or R-BUS). The first one started in the end of 1977 and the second one a few months later. They were privately operated and ran in sub-urban and rural areas, allowing people to travel in a stop-to-stop system through computerized dispatching. They met a relative success which allowed their development in the country (UMTA, 1981).

France made its trials and the most successful early operation was the Confluent Busphone, operated by Renault in three small communities near Paris. This stop-to-stop system was less technological than the German ones but the more social participatory planning and operational styles were the main contributions provided by the French (UMTA, 1981). One interesting feature about the German and the French DRT is that the choice for a stop-to-stop system was the low telephone ownership rates (UMTA, 1981).

In Sweden, the first somehow DRT operation began in Gothenburg, in 1968. In partnership with Volvo, the radio taxi/ jitney service was considered a success but did not inspired other pilots (UMTA, 1981).

Public transport was seen very differently in the USA and Europe, as culturally the Americans did gave as much importance as Europeans to the idea of transit as a social tool. In the old continent, the government was usually more present in transport operations but for DRT this situation was different as the Europeans states saw the concept of DRT as not having much potential, characterizing the initiatives by limited public participation and stricter regulatory frameworks (UMTA, 1981).

### 13.7 Shared-ride taxis experiences

SRT experiences also appeared during these decades, since taxis already incorporated features of dial-a-bus systems back in the 70’ (École Polytechnique de Montréal, 1973, appud TRB, 1973). The Los Angeles

<table>
<thead>
<tr>
<th>Year</th>
<th>USA</th>
<th>Great Britain, England</th>
<th>Year, region</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>78%</td>
<td>31%</td>
<td>1961, GB</td>
</tr>
<tr>
<td>1970</td>
<td>83%</td>
<td>52%</td>
<td>1971, GB</td>
</tr>
<tr>
<td>1980</td>
<td>87%</td>
<td>60%</td>
<td>1981, GB</td>
</tr>
<tr>
<td>1990</td>
<td>88%</td>
<td>68%</td>
<td>89/91, EN</td>
</tr>
<tr>
<td>2000</td>
<td>91%</td>
<td>73%</td>
<td>98/00, EN</td>
</tr>
<tr>
<td>2010</td>
<td>91%</td>
<td>75%</td>
<td>2010, EN</td>
</tr>
</tbody>
</table>

*Table 33: Car possession in the USA and in Great Britain*

*Source: Gov UK (2013), BTS (2017a)*
Yellow Cab Company and the Diamond Cab Association of Montréal, for example, documented experiences with the computerized dispatching. Automated systems brought faster and more precise handling of orders, reduced piracy, improved pay-miles and general fleet management issues (Shackson et al., 1974).

However, the taxi industry had an image of weakly innovative: while bus and rail systems faced constant changes in governance during previous decades, the structure of the this business changed little remaining mainly an independent owner-driver. This fixed business model was due to the fragmentation, economically profitable activity and independence of public subsidies. This situation started to change in the 70’s, due to the raise in fuel, vehicle, insurance costs, impacts in congestion and new types of business models were expected to emerge, such as (UMTA, 1981):

- **Route taxi**: a system that helped agencies to maintain frequency in lines where the demand was low. The strategy consisted of simply replacing buses by taxi that would offer similar services to traditional transit. The first results in Germany and Sweden showed good economic performance and acceptance;

- **Shared taxi**: promising in the US context, the possibility of raising occupancy and offering taxi services for lower fares was appealing.

The demand-responsive shared-taxi attempted to improve operational features such as lower waiting times, higher occupancy and lower fares. It was seen as an alternative to low-productivity dial-a-bus systems but the dispatching/controlling problem for larger fleets – usual of taxi companies - was already seen as one of the reasons why taxi operators were reluctant to move into shared ride market. (Strobel, 1982).

### 13.8 The following decades

In the USA, the context in the beginning of the 80’s was characterized by budget cuts during the administration Reagan, stimulating the replacement of regular services by shared taxis and dial-a-ride bus options (Wilds and Talley, 1984).

The subsequent years saw the development of diverse technologies, such as GPS, telephone, computers and GIS and, during the 90’s, they enhanced the level of communication, control strategy and real-time scheduling – important ameliorations for the DRT business model. Moreover, already at that time the concept of MaaS could be delineated with the idea of different transportation providers offering their services in an integrated billing and ticketing platform (US DoT, 1994).

Moreover, disaggregated data collection was also a major issue: from a demand perspective, the Automated Identification and Billing Services, AIBS, is a system that would permit operators to better identify and characterize their users. Interestingly, automated trip payment via smart-cards was also starting its diffusion (US DoT, 1994).

From a supply point of view, more precise data came from Automatic Vehicle Location technologies, AVL. Different technologies, such as odometers and dead reckoning, signposts, Loran-C and GPS were used for this finality. In regard to the last one, it was a novelty during the 90’s that was considered as having great potential in spite of difficulties of being applied in urban centers (Lam, 1994).
Concerning transmission of messages, the main solutions for transit agencies were cable, analogic and digital radios, microwave and cellular communications. Wire solutions permitted a high-quality service but had issues when equipping vehicles. On the other hand, radio and microwave technologies allowed moving parts to exchange messages with the central but suffered from interference saturation of bandwidths and atmospheric conditions (Lam, 1994). Cellular technology provided a high-quality wireless conversation but the main drawback were the costs (Lam, 1994).

In regards to communications, comments should be made about telephones, as they were considered a source of inefficiency for DRT operations: considerable percentages of requesting calls were missed, voice messages consumed about 75% of the time of dispatchers and their incomprehension was recurrent problem common. In the beginning of the millennium, internet started to be incorporated and was considered as a solution for these issues (Lasdon et al, 2000).

13.1 Discussion about the first experiences
Before passing to the discussion itself, it is important to expose the following image, which summarizes the information discussed before:

![Diagram showing the context of the development of DRT](image)

**Figure 18: Context of the development of DRT**

The differences between the context back during the 60’s and 70’s and nowadays – more women working, ageing population, more accentuated internalization of the ideals of sustainability and diffusion of mobile internet and smartphones – is bringing new transit offers. In regards to the current DRT experiences, raising from the second decade of this millennium are still questionable about their durability: making them viable economically is a real issue.

Even if studies at that time pointed that the DRT was already technically viable, had a proper market and induced trips, the economic performance was already suspicious (Guenther, 1973). The low demands and high costs, composed primarily by labor, made even the most performing systems at that time incapable of covering its expenditure with the fare revenues. This fact discouraged private enterprises such as GM and Ford – that were already conducting studies about “transportation systems business” and making trials with DRT systems – to keep investing into this new technology but did not inhibit communities from planning and expanding them (Guenther, 1973, UMTA, 1979a).

Furthermore, considering that DRT operations were seen as one of the main tools for tackling car dependency but during the 70’s, the costs of automobile ownership and operation were not related to the number of kilometers drove but rather dominated by depreciation, insurance and licensing – fixed costs (Berla, 1973). As marginal costs were considerably low, once a household was capable of buying a car, trips that could have been made by transit were more conveniently and cheaply made by car (Berla, 1973). This shows a potential for a “taxi-based” offer, SRT, which functions in a similar way but has smaller depreciation costs.

Another interesting point is that since the beginning, generating demand on a given area has always been a major issue and although the first experiences showed that DRT had greater ability to attract more users than conventional bus services, the demand but also the fare levels in that time were usually not high enough to create an economically efficient operation (Guenther, 1973).

However, it is fundamental to note that transit systems in North America were very often subsidized thus operating in partnership with transit agencies (Atkinson, 1973) and in general, DRT operations reduced the subsidy levels when compared to traditional transit, like in Bay Ridges, Toronto, and Regina, Saskatchewan (McDougall et al, 1974).

Concerning the nature and objectives of DRT systems, they face an instable nature: the main motivations to implement them are generally to serve low demands in a more optimized way. The first experiences showed that to reduce subsidies, the systems had to raise the occupancy. But the raise of occupancy often indicates the necessity of a regular line and finding this proper interval has always been an issue. On the other hand, if one tries to reduce subsidies without raising the occupancy, he would reduce the level of service – vehicles making longer routes to assemble enough passengers – discouraging the demand and even impacting operational costs (Vuchic, 1981).

This idea shows the importance of well understanding the passenger’s trade-off between cost and level of service, allowing the identification of the market for this solution. The role of DRT may be, for example, seen as a “developer” of the demand as in low-demand situations DRT has normally lower costs than regular transit, i.e. unlocking the demand. In addition, the reduction of costs that have less impact into the level of service must be seen as a priority. In this category the downsizing could offer opportunities for savings – again, one is pushed to believe that SRT systems would be more suitable.
Another “mobility paradigm” is well suited to the planning of a DRT operation: higher penetration and door-to-door service with larger trip lengths and smaller walking distances or stop-to-stop service with lower trip lengths and high walking distances? To address this question, it is necessary to know the user preferences – age, physical conditions, or momentary reduced mobility should be taken into account when designing the new line (Webster, 1974).

As previously mentioned, the induction effect coming from DRT systems, 12% in Haddonfield and 20% in Ann Arbor (UMTA, 1979a), raises a question: where did this ridership came from? From an urban planner perspective, the ideal case would be drivers leaving their cars at home and using transit. Nonetheless, the competition with other industries deserve some deepening since it is not that evident: while for Haddonfield there are indications of dispute with the local taxi industry – and even the federal government compensated the revenue loss for taxi drivers (Altshuler, 1976) - in Batavia there were no complaints coming from those operators (McDougall et al, 1974).

Another important point is the usage of the system for package delivery. This happened in Batavia whose main clients were hospitals, drugstores and the post, and the coming revenues represented 10% to 15% of the total (McDougall et al, 1974).

Finally, even if the DRT technology was seen as a potential solution to tackle major urban issues - accessibility, pollution, equality (HUD, 1968), and almost all projects had a social motivation coming from providing transit to underserved areas, most of the indicators used to assess the mentioned operations were ridership, costs, productivity and sometimes, user satisfaction. This express an imbalance between public power’s ideals and objectives and their internalization, which should be translated in social indicators. Berla (1973) evocated the inequality between supply and demand analysis at that time, saying that due to the difficulty to establish and quantify the factors impacting consumer behavior, supply was much more in evidence than demand. However, this situation changed and nowadays one can easily assess those indicators.

14. Appendix C – Current experiences

14.1 Context
As seen previously, the concept is not a new idea: even before the 1970’s there are primitive offers of transportation that combine features of conventional and purely demand-responsive service in North-America and Europe. At that time, they were not scaled due to the limited technological context as well as the social, market economic and institutional situations (González et al., 2017, and Davison et al., 2014). Moreover, considering that neither the presence or the private sector nor the demand-based routing are disruptions in transportation (Walker, 2018) the technological innovations that permitted the redesign of the DRT are the smartphones and mobile internet which are allowing transit agencies to meet customer’s needs in new ways (Smith, 2017, appud Westervelt et al., 2018).

An illustration of this phenomenon is the fact that in October 2016 - after less than 10 years of the first version of the most iconic smartphone, the Iphone, was launched, the number of pages viewed through a smartphone and/ or tablet exceeded the number of vi-ews through desktops and laptops (GS Statcounter, 2016).
Its role is crucial providing operators with better data on mobility patterns (CityLab, 2015), and, for those acquainted with the technology, ease of use. This last point is very sensitive as digital literacy is being considered a barrier for the deployment of DRT systems (Westervelt et al., 2018). One way or another, the wide smartphone access is making flexible, on-demand transit more possible than ever (CityLab, 2015). Furthermore, the development of information and real-time routing technologies gave the possibility for those services to be viable (Weckstrom et al., 2017).

We cannot forget that the context is also different: the demographic metamorphosis - such as ageing population, women entering the job market, the growth, ethnical diversification and miscegenation - technical capacities - developed computational power and scientific models that can evaluate more precisely sustainability indicators, allowing better comprehension of this phenomenon.

And so, the proper question should be: can this new context offer a market for DRT operations?

14.2 DRT nowadays

From a community perspective, DRT is designed to fill gaps in transit systems when a regular one is not convenient (Peterangelo and Henken, 2017) or when the service offered lacks quality (Walker, 2017). The rediscovery of the concept in current days is being pioneered by the private sector companies and the increasing popularity induced transit agencies to deploy their own pilots (Department of Transportation, 2018).

One may distinguish between two main types of regular offer of current DRT operations - i.e. excluding airport shuttles, that do not generally provide regular trips – nowadays, which are:

- In high-demand areas: usually in urban centers, the service is considered an additional offer between the costly private car trip and an inexpensive transit ride (TCRP, 2018, Vox, 2015);
In low-demand areas: characteristic of rural or suburban areas or for specific demand, such as handicapped, this service usually arises from different sorts of partnerships between private and public entities, providing connection to high capacity transit systems (TCRP, 2018).

In the second case, usually more than one stakeholder is involved into a project (Westervelt et al., 2018). For the private enterprise, it is an opportunity to make profit, while for public agencies, it is a chance to increase accessibility, attract car users and address the last mile problem in a more economically reasonable way (Department of Transportation, 2018, and Peterangelo and Henken, 2017). The perfect business model is still an issue and the diversity of different pilot programs and services offered evidence this statement.

Yet, while the privately operated non-subsidized DRT system may benefit of more flexibility - designing lines based on demand data and user requests (Vox, 2015), publicly operated projects may have their designs more constrained but they benefit from subsidies (HSL, 2016, CityLab, 2017a). For the instance, due to the difficulty of drawing such a business model in absence of subsidies, DRT startups should prioritize partnerships with transit agencies (CityLab, 2017a).

Indeed, many projects still rely on public money to keep prices low (Department of Transport, 2018). Also, a fundamental step to ensure a good economic performance are the high levels of demand: besides the ticket revenues, they create routes with lower detours, as trip requests tend to be closer to each other (Vox, 2015). This has a double impact: lower trip times and better vehicular productivity - pass*km/veh*km. The main question is then how to create more demand with evidences suggesting marketing - making population acquainted to the technology -, service area and times - serving proper desire lines - are fundamental issues to enhance demand (HSL, 2016, Marshall, 2017, Transit Center, 2017, Westervelt et al. 2018).

In general, DRT is still finding a sustainable business model and the reasons are still unclear as enterprises hardly share their data (Department of Transportation, 2018). Nonetheless, some general characteristics seem to justify this statement (TCRP, 2018):

- Cost-intensive nature: leasing vehicles and paying drivers as employees;
- Similarity with regular: and generally subsidized transit;
- Low patronage attraction: the system is not well understood and accepted.

In regards to regulation, due to the immaturity of the offers, much is to be done. It is important to know that historical evidences show a risk of a competition between DRT and current transit, and public agencies should work to make this disruption a supportive partner (Mission Local, 2016). Moreover, as previously evocated, much focus has been given to traditional metrics, such as ridership and farebox recovery rate. Public entities must take into consideration other indicators, such as improved mobility, safety and customer experience. (Westervelt et al., 2018). One thing is certain: the longer cities wait to address the rise of DRT, the harder it becomes to coordinate and regulate these networks (CityLab, 2015). However, the current laws already allow them to properly do it (Walker, 2017).

About the bidding process, they should also use contracting mechanisms that permit quick decisions outside of the standard processes and invest in marketing and outreach to ensure that potential customers understand how to use these new services (Westervelt et al., 2018). Indeed, the outcomes of the first experiences suggest that the necessity of smartphone and data connectivity make challenging for
people to access DRT (TRB, 2016, appud Westervelt, 2018) highlighting the importance of a marketing strategy focused on digital literacy but also smoothening the change to the new system, another crucial step for the success of the project (Westervelt et al., 2018).

Furthermore, regarding vehicle-kilometers travelled, competition with transit and cost effectiveness are still uncertain. In 2016, TCRP published a study based on a survey that suggested the potential of on-demand dynamic routing transportation technologies had to complement existing transit network, i.e. the ridership of these services was higher when the transit offer was limited or inexistent, such as in night services (TCRP, 2016, appud Westervelt, 2018). However, another report from 2017, made by the University of California, suggested the competition among ride-hailing companies and low-speed regular transit (Clewlow, 2017, appud Westervelt, 2018).

14.3 Recent experiences

The emergence of transportation network companies, TNC, started in 2009, and their natural development brought them to start pooling multiple trips in the same vehicle through their software, giving origin to the current DRT systems (Westervelt et al., 2018).

Between 2012 and 2016, the most emblematic recent DRT companies launched operations just like Via, Kutsuplus, Bridj, Chariot, Padam, Leap, Loup, UberPool, Lyf Lines and Shuttle (Crunchbase, 2018, and Westervelt et al., 2018). Even if ultimately all of these enterprises propose as final and ideal service a shared trip in a car where prices and level of comfort are situated somewhere between regular transit and VTC/ taxis, their business models vary considerably between enterprises and even accordingly to the cities where they are implemented.

14.3.1 Bridj

Bridj is one of the first for-profit DRT enterprises. It launched the first operation in the metropolitan area of Boston, Massachusetts – specifically in Boston, Brookline and Cambridge - offering non-stop fixed routes trips in premium buses, demanding users to walk a few blocks away from their residences to reach the pick-up point (Gizmodo, 2014).

The initial routes were established after the trial period, using passengers’ preferences, government information and social media. This strategy to “crowd-source” the routes was also applied during the successive expansions (Gizmodo, 2014, Next City, 2014, Beta Boston, 2014a, Techcrunch, 2014).

Figure 19: First routes of Bridj
Source: Gizmodo (2014)
Since the beginning, the company faced problems with regulations: it applied for jitney's licenses in these three cities but Cambridge just gave its endorsement a few months later than the others as Bridj was situated in the so called “grey zone” between taxis and regular transit for whom regulation was not perfectly suited (Beta Boston, 2014b). The initial license allowed the enterprise to operate in three different routes (Group Zoom, 2014).

During the following months, the company went through important changes: the distance-dependent fare was replaced by a flat one, the 50-seats buses were substituted for 14-passenger vehicles, it launched the app - that allowed clients to book trips and track the vehicles - and stopped offering the monthly subscription – as the demand was concentrating during the peak hours (Beta Boston, 2015a, Xconomy, 2015 and Beta Boston, 2015b).

Still in 2015, Bridj started in a second city, Washington D.C., in a flat-fare system with surging price (Americaninno, 2015a). The choice for the capital was motivated by the irregular trip patterns – allowing better use of the vans -, the low car-ownership, the weak job accessibility via regular transit and the weather (Beta Boston, 2015c, and Americaninno, 2015b).

The next expansion was to Kansas City. A pilot program partnered by the local authority, the automaker Ford and Bridj, starting in 2016. The system offered also a flat fare of US$ 1,50, equal to the current regular system, serving large employment areas – that already had transit options – and working only during peak hours (Kansas City, 2016, and Peterangelo and Henke, 2017).

The investment was US$ 1,5M and the project did not meet the initial ridership expectations: while it was planned to provide 200 trips per day, in the 6th month, it had only provided 597 trips in total and in the end of the 12th month, only 1480 rides, about 11 per day. One third of the riders took more than 10 trips and the cost of the pilot mounted to US$ 1000 per trip (Westervelt et al., 2018). The main reasons for this weak number was the insufficient marketing and inadequate times - as the pilot just ran during peak hours – and served areas, that did not meet the population’s need of commuting (CityLab, 2017a, Shaheen et al., 2016).
In April, 2017, Bridj shut down its operations due to a deal that fell through with a major automaker. The CEO, Matt Georges, announced that the company was profitable but it needed funding to grow (WBUR, 2017). It was acquired by an Australian transport operator and relaunched in Sydney (Americaninno, 2017).

### 14.3.2 Chariot

Chariot is a fixed-route, fixed-schedule DRT offer, in opposition to Via and Bridj, which operate/operated under a flexible route and on-demand or flexible schedule (Department of Transportation, 2018). The drivers of the 14-passenger vans are employees (TCRP, 2018). It has two main offers: a service open to the public, i.e. to anybody with the application, but also a private one, in partnership with enterprises, that is accessible only to the employees of the sponsor (TCRP, 2018).
The operations began in April, 2014, in San Francisco (Chariot, 2017 appud Walker, 2017) in corridors already served by transit lines (Atlantic, 2014). It started offering single rides during peak hours with time and distance-based fares ranging between US$ 3.50 to US$ 4 – more than the US$ 2.25 of the local bus ticket and about a third of a similar Uber ride - and a monthly pass ranging between US$ 96.75 and US$ 116.10 (TechCrunch, 2014, Mission Local, 2016, Statesman, 2016). Furthermore, as the company is registered as a Bay Area commuter benefit, users may take profit of the pretax commuter benefits, which is a type of transit subsidy where the employer pays part of the commuting expenses of the employees, leading to a saving of up to 40% for the user (Chariot, 2018, and Biz Journals, 2015).

The crowdsourcing and crowdfunding of the routes are interesting techniques: if a certain number of users vote for a certain route and buy monthly pass upfront, Chariot launches the line in a few days (TechCrunch, 2014). The number of voters required vary accordingly to the length of the route, ranging between 150 and 200 and makes the process of creating new routes much more economic and quicker (Vahabzadeh, 2015).

However, the ease to create them also works in the other sense: the company do not hesitate to eliminate under-performing routes or stops. This is completely different from a conventional city transit planning: as equity and accessibility are public stakeholders’ priorities, they cannot simply shut down bus stops nor routes leaving low-income users vulnerable because there is not enough demand (TechCrunch, 2015b).
An interesting case is the one of Muni, the Municipal Transportation Agency of San Francisco. It had issues with the system’s low speed due to the excessive number of stops. The agency could not exclude some of them due to its commitment to vulnerable populations – i.e. those who could not walk longer distances due to criminality but also elderly and handicapped people (StreetsBlogSF, 2014, TechCrunch, 2014), being another topic for public regulation.

Again, due to its business model, competition with public transit is an important issue when analyzing Chariot. The risk of capturing users from the regular service, funneling revenues that otherwise would go to regular public transport system impacts the economic performance, affecting mainly low-income communities (TechCrunch, 2015a, and Icic, 2015).

Another differential between Chariot and other San Franciscan startups is that it operates vans instead of buses, making it subject to looser licensing, insurance and parking requirements, even if the service provided is essentially similar (Forbes, 2015). Also, it does not use agency’s bus stops, opting to pick-up and drop-off passengers in legal loading zones (San Francisco Chronicle, 201).

The enterprise met a growing trend, being acquired by Ford in September, 2016 (TechCrunch, 2016), and expanding its operations to Austin (Curbed Austin, 2016), one month later, to New York (TechCrunch, 2017) and Seattle in mid-2017 (The Verge, 2017b) and to London and Columbus, in early, 2018 (Ford, 2018, and TechCrunch, 2018).

The company has different strategies and offers accordingly to the market. In Austin, Seattle and Columbus, it started operate private shuttle services partnering both enterprises and public stakeholders (Curbed Austin, 2016, The Verge, 2017b, TechCrunch, 2018). While in New York, similarly to San Francisco, it is essentially a service open to public (TechCrunch, 2017). Above that, charter for long-distance displacements and late-night service is available in some locations, like Austin (Community Impact, 2017). In Seattle, a year-long pilot open to public will start, initially free and afterwards costing the same price as regular transit, offering the possibility to pay with the local transit card (GeekWire, 2018).

Concerning the operation in New York, Chariot offer a at US$ 4,00 serving mainly an area already well-served by existing transit services – until here, nothing different. However, the system is facing low demand problem, with daily average about 5 rides per vehicle per day, a tiny percentage of the 125-150 passengers per vehicle per day carried by the dollar-vans – local informal DRT service that offers essentially the same product (StreetsBlogNYC, 2018). Indeed, the competition with dollar-vans is a main issue, with authorities favoring the start-up in spite of the pre-existing system, creating a social friction (Brookelyn, 2017).
14.3.3 Via

Via launched its first operation in New York in September, 2013 (Observer, 2015). The system ran during rush-hours and charging US$ 5 for pre-booked trips and US$ 7 for real time and riders were demanded to walk a few blocks to “virtual bus stops” (Crains, 2015).

An important differential is the fact of being area-based, allowing people to go absolutely anywhere within the served zone (CityLab, 2017b). Again, the expansion to both new areas and time-frames is based in crowd-sourcing, but also low-fares during the initial weeks and bonus for indications of new users (Via 2015, Via 2016a, Via, 2016d). This approach allowed it to meet a constant expansion trend:

- In November, 2015, to Chicago (Observer, 2015);
- In December, 2015, to a suburban area in Orange County, California, in partnership with Mercedez-Benz (PR Newswire, 2015);
- In August, 2016, to Washington D.C. (Americaninno, 2016);
- In January, 2017, to Paris, partnering LeCab and Keolis to offer the rideshare technology to Parisian taxis (Via, 2017a);
- In March, 2017, to the UK, in partnership with Arriva Bus UK, in Kent Science Park and Sittinbourne (Via, 2017b);
In June, 2017, a partnership with Curb, a New York City taxi company, to introduce a shared-taxi function in its app (Via, 2017c);

In November, 2017, to Arlington, TX, replacing the only existing fixed-route (The Verge, 2018), and to Los Angeles, providing feeder service to a few stations of Metro LA (Metro, 2017) and to Queenstown, in New Zealand, in partnership with a local bus company, Go Bus (Via, 2017d);

In January, 2018, to Newcastle, Australia, in partnership with the Keolis, which is the local transit operator (Via, 2018b);

In February, 2018, to Singapore, where it was selected by Singapore’s Land Authority to incorporate its algorithm to the local transit system (Via, 2018c)

In March, 2018, to Amsterdam, its first European operation (Via, 2018d);

In April, 2018, to London (Business Insider, 2018);

In the spring of 2018, to Berlin, in partnership with Berliner Verkehrsbetriebe, the local transit authority;

In May, 2018, to West Sacramento, where the enterprise was responsible to ran a city-wide project, offering the technology, the vehicles and the drivers (CPR, 2018);

In July, 2018, to Tokyo, through a partnership with Mori Building, offering a private service for the employees of the enterprise (Via, 2018e);

In the summer, 2019, to Liverpool, operating a similar system as in Sittingbourne but going through the city center (Mersey, 2018).

These expansions highlight another important feature of these new business models: the flexibility. In the case of Via, three main features justify the last affirmation:

- Different market products: hanging 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 transit authority or operator, Via uses its expertise and gathered data to offer diverse type of products;

- Different levels of service: even when one product, for example, trips, Via gives the final client the option for a more direct but costly service, Via Express (Via, 2018a);

- Different environments: when analyzing where it operates, the contexts vary from suburban context and/or areas underserved by transit systems, such as the operations in Orange County and in Kent Science Park/ Sittinbourne, to dense urban centers, such as New York (Via, 2018a).
Other interesting strategies of this business model include a constant search for the raise of shared rides, charging additional passengers, the called “1s”, much lower than the first one (Via, 2016b, Via, 2016c), equilibrating the demand in non-peak hours through reduced fares in these time frames (Via, 2016b) and finally, offer a more comfortable displacement as leather seats, restricting the car models that may be used, WiFi, USB ports and recharging points area common features of the vehicles (Americaninno, 2016 and Via, 2017b).

As previously mentioned, the operation of Via in Amsterdam started in March, 2018, focusing initially in the central city zone, offering a flat fare of 5,00 € (Via, 2018d). The system expanded and now can be used from almost all parts of the city:
14.3.4 Rural and suburban experiences

The rural context presents different challenges when compared to the urban counterpart, mainly due to the sparse distribution of the population, resulting in low-density areas. This adverse environment makes hard for agencies to structure transit systems as trips cover longer distances, have higher costs and lower productivity (Hosen and Powell, 2011). This materializes in fewer options and physical isolation, limiting the access of the community to public services, health care, leisure activities, jobs and school. As trips tend to be longer and incomes, lower, - respectively 33% more and 27% when compared to urban centers – this results in higher expenditures with transportation for the population, being a critical issue for low-income households, where the family is left with no money for primary necessities, such as food and medicine (Litman, 2017).

Even if rural population is declining in the USA, the rural mobility is raising in absolute levels, even more than the urban counterpart (Litman, 2017). Furthermore, besides poorer, rural communities tends to be older, rendering transit crucial as these groups are possibly more incapable of driving a car for economic or physical reasons (Ellis and McCollom, 2009). For them, the only solution when not served by transit is to rely on friends and family to displace (Litman, 2017). Another latent problem are the fatalities: rural communities represent only 19% of the US population but are responsible for 49% of traffic fatalities (Litman, 2017).
For these reasons, transit is crucial in rural areas: demand is repressed and externalities burden communities' budgets. This results in high cost-benefit ratio when it comes to investments in rural transit (Southworth et al, 2005, appud Godavarthy et al., 2014, and Burkhardt, 1999, appud Godavarthy et al, 2014). Brief, even if the demand is not high, it is very valuable and have an important social impact (Litman, 2017).

In regard to the supply, serving rural areas with fixed routes offers tend to provide convoluted routes or irregular services, being DRT a natural solution to undertake transit issues (Davison et al., 2014). Indeed, the majority of the DRT systems in the USA and in the UK - 74% and 61%, respectively - are rural. The main motivation for their implementation is to provide accessibility reducing costs thus subsidies (Davison et al., 2014, Ellis and McCollom, 2009).

The differences between a rural and urban context show why transit authorities should assess differently these operations. While in urban contexts agencies are pushing DRT to raise demand and reduce costs per trip, in rural areas the main challenge is to keep the system running in a low-investment context. This means that for a rural DRT, instead of being assessed by the numbers of patronage, they should be evaluated accordingly to the level of comfort, keeping the aging fleet of vans in worthy conditions for the use (Ellis and McCollom, 2009).

**14.3.5 Kutsuplus**

Kutsuplus was a publicly operated DRT pilot program in Helsinki metropolitan region that started in October, 2012, opening to public in April, 2013, and ceasing operations in December, 2015 (HSL, 2016). The initial fleet of 10 high comfort 8-passenger vans was extended to 15 in November, 2013 (HSL, 2013, Weckstrom et al., 2017). Different offers were proposed for the users: from faster and more expensive to lower and cheaper options were available. Customers could book trips up to 30 minutes in advance. The fare system was a base-fare + a distance based, as shown in the following table (Weckstrom et al., 2017):

<table>
<thead>
<tr>
<th>Inclusion</th>
<th>Unnamed</th>
<th>Economy</th>
<th>Normal</th>
<th>Fast</th>
<th>Taxi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct, 12</td>
<td>1,88 € + 0,19 €/km</td>
<td>1,88 € + 0,19 €/km</td>
<td>2,63 € + 0,26 €/km</td>
<td>5,70 € + 1,48 €/km</td>
<td>5,70 € + 1,48 €/km</td>
</tr>
<tr>
<td>Feb, 13</td>
<td>1,50 € + 0,15 €/km</td>
<td>1,88 € + 0,19 €/km</td>
<td>2,63 € + 0,26 €/km</td>
<td>5,70 € + 1,48 €/km</td>
<td>5,70 € + 1,48 €/km</td>
</tr>
<tr>
<td>Mar, 13</td>
<td>1,50 € + 0,15 €/km</td>
<td>1,88 € + 0,19 €/km</td>
<td>2,63 € + 0,26 €/km</td>
<td>5,70 € + 1,48 €/km</td>
<td>5,70 € + 1,48 €/km</td>
</tr>
<tr>
<td>Apr, 13</td>
<td>2,80 € + 0,36 €/km</td>
<td>3,50 € + 0,45 €/km</td>
<td>4,90 € + 0,63 €/km</td>
<td>5,70 € + 1,48 €/km</td>
<td>5,70 € + 1,48 €/km</td>
</tr>
<tr>
<td>Nov, 13</td>
<td>2,80 € + 0,36 €/km</td>
<td>3,50 € + 0,45 €/km</td>
<td>4,90 € + 0,63 €/km</td>
<td>5,70 € + 1,48 €/km</td>
<td>5,70 € + 1,48 €/km</td>
</tr>
<tr>
<td>Jan, 15</td>
<td>3,50 € + 0,45 €/km, 20% disc. bet 10:00 and 14:00</td>
<td>5,90 € + 1,55 €/km</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 34: Fares for Kutsuplus*

*Source: Weckstrom et al. (2017)*

The system also offered group discount of up to 50% for 5+ passenger bookings. The transit ticket was € 3,00 for single zone, € 5,00 for two-zone and in average and for those who had the season ticket, € 0,66 per trip (Weckstrom et al., 2017).

Scale was seen as fundamental to achieve better economical performances and the initial idea was to grow the fleet to 45 buses in 2016 and 100 in 2017 but due to challenging financial situation of the municipalities, this target was not met (CityLab, 2016, HSL, 2016). The targets of ridership were five trips
per vehicle hour and two trip kilometers per vehicle kilometer by 2018 (HSL, 2016). It is important to
mention that the system did not dispose of a smartphone application and the user experience booking
trips was not easy, probably impacting ridership (HSL, 2016).

14.3.6 Developing countries

These flexible systems in underdeveloped countries have different challenges to face.

These systems mainly develop when the public authority does not dispose of the proper financial and
institutional capacities to plan, implement, maintain or supervise a regular transit operation, what make
these systems whether inexistent in some areas or cities, or in a deteriorating situation (Golub and
Cervero, 2001). If in one hand they cause positive externalities, such as accessibility for those who are
neglected by the existing network, great adaptative capacity to respond the changing demand and jobs
for low-skilled employees, on the other side they contribute to traffic congestion, air and noise pollution
and accidents, which comes from (Golub and Cervero, 2001):

- Low capacitated drivers: the lack of training and common labor abuses reduces the
  operational costs but has as consequence aggressive driving - which raises accident rates and
  congestion - and disrespect of basic road rules, such as stopping anywhere to get customers;
- Poor investment in vehicles: aging vehicles and poor maintenance cause safety and
  environmental issues;
- Tax evasion: they are usually undocumented and can easily avoid paying taxes;
- Market skimming: these operators tend to serve only busy lanes in peak hours and neglect
  the “public mission” statement of the transit.

Taking a look at specific experiences, demonstrate that these DRT offers diversify the pricing options
available to the population, serving both low-income and high-income neighborhoods (Golub and
Cervero, 2001, and Choocharukul and Sriroongvikrai, 2011). In the Brazilian case, hey emerged during the
90’s, in contrast to the formal concentration of the bus system on the hands of few owners in the wake
of radical social, political and economic changes, rendering the regular offer with low quality, comfort and
safety, poor route connections, rising fares and increasing waiting and travel times (Golub and Cervero,
2001). On the other side, in Bangkok, they were born during the 80’s, when the Royal Thai Police started
hiring these vehicles to serve routes where the growing demand overcame the transit offer (Choocharukul
and Sriroongvikrai, 2011). Similar to Brazil, the informal DRT operations compensates the substandard bus
system and diversify the pricing options available to the public serving both low-income and high-income
neighborhoods (Choocharukul and Sriroongvikrai, 2011).

Brief, these diverse forms of transport tend to be part of the problem, not part of the solution basing the
economic profitability in strategies that raise externalities (Golub and Cervero, 2011).

14.3.7 Current Dutch experiences

When it comes to the Netherlands, Mokumflex is not the first Dutch DRT experience. In the end of 2016,
the region of Arnhem-Nijmegen started a pilot called Breng flex, offering a stop-to-stop connection
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 € (González et al., 2018). The analysis made by González et al.
(2018), showed that users perceived the DR system as having a lower generalized journey time - i.e. the
perceived journey time, despite a similar generalized cost – as the DR alternative was costlier.

Additionally, in December 2017, Helmond and its surroundings started another DRT, Bravoflex: pre-
booked rides costed 3,00 € in a stop-to-stop regime (Hermes, 2019). In December, 2018, RMC started
another similar project in Rotterdam, with the local transit operator, RET, named RET STOPenGo (RET,
2019).

14.4 Discussion about the recent experiences
As previously stated, the greatest difference existing between the context during the 60’s and nowadays
is the smartphone. This gadget allowed not only enhanced data collection from the clients but made easier
the interaction with them, making possible the offer of more flexible and tailored displacements. In
practical terms, this is reflected, for example, in the simpler implementation of new lines and different
levels of service. Still, in opposition to the ancient systems, nowadays programs are easily replicable with
low computational implementation costs when, for example, starting in a new city (Golde and Ramot,
2017). A summary with the main characteristics of the most relevant current experiences is proposed
below:

<table>
<thead>
<tr>
<th>Nature</th>
<th>Platform</th>
<th>Modality</th>
<th>Scheduling</th>
<th>Routing</th>
<th>Geographic coverage</th>
<th>Countries of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRIDJ</td>
<td>Private</td>
<td>App-based</td>
<td>STS</td>
<td>Flexible</td>
<td>Area based</td>
<td>USA</td>
</tr>
<tr>
<td>chariot</td>
<td>Private</td>
<td>App-based</td>
<td>STS</td>
<td>Fixed</td>
<td>Line based</td>
<td>USA and UK</td>
</tr>
<tr>
<td>VIA 🚛 VAN</td>
<td>Private</td>
<td>App-based</td>
<td>STS</td>
<td>Flexible</td>
<td>Area based</td>
<td>USA, Germany, Netherlands, UK, France, New Zealand, Singapore and Japan</td>
</tr>
<tr>
<td>HSL HRT Kutsuplus</td>
<td>Public</td>
<td>Website-based</td>
<td>STS</td>
<td>Flexible</td>
<td>Area based</td>
<td>Finland</td>
</tr>
<tr>
<td>brengflex</td>
<td>Public</td>
<td>App-based</td>
<td>STS</td>
<td>Flexible</td>
<td>Area based</td>
<td>Netherlands</td>
</tr>
</tbody>
</table>

Table 35: Characteristics of some current experiences

14.4.1 Remuneration of the drivers
A major issue when it comes to new TNC and DRT companies is the driver’s remuneration. In New York,
they are 80.000, far more than the 13.587 taxi drivers, and the typical profile is an immigrant that bought
the vehicle only to enter this industry, earning less than the minimum net pay standard – US$ 17,22/ hour
for NYC - whose only job is driving (Parrot and Reich, 2018).

Parrot and Reich (2018) explained that this weak remuneration comes from the nature of the business:
since companies compete with each other by minimizing waiting times - and decreasing fares - to achieve
quick responses, a considerable supply of idle drivers must be available thus reducing driver’s productivity,
meaning that in order for this business model to work, driver utilization – and hourly payment – should be low (Parrot and Reich, 2018).

14.4.2 Social issues

These new enterprises face different social issues: they are accused of gentrification, discrimination, risking poorest population’s mobility and unequal competition with pre-existing operators.

First, the gentrification. As usual, the service is offered at higher prices than local transit and some San Franciscan’s initiatives were accused of creating a two-tiered transit: separating the population in groups by offering a better but more expensive transit which can only be afforded richest inhabitants (New York Times, 2015, The Verge, 2015, Walker, 2017).

This problem is originated before the DRT startups, when the buses provided by tech companies, such as Apple and Google, displaced their employees in a high comfort vehicle (The Verge, 2013, Walker, 2017). What is interesting is that the operation of Via in the UK, which is similar to the San Franciscan’s offers, is not being accused of gentrification by the local population for its high-tech leather seat equipped buses (Via, 2017b, New York Times, 2015).

When it comes to discrimination, this is a problem that Via’s operation had in Washington D.C., as the company excluded two predominantly black neighborhoods from its coverage area. One must remember that the local jurisdiction prohibits the company’s geographical distribution but the local agency authorized the operation in spite of this law (Slate, 2018).

In regards to the equity issues, the argument used it that, in a situation of constrained budget, investing in DRT initiatives would necessarily means to disinvest in regular transit, affecting mainly low-income communities (Icic, 2015). The defenders of this idea argue that this becomes even more critic because usually housing becomes more expensive the closer you get to a transit hub thus poor populations are naturally pushed to zones with the least accessibility, making its commute harder, more expensive and lengthy (Medium, 2017). This implicates that, in necessity of optimizing public transport networks, these areas are the possibly the first candidates to lose their offer since non-traditional metrics are not usually used in these kind of decision making.

Finally, the unequal competition. The existence of local informal operators - such as the dollar-vans in New York City - that provide a similar service should have been observed before the implementation of both Via and Chariot. As previously mentioned, the problems are sharpened when the population perceive the transport authority favoring the start-up in spite of the pre-existing system (Brookelyn, 2017).

These arguments, however, must be regarded rationally. In the case of the gentrification, it is natural in a society the existence of different products for distinct social strata: when someone goes to the supermarket, he will see different prices for similar products, why this must be different with transit? Of course, the basic service should be reliable, fast and comfortable.

In the case of discrimination, not being in accordance with the local jurisdiction is not correct but targeting Via is not a rational decision neither, since the public power dispose of the jurisdictional tools to regulate the behavior of the company. It is important to understand that the comportment of a firm is aimed at making profit and the rules under which it will make profit should be managed by the public power. It is
also important to notice that creating very strict laws may difficult the functioning of enterprises, hindering the exercise of the free market.

Thirdly, investing in these startups can optimize the budget of the local transit operator: in the case of low-demand areas, for example, a regular line will naturally be more expensive than a demand-responsive one. Also, partnering with these enterprises to serve high-demand areas can also help ameliorate the usage of public money, as will be explained in the next section.

When it comes to the dollar-vans, the critics make sense. If there is an existing informal operator that provides a similar service and that has inherent social issues, why not resolving this situation before investing in a startup?

The most important idea in this topic is to have in mind that the local social context must be studied before the implementation of a new transport system.

### 14.4.3 Partnering with public authorities

In conversation with an employee of an important start-up, it was said that partnering with the public partner is a preference for these enterprises. This means that the trade-off between the benefits coming from subsidies and closer relation with agencies are more tempting than the flexibility they would have in case of inexistence of this collaboration. In practical terms, this means that there is a preference to respond to a request for proposals instead of starting an operating by the requirement of the proper license.

As previously explained, in the case of low-demand areas, DRT offer the possibility of enhanced accessibility, attraction of car users and addressment of the last mile problem in a more economically reasonable way (Department of Transportation, 2018, and Peterangelo and Henken, 2017). For the saturated corridors, these kind of initiatives gives the possibility of reducing the fleet, potentially diminishing expenditures, since increased concentration of demand during peak hours raises the supplying services’ costs (Lave, 1991) as the number of buses is calculated based on the critical peak-hour demand (ITDP, 2017).

Finally, this closer relation gives the public power more benchmark for regulation and this is a critical issue with problems being far from negligible. Some examples of this limitation are the abbreviation of the life of some enterprises due to institutional problems, such as Leap and Night School (Walker, 2017), and temporary cease of operations for a few days for not disposing of the proper license, in the case of Chariot (CityLab, 2017c) and Bridj, that had to postpone its beginning in Cambridge (Beta Boston, 2014b).

### 14.4.4 Considerations about fare

To analyze the fare issues, an interesting case is Bridj. In Washington D.C. and Boston, where the service was offered at a higher fare than public transit, this final price was not enough to cover the costs and the enterprise was relying in private investors to keep the operation (Transit wire, 2017) showing the difficulty to develop a business in a market that historically does not make profit and demand subsidies (Boston Globe, 2017).

Naturally a question arises about the impact of disturbances caused by regular public transit internal subsidies, that possibly extend to the whole mobility chain. The literature explain that this effect can be
particularly distorting in competition between firms undertaking similar activities specially when it is only available to one part of the competitors (HM Treasury, 2007) and this is exactly the context that these new mobility offers are facing. Indeed, the development of DRT operations in California in the last century met an unfair competition against heavily subsidized modes, such as car and regular transit (Cervero et al., 1995, appud Enoch et al., 2006). This demonstrates the necessity of enterprises to provide an even more “premium” service - to reduce direct competition by providing an even more differentiate product - or to look for investors to maintain its activities, as for the instance even the most performing routing algorithm is incapable of making fares to support a DRT operation (CityLab, 2017a).

One may argue that scale could also enhance the performance of the system and that all these operations did not reach higher demand levels, and this is true. However, the Uber case, which is already a global-scale enterprise with questionable but theoretically performing costs - that still loses money subsidizing trips not only for growing its markets, but also to maintain the current prices - may be another practical evidence that these disturbances are heavily impacting (CityLab, 2017a, Reuters, 2017).

This is an important idea: instead of expecting DRT operations to be profitable in a high-competitive subsidized market, transport stakeholders must see DRT as a potential solution to reduce subsidies per passenger*km for transit offers. Deepening in this particular subject may give important conclusions on how to regulate and subsidize different transit offers and, of course, a pertinent analysis on cities that dispose of poorly publicly financed transit networks could help.

On the other hand, the Kansas City experience. The operation happened in partnership with the local transit agency, offering a theoretically more convenient and comfortable service at the same fare as regular transit. However, the demand was low and the surveys conducted after the pilot showed operational issues – area of service and walking distances – but also marketing problems - getting people aware of the existence of the service and acquainted with the smartphone technology – as the main causes of the “failure”. In regard to the importance of introducing the habit of using a platform to move around, stakeholders must be aware of the inherent “inertia” of human beings toward changes, the difficulty to disrupt the human’s body homeostasis, and how it can impact final ridership (Psychology Today, 2017).
15. Appendix D – Spatial characterization

15.1 Local environment

The following figures will give the user a more precise idea of the distribution of the stops in both areas. Firstly, the line 490:

![Map of stops for line 490](image)

*Figure 26: Location of the new stops of the line 490*

*Source: CBS (2017) and Google Maps (2018)*

Secondly, the line 301:
In regards to the characteristics of both areas, the following table will introduce some indicators that reinforce the low-demand aspect of the study zone. It also shows information per boroughs as well as for the 4-digit postcodes served by both lines whose characteristics were summarized in the rows named 490 and 301.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Amsterdam</td>
<td>844,850</td>
<td>212,8</td>
<td>3,970,7</td>
<td>15,0%</td>
<td>12,1%</td>
<td>5,702</td>
<td>1,60</td>
</tr>
<tr>
<td>Centrum</td>
<td>84,087</td>
<td>8,9</td>
<td>9,400,8</td>
<td>9,4%</td>
<td>13,9%</td>
<td>8,605</td>
<td>1,00</td>
</tr>
<tr>
<td>Nieuw-West</td>
<td>164,921</td>
<td>33,7</td>
<td>4,890,9</td>
<td>17,7%</td>
<td>12,2%</td>
<td>4,125</td>
<td>1,17</td>
</tr>
<tr>
<td>Noord Rural</td>
<td>1,525</td>
<td>35,9</td>
<td>42,5</td>
<td>15,4%</td>
<td>22,0%</td>
<td>96</td>
<td>4,98</td>
</tr>
<tr>
<td>Noord Suburban</td>
<td>93,225</td>
<td>21,5</td>
<td>4,327,7</td>
<td>18,0%</td>
<td>15,1%</td>
<td>2,442</td>
<td>1,66</td>
</tr>
<tr>
<td>Oost</td>
<td>135,820</td>
<td>29,3</td>
<td>4,634,1</td>
<td>16,3%</td>
<td>9,3%</td>
<td>5,339</td>
<td>1,28</td>
</tr>
<tr>
<td>West</td>
<td>128,720</td>
<td>11,1</td>
<td>11,598,9</td>
<td>12,9%</td>
<td>9,2%</td>
<td>9,077</td>
<td>1,00</td>
</tr>
<tr>
<td>Westpoort</td>
<td>7,575</td>
<td>33,0</td>
<td>229,6</td>
<td>12,2%</td>
<td>12,5%</td>
<td>5,894</td>
<td>1,15</td>
</tr>
<tr>
<td>Zuid</td>
<td>141,138</td>
<td>17,2</td>
<td>8,183,3</td>
<td>12,7%</td>
<td>14,9%</td>
<td>7,100</td>
<td>1,04</td>
</tr>
<tr>
<td>Zuidoost</td>
<td>87,840</td>
<td>22,1</td>
<td>3,983,5</td>
<td>17,1%</td>
<td>11,1%</td>
<td>2,793</td>
<td>1,64</td>
</tr>
<tr>
<td>Weesp</td>
<td>18,490</td>
<td>24,1</td>
<td>766,6</td>
<td>16,1%</td>
<td>19,8%</td>
<td>1,684</td>
<td>2,53</td>
</tr>
<tr>
<td>490 Weesp</td>
<td>14,880</td>
<td>16,3</td>
<td>910,5</td>
<td>16,3%</td>
<td>20,3%</td>
<td>1,812</td>
<td>2,10</td>
</tr>
<tr>
<td>490 Zuidoost</td>
<td>4,510</td>
<td>4,6</td>
<td>986,6</td>
<td>14,3%</td>
<td>19,7%</td>
<td>1,454</td>
<td>1,86</td>
</tr>
<tr>
<td>301 Rural</td>
<td>1,525</td>
<td>35,9</td>
<td>42,5</td>
<td>15,4%</td>
<td>22,0%</td>
<td>96</td>
<td>1,08</td>
</tr>
<tr>
<td>301 Suburban</td>
<td>33,185</td>
<td>6,7</td>
<td>4,977,5</td>
<td>18,3%</td>
<td>17,1%</td>
<td>2,626</td>
<td>1,76</td>
</tr>
</tbody>
</table>

Table 38: Density and urbanity for each borough and for the 4-digit postcodes directly served by Mokumflex
Firstly, note that:

- The catchment area of Mokumflex’s stops was considered to be 0. This means that exclusively the 4-digit postcodes that had stops were took into account for this calculation. This is a considerable limitation since the usage of bike has a considerable impact on enlarging the catchment areas of bus stops in the Netherlands (Judith et al. 2017);

- EAD stands for Environmental Address Density, which is the number of addresses within a one-kilometer radius circle around a certain address (CBS, 2017b).

- Urbanity, similarly to EAD, is a measure of urbanization for each postcode. It is defined from 1 to 5. The average urbanity for a borough was calculated by summing the product of the population living in each level of urbanity per 6-digit postcode times the urbanity level of this 6-digit postcode divided by the total population of the borough. To define the urbanity level, the following rules are applied (CBS, 2010b):
  - 1, very strong urban: average more than 2500 environmental addresses per km²;
  - 2, strong urban: average 1500-2500 environmental addresses per km²;
  - 3, moderately urban: average 1000-1500 environmental addresses per km²;
  - 4, weakly urban: average 500-1000 environmental addresses per km²;
  - 5, not urban: average less than 500 environmental addresses per km².

The four areas directly affected by Mokumflex have a considerable percentage of old and young population, which are possibly “vulnerable” from a point of view of mobility, as, in case of non-existence of transit services, they probably rely on family and/ or friends to displace.

Furthermore, indicators per household – income and education – may help the user to get acquainted to the local context:
Table 36: Information about household for each borough and for the 4-digit postcodes directly served by Mokumflex


N.b.: the population’s education was calculated based on the level of educational attainment: low (laag) = 1, secondary (middelbaar) = 2 and high (hoog) = 3. Each postcode had a percentage of population attaining each level. For each borough, summing the product of the population in the end of 2011 by the educational attainment for each postcode and dividing the result by the whole population of the borough made possible to state this indicator. Data for education in Amsterdam Noord Rural was not available.

15.2 Bidding contract

The contract existing between the Vervorregio Amsterdam and GVB determinates how the operator should work, defining schedules, headways and other operational indicators. The current one was part of the bidding of 2014 and to it, the concessionaire – GVB - should provide transportation, in the case of residential areas, for 90% of the neighborhoods with more than 1.000 inhabitants and average density of at least 20 inhabitants per hectare (Stadsregio Amsterdam, 2013). This results in the following zones, in green, that are supposed to have transit offer:
A household is considered to be served by the transit system if at least 90% of all addresses are within a radius of 800 meters from a stop. In addition, the lines that serve these stops should have a minimal frequency depending on the area where the stop is situated and the maximum headway allowed is 30 minutes (Stadsregio Amsterdam, 2013).

As one can see, only the area of Amsterdam Noord and part of Amsterdam Zuidoost is supposed to be served by GVB. Furthermore, this is an interesting example of the necessity of finding new indicators to regulate on-demand services since headway has no importance for DRT operations. When contacted, GVB mentioned that even if they are not obliged to provide an offer in these areas, leaving them with no transit offer would be very radical since the lines “grew historically”.

Figure 28: Areas that should be served by the operator

Source: Stadsregio Amsterdam (2013)
16. Appendix E – Ridership features

16.1 Daily distribution

Another basic analysis is the daily distribution of the demand. The next graphic shows the average number of passengers per month during the working hours. Data collected between January and May, 2016, for the lines 30 and 31 made possible a comparison with Mokumflex.

![Graphic 19: Daily distribution of the demand](image)

This graphic permits some important observations. Besides the lost patronage, its comportment during the day changed as the influence of the peak was smoothed. The line 490 had an important late-night ridership, demonstrating the non-commuting usage of Mokumflex.

16.2 Number of trips per user

Understanding how Mokumflex is used is necessary for the comprehension of the operation and a basic number is the how frequently users traveled:
These numbers are showing the subscribed users – 0 realized trips – and 1, 2, 10, 25, 50 and 100 realized trips vs. the total population of the 4-digit postcodes that had Mokumflex’s stops: 18,990 for the line 490 and 34,710 for the line 301. The number of subscriptions is very low and when it comes to the number of users with more than 50 trips, they are 15 for the line 490 and 26 for the line 301.

Even if no information about the mobility behavior of the citizens of these areas was available – i.e. the number of trips a regular inhabitant from these areas make – it is probable that Mokumflex was not used in a regular basis - for commuting or going to school, as previously evocated in the section “Influence of the extended time frame and new intricacy”. This will be discussed later in the “Survey” section. Finally, the number of trips is important but one must know who uses the system, since these displacements can be highly valuable if they are made by vulnerable users.

### 16.3 Composition of the fleet and emissions

As previously explained, Mokumflex used the cars of the existing AOV system to provide mobility to Amsterdam Noord and Amsterdam Zuidoost.

More than 300 different vehicles were used to operate Mokumflex and their main characteristics are summarized below:

- 5 to 9 seats;
- Gasoline – GAS -, diesel – DIE -, compressed natural gas – CNG -, hybrid – HYB - or full-electric engines - ELE;
- Possibility of being wheelchair accessible;
- Average age of 2 years.

It is important to say that the municipality has plans to turn the fleet 100% electric but some efforts were already made by RMC, with a high participation of both electric vehicles and hybrid cars from Mars, 2018, onwards. The following graphics show the kilometers traveled per realized tour per type of fuel.
The beginning of the operation met a shy presence of electric and hybrid vehicles but the final average miles travelled by them was more than 45% of the total. This result came from the performance from May onwards, as the Municipality started stimulating the inclusion of these cars in March and April. Moreover, there are plans to turn the fleet totally electric.

In regard to the emissions, the database of the Netherlands Vehicle Authority, RDW, contains information about CO2 per individual vehicle. Knowing which vehicle was used for each tour and the displacing and tripping distances, the CO2 tank-to-wheel emissions including realized and no-show trips can be calculated as follow:

<table>
<thead>
<tr>
<th></th>
<th>Mokumflex</th>
<th>Golf</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tour length (km)</strong></td>
<td>8,3</td>
<td>-</td>
</tr>
<tr>
<td><strong>CO2 emission per tour (gCO2)</strong></td>
<td>517,3</td>
<td>-</td>
</tr>
<tr>
<td><strong>CO2 emission per veh * km (gCO2/ km)</strong></td>
<td>62,7</td>
<td>105,0</td>
</tr>
<tr>
<td><strong>CO2 per pass * km (gCO2/ pass * km)</strong></td>
<td>90,5</td>
<td>75,0</td>
</tr>
</tbody>
</table>

This table shows that despite the efforts to electrify the fleet, for the current year, Mokumflex does not have lower emissions per pass * km than a regular car in the Netherlands – the Golf 1.0 was used to compare, with a vehicular occupancy of 1,4 as previewed by Bleijenberg (2014). Even if the CO2 emission per veh * km is good, the system loose performance due to the high displacing distances.
17. Appendix F – Economic evaluation

17.1 Depreciation

The graphical representation of depreciation has the following behavior:

As expected, the first 40,000km are very costly and the curves for smaller vehicles have a better behavior when compared to the Combi and the Crafter, even if the e-Golf has a similar catalog price. Still about this last one, the depreciation is considerably higher when compared to the gasoline version. In regards to the Citaro, despite the fact that the first kilometers are very depreciative, the curve almost stabilizes after the 40,000km limit.

17.2 Economic evaluation

<table>
<thead>
<tr>
<th></th>
<th>CO</th>
<th>HC</th>
<th>Nox</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combi</td>
<td>$0,00</td>
<td>$0,01</td>
<td>$0,03</td>
<td>$0,00</td>
</tr>
<tr>
<td>e-Crafter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rapid</td>
<td>$0,00</td>
<td>$0,08</td>
<td>$0,41</td>
<td>$0,00</td>
</tr>
<tr>
<td>Caddy</td>
<td>$0,00</td>
<td></td>
<td>$1,09</td>
<td>$0,00</td>
</tr>
<tr>
<td>Golf</td>
<td>$0,01</td>
<td>$0,23</td>
<td>$0,35</td>
<td>$0,00</td>
</tr>
<tr>
<td>e-Golf</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Citaro, 49</td>
<td>$0,24</td>
<td>$13,05</td>
<td>$163,69</td>
<td>$618,88</td>
</tr>
<tr>
<td>Citaro, 30</td>
<td>$0,07</td>
<td>$4,01</td>
<td>$50,30</td>
<td>$190,16</td>
</tr>
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<td>Citaro, 31</td>
<td>$0,25</td>
<td>$13,62</td>
<td>$170,84</td>
<td>$645,92</td>
</tr>
</tbody>
</table>

a: For the HC, the price used was the CH4

Graphic 24: Cost composition for the system’s pollutants
<table>
<thead>
<tr>
<th>Cars</th>
<th>Operating costs</th>
<th>CO2 cost</th>
<th>Pollution cost</th>
<th>Acc costs</th>
<th>Tax revenue</th>
<th>Final cost</th>
</tr>
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<tr>
<td>Combi, 1,17</td>
<td>-8,290,7</td>
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<td>-0,3</td>
<td>-187,3</td>
<td>278,2</td>
<td>-8,239,4</td>
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<td>-0,3</td>
<td>-187,3</td>
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<td>-0,8</td>
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<td>-0,8</td>
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</tr>
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<td>3,596,8</td>
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<td>Citaro, 30</td>
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<td>-78,1</td>
<td>1,105,1</td>
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<tr>
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<td>-830,6</td>
<td>-265,3</td>
<td>3,753,9</td>
<td>-34,348,1</td>
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</table>

Table 37: Final costs (€/month)
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
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<td>30</td>
<td>-$430</td>
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<td>$300</td>
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<tr>
<td>150</td>
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<td>$281</td>
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<td>-$1.023</td>
<td>-$178</td>
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<td>$64</td>
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<tr>
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<tr>
<td>600</td>
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<td>-$238</td>
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<tr>
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<td>-$452</td>
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<td>-$217</td>
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<td>-$4.674</td>
<td>-$3.624</td>
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<td>1.200</td>
<td>-$5.730</td>
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<td>$112</td>
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</table>

*Table 38: Breakdown of the costs for the sensitivity analysis*
<table>
<thead>
<tr>
<th>Demand (pass / day)</th>
<th>Demand (pass / month)</th>
<th>Cost per car (€ / month / car)</th>
<th>Cost per REA passenger (€ / month / REA pass)</th>
<th>Cost per veh * km (€ / month / SYS veh * km)</th>
<th>Cost per REA passenger (€ / month / SYS pass * km)</th>
</tr>
</thead>
<tbody>
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<td>1,0</td>
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<td>$0,85</td>
</tr>
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<td>-$6,166</td>
<td>$6,32</td>
<td>$1,15</td>
<td>$0,84</td>
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<td>140,0</td>
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<td>$6,19</td>
<td>$1,15</td>
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<td>150,0</td>
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<td>-$6,831</td>
<td>$6,07</td>
<td>$1,15</td>
<td>$0,80</td>
</tr>
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</table>

*Table 39: Indicators of economic performance for the sensitivity analysis*
Graphic 25: Cost comparison in €/ month/ REA pass
18. Appendix G – Population’s perception

18.1 Motivation and purpose

The next question was about the motivation for using the system – “What is the reason why you are travelling with Mokumflex?” – and a set of pre-defined answers was given. For the line 490, users were supposed to compare their option for Mokumflex instead of the regular service, while for the line 301, the options were about the purpose of the trips:

- Line 490: “49 is not available when I want to travel”, “Line 49 has no stops near my house”, “Mokumflex is better than regular service” and “Not applicable”. No multiple choices were possible;
- Line 301: Commute, residential, shopping, recreational use and other were the answers available. Multiple choices were possible.

For the line 490, the motivations for the users of Mokumflex for not using line 49 was:

**Line 490**

![Graph showing motivations for line 490 users and non-users]

*Graphic 26: Motivation for the users and non-users for the line 490*

This graphic shows the importance of the extended service: both the time-frame and the created intricacy in attracting people for public transport. This reinforces the idea of the section “Daily distribution”, where was demonstrated the late-night usage of Mokumflex. For the line 301, the purpose of the 21 users was:
When it comes to the purpose of the trips, less than one third of the users said that Mokumflex helped him to commute and almost 60% of the usage was for recreational use or shopping. As evoked before, this information confirms the non-commuting profile of Mokumflex.

It is important to mention that elaborating questions for a survey can be tricky. In the case of line 490, not giving the possibility of selecting multiple choices and the inexistence of “other reasons” answer could hide some possibilities. Furthermore, replacing “near my house” by an expression that unifies both origin and destination could render clearer the question.

18.2 Car usage and induced trips

The following of the surveys, users were demanded to measure the impacts of Mokumflex in car usage – “Because of Mokumflex, I use less my car/ bike” – and induced trips – “Because of Mokumflex, I travel more”
18.3 Usage of the line 49

Finally, only for those from Driemond, they were asked about the impacts on the line 49 – “Because of Mokumflex, I make less use of the line 49”:

N.b.: 5 represents reduction in car usage and 1, no effects. Similarly, 5 represents large effects of Mokumflex in inducing displacements while 1 express no consequences of Mokumflex in creating new demand.

For the line 490, users considered that Mokumflex had more potential to reduce car usage than in Amsterdam Noord. For induced trips, users of the line 490 also thought that the operation had more impact in creating supplementary demand.

The numbers for the line 301 were considerably lower: no reduction of car usage nor induction of trips. Again, it is important to highlight the risk of these results being biased: since the line 301 was badly seen by the inhabitants, there is a possibility of them having voted negatively to express their frustration to exert some pressure on the public power to return the previous system.
Usage of the line 49

N.b.: 5 means that they use less line 49 while 1 means that Mokumflex had no repercussion in the regular service.

The result of this section is not surprising: users said that they were using less the line 49 – as could be expected, since line 49 is paid while Mokumflex is free – the non-users said that they kept using line 49.

Finally, an open question demanding the personal opinion about the system had interesting answers, giving evidences for improvements. Besides local competition with the local taxi, more demand could be attracted by?

- Reduce the pre-booking time to 30 minutes;
- Reduce the 15 minutes time-frame, which is considered too long for commuting and leaves users in a vulnerable situation when waiting for late-night trips;
- Improve punctuality;
- Improve the call-center, which is not always available;
- Enhance communication with the driver, by allowing messages to be exchanged between traveler and driver;
- Anticipate the informative window for more than 7 minutes before the arrival time;
- Offer child seats;
- Ease the app-usage.

The poor communication is specially badly seen, since it prevents non-local people of visiting the area - both foreigners and relatives. Also, considering that elders are a numerous and mobility-vulnerable group – since have more probability of being incapable of driving or taking transit by their own – special marketing campaigns focusing in their inclusion, i.e. digital literacy, or enhance the call-center functioning could make the system more attractive for them.
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