Environmental and social effects of the Rotterdam low emission zone: an empirical approach

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Abstract

Congestion and pollution in cities across Europe is an ever-increasing problem. This paper aims to explain the different TSM and TDM measures that aim to reduce congestion and pollution. Especially the effects of a Low Emission Zone (LEZ), both technical and social, will be discussed using a literature study, a case study and a survey among users of the affected roads. Results showed that the LEZ is a one-shot measure that can only be repeated in the long run. Socially a LEZ might cause social exclusion or a decline in accessibility and mobility.

1. Introduction

Cities face an ever-increasing demand for the use of road use within city limits. Over an eight-year period, congestion in cities worldwide grew with an average of 23% (Nu.nl, 2017). In Rotterdam, the extra travel time incurred by congestion is 28% on average for non-highways, 19% higher than the average congestion on highways. Also, during morning and evening rush hours the level of congestion rises to an average of 27% and 42% respectively over all road types (TomTom, 2017). The rising level of congestion thus influences the travel times of travelers strongly, which may enlarge other negative externalities of car use.

One of these negative externalities is pollution. Pollution occurs through the emission of greenhouse gasses, particular matter, noise and other pollutants (Stopher & Stanley, 2016). Congestion increases pollution as roads will be more crowded (more emissions) and vehicles will be stationary at a particular part of the road infrastructure for a longer time. As stated by Somsen (2014) the quality of air in the Netherlands is far below the rest of Europe and does not suffice the European regulations on air quality (Somsen, 2014). In a recent evaluation report of the European Commission, Rotterdam is one of the worst scoring urban areas on air quality in Europe (Redactie AD, 2017).

The municipality of Rotterdam faces the challenge of increasing air quality in the city, without interfering with daily economic activities related to the transportation of people and goods in and out of the city. Travel demand management strategies, or TDM strategies for short, provide multiple policy options that can be used to tackle congestion and pollution. In order to reduce pollution, the municipality of Rotterdam implemented a low emission zone. Starting the first of January 2016, old polluting cars were no longer allowed into the Rotterdam city center. From the first of May onwards, unwanted cars were fined with a 90 euro penalty (NOS, 2016).

1.1 Aim and research question and Methodology

The aim of this thesis is to understand the effects TDM and TSM strategies can have on transport related externalities and road users. In particular the low emission zone of Rotterdam will be discussed and compared to alternatives in other cities. The research question of the thesis is as follows:

RQ. What are the effects of the low emission zone on the city of Rotterdam?

The research question can be broken down into two separate sub questions. The first sub question aims to find the technical results of the low emission zone. Technical results are results the low emission zone got in reducing the level of polluting and cleansing the vehicle fleet. The first sub question is thus formulated as follows:

SQ1. What are the technical effects of the low emission zone?

This sub question will be addressed using a case study of the city of Rotterdam in which the implementation and consequences of the Rotterdam low emission zone will be thoroughly discussed.

The second sub question that will be used to formulate an answer on the research question aims to find the social effects the low emission zone has on its users. Its users are all travelers that traverse the low emission zone in a vehicle. The social effects considered in this sub question do not include the effects of pollutants on people, as this is considered a more technical effect of the zone. Instead, examples of social effects meant with this sub question are social exclusion and changes in travel behavior. The second sub question is formulated as follows:

SQ2. What are the social effects the low emission zone has on its users?

This sub question will be discussed and answered using empirical research in the form of a survey.

This paper will first provide a detailed overview of multiple TSM and TDM strategies that can be used to reduce congestion and pollution. Next, the environmental zones in the Netherlands will be discussed, starting with a brief overview of the environmental zone in Utrecht. This brief overview of Utrecht is followed by a thorough case study of the environmental zone in Rotterdam. The conducted survey will be presented next and its results and implications will be discussed. After that, the conducted survey will be discussed and evaluated. Finally, the findings from the literature and the survey will provide an answer on the research question. Also, some policy recommendations will be formulated.

2. Literature review

In this part of the paper the existing literature on TSM and TDM will be discussed. First, an overview of the concept will be given, followed by examples of TSM and TDM systems. Finally, the case of the Rotterdam environmental zone will be discussed and compared to similar initiatives.

2.1 Transportation management

Travel Demand Management (TDM), Transport System Management (TSM) and Voluntary Travel Behavior Change (VTBC) are low-capital strategies especially used to deal with pollution and congestion. In the seventies, the dominant strategy to reduce congestion was to build more roads. This resulted in an increase in traffic volume and therefor an increase of noise and pollution. Also, construction costs were high and used much space (Börjesson, Hamilton, Näsman, & Papaix, 2015). More recent, alternatives were explored and found in TSM and TDM. TSM strategies look for solutions in the supply-side of the transport equation and aims to increase capacity and the optimization of capacity use. TDM, in contrast, is about managing the demand side of the transport equation by changing the behavior of travelers. This is commonly done using schemes and measures that divert traffic away from certain places and time periods in order to increase the efficiency of road use. Formulated this way, VTBC can be seen as a subsection of TDM as it is defined as changes travelers make in their travel decisions based on personal rewards instead of a top-down mechanism (Ampt, 2013). TDM and TSM strategies complement each other, implying that implementing a TDM strategy will be inefficient if it is not backed up by a TSM strategy (Stopher & Stanley, 2016). As mentioned, TSM and TDM are low-capital strategies that both aim to optimize the flow of travelers through the transport infrastructure. TSM does so in optimizing the use of available road space in many ways, example given by narrowing traffic lanes or managing traffic lights. The TSM approach thus is more technical in nature. TDM systems, in contrast, aim to increase traffic flow by changing the behavior of travelers. As an example, this can be done by ride sharing and carpooling initiatives that reduce the number of cars on the road, and thus reduce the likelihood of congestion and pollution.

Now that the essence of TSM and TDM strategies have been addressed, the next part will provide an overview of some TSM and TDM strategies described in available literature.

2.2 TSM strategies

2.2.1 Dedicated and priority bus lanes

One of the TSM strategies mentioned by Stopher & Stanley (2016) is the implementation of dedicated bus lanes and bus priority lanes. These lanes are dedicated for buses, so they can stay on schedule even when the normal lanes are congested. In many cities, buses are the most commonly used type of public transport. As buses can carry a large number of passenger, they make efficient use of road space. Like all other road users however, they have to deal with congestion, reducing their speed and decreasing their reliability in terms of on-schedule travel. In order to keep them as reliable as possible, delays should be minimized. Dedicated bus lanes cannot be facilitated at all places where they are necessary, so other measures should be explored. One of these measures is bus priority at traffic lights. This measure recalls or lengthens the green light periods upon detection of buses in order to minimize their congested time (Ahmed, Hounsell, & Shrestha, 2016). Both dedicated bus lanes and bus priority are fine examples of TSM strategies as they are both low-cost and aim to optimize the utilization of the available capacity. In terms of congestion reduction, both measures are only viable for buses and tackle only a small part of the congestion problem experienced in most cities. On the other hand, if people are well-informed about the privileges buses get in congested areas, more travelers might consider to change their choice of transport mode. This will decrease the number of vehicles on the road, reducing the probability of congestion. As mentioned in the theory, TSM and TDM strategies complement each other. For the best outcome, it is therefore necessary to implement a strong TDM strategy that also aims to promote the use of public transport.

A variation of dedicated bus lanes are dedicated lanes for lorries and buses on highways. On highways A16 and A20 in the Netherlands, 3 lanes are available from which one is dedicated for buses and lorries. This has two effects. Buses and lorries face less congestion as their dedicated lane will be less crowded. At the other side, normal transport will also face less congestion as buses and lorries will use the dedicated lane, reducing the amount of traffic on the normal lanes.

2.2.2 Driving lane optimization

The next low-capital measure to tackle congestion at the supply side of the transport equation is the clever usage of available driving lanes at peak times. In China, for example, two way roads become one way roads at certain peak times in order to reduce congestion. Another measure is to change two-lane two-way roads into a three-lane and one-lane two-way road, as two-lane two-way roads are often only separated by a line. In this case, only appropriate signing is needed to show the current direction of the corresponding lane (Zhang & Gao, 2007). This TSM strategy, in contrast to the earlier mentioned strategies, aims all vehicles on the road and therefore is expected to have a larger impact on the level of congestion. An additional lane comes available at the moment when the maximum capacity of the initial lane(s) is reached. Theoretically, this means that flow will increase and the chance of congestion will decline. In practice, this might not be the case. As more capacity comes available, automobilists think they can obtain more benefit from using the extra capacity. This goes on until the maximum capacity of the new situation is met, at which time flow will decrease and the road becomes congested again. Policy should recognize this caveat and enroll this strategy with caution.

2.2.3 HOV and HOT lanes

The fourth strategy that will be discussed concerns the use of dedicated High-occupancy vehicle (HOV) and High-occupancy and toll (HOT) lanes. In essence similar to the dedicated bus lanes, the use of HOV-lanes is only permitted when there are at least two travelers in the vehicle. This, as a matter of fact, also includes buses as they normally transport multiple persons. HOV lanes always have been a topic of discussion, as people argue that HOV lanes are often underused and would be more effective in terms of congestion reduction if converted to normal lanes, also known as General Purpose Lanes (GPL's) (Burris & Lipnicky, 2009). It is also argued that there is a loss in efficiency in the width of the HOV lane, as it should give ongoing traffic a possibility to pass a breakdown on the HOV lane. This means that a HOV lanes needs as much space as two GPL's (Harlow, 1993). The criticism led to multiple initiatives to make the HOV lanes more efficient. It was argued to allow hybrid cars on HOV lanes in order to deal with the constant underuse (Shewmake & Jarvis, 2014) or change them into HOT lanes (Konishi & Mun, 2010).

The first initiative was implemented by the government of California, as they distributed so-called "Clean-Air Access" stickers among owners and buyers of hybrid cars. These stickers granted permission for low emission hybrid cars to use the HOV lane without meeting the minimum occupancy rule. Owners of certain hybrid cars, that sufficed the conditions as stated in Assembly Bill 2628, could write the DMV and obtain a set of stickers for 8 dollars between 2005 and 2007. In total, 85,000 stickers were distributed over three installments. First, 50,000 were distributed and its effect on congestion on HOV lanes was analyzed. As the distribution of the stickers did not lead to congestion on the HOV lanes, 25,000 more were distributed in the second installment. At last, there were 10,000 extra stickers available during installment three (Shewmake & Jarvis, 2014). The issuance of the clean air access stickers thus had an impact on the usage of HOV lanes. HOV lanes were first intended to motivate commuters to carpool, so that the number of cars on the road would decline and therefore congestion and pollution would decline. With the issuance of the clean air access stickers and the admittance of hybrid cars on HOV lanes, the initiative was more about reducing air pollution than congestion, as the number of cars on the road is not affected by the stickers, as they grant the privilege of using the HOV lanes, even when traveling alone. Another conclusion that can be made follows from the assessment of second hand cars, as it was found that a clean air access sticker boosted the value of a car by an estimated 3,400 dollars (Shewmake & Jarvis, 2014). This suggests that commuters greatly valuate the use of HOV lanes and are willing to pay a fair amount of money to obtain access. This can be explained in two ways. First, people may be concerned about the environment and are willing to pay more to pollute less. Second, people value time. As the HOV lanes are often not congested, travel times tend to be shorter, improving the welfare of the people using them. Also, as the number of cars on the road will not decline, but the number of cars that are on the road will be better distributed over the lanes, congestion should also fall on the GPL's. This is expected to lead to an improvement in welfare for users of GPL's.

Another initiative to make more use of the HOV lanes is described by Konishi & Mun (2010). In their research, they argue if HOV lanes should be transformed into HOT lanes. One of the arguments in favor of the transformation is that the existence of HOV lanes cause a distortion from the congestion levels between the different type of lanes, which may reduce social welfare (Konishi & Mun, 2010). From this point of view, it is socially feasible to transform the HOV lane into a HOT one, diverting some, but not all, travelers from the GPL's to the HOV lane. This will omit the distortion between lane types but is likely to reduce flow at the HOV lane, decreasing the welfare for the travelers on the lane. This problem is outweighed by the problem of pollution. The main purpose of HOV lanes is to encourage people to carpool, and therefor reduce the number of cars on the road. In turn, this will reduce the exhaust of pollutants. With the transformation into HOT lanes, single occupancy vehicles can buy themselves into the HOV lanes, offsetting the initial idea of car reduction. It is not unrealistic that the transformation may cause social benefit losses (Konishi & Mun, 2010). These losses are mainly accounted for by the increase in pollution if compared to the HOV initiative. On the other hand, one may argue that the single occupancy vehicles will be present on the freeway independent of the presence of HOT or HOV lanes. If HOV privileges can be bought, which is the definition of a HOT lane, the government can make use of the willingness to pay of GPL-travelers to travel on a restricted lane and raise money for the government. This can be countered by the assumption that current carpoolers might be encouraged to travel alone in separate cars if the price for the HOV lane is not too high.

As mentioned, the strategies discussed so far all aim to reduce congestion and pollution by optimizing the use of available capacity from an engineering point of view, thus from the supply side of the transport equation. The main theme discussed is the smart use of road space in an infrastructure network.

2.3 TDM strategies

Now that some supply-side strategies are discussed, the following part will contain an overview of some TDM strategies employed at different locations.

2.3.1 Spitsmijden

The first TDM strategy that will be discussed concerns the Dutch initiative of "Spitsmijden", which can be best translated to "rush hour evasion" or "peak hour avoidance". Spitsmijden is a collection of local projects that aim to divert traffic away from the peak hours by foreseeing rewards for drivers that meet certain criteria. At the moment, one of the projects that is employed concerns the A2 from Nederweert to Eindhoven and rewards automobilists that don't drive this particular highway in the morning peak hours. By doing so, participants can earn gifts worth up to 80 euros per month.

Participants are eligible to take part in the program if they were detected during morning rush hour at least once a week over a period of four weeks prior to the start of the initiative. Rush hour evasion behavior is registered using the "Spitsmijden" app which detects the location and speed of a traveler, from which it can derive if the to be evaded road was really evaded. At the end of the month, a point total is awarded based on the behavior prior to the project and during the project. With these points, vouchers or gifts can be bought, as well as public transit fares (SpitsmijdenA2, 2017). Similar projects were recently employed in Maastricht, Brabant and Utrecht (Spitsmijden.nl, 2017).

The initiative tries to change the behavior of travelers in such a way that other modes of travel or other moments of travel are chosen. It aims to spread the total demand of the road in a way that congestion is reduced at peak hours, as many roads are underutilized between the two rush hour periods. Another possible effect of this strategy is the choice of alternate transport modes, which relaxes the number of vehicles on the road at peak moments, without increasing the number of vehicles on alternative times and/or roadways. The program is best used as a measure to battle increasing congestion during peak hours.

Spitsmijden can also have positive effects on air quality. As volatile organic compounds (VOC's) and oxides of nitrogen (NO_x) will react into ozone under sunlight, changing the clock time might have a positive effect if dispersed before sunrise. The sun will not be strong enough at that time to cause the reaction to happen (Mingardo, 2017).

As with every TDM strategy, also Spitsmijden has its limitations. As travelers that alter their behavior are rewarded with gifts, the municipality, local government or government has to pay for the gifts earned. The costs of these rewards are manageable when a project is implemented on a small scale. On a larger scale, the costs might start to outweigh the benefits at one point leading to a net deficit. Therefore, the scope of the program is too small to make a direct impact on overall congestion. The costs are spread out over different governmental bodies as each program is employed by another contractor. This leads to the costs of the total program being proportionally allocated to the according contractor. On the other hand, for the small scale that it is meant for, local congestion may decline. In order to get optimal results, the initiative should aim to employ the number of participants that maximizes social benefit. This will be the case when marginal social benefit equals the marginal social costs. Employing more participants will lead to a decrease in social benefit and is therefore not desirable. An excess of participants should be avoided by setting limitations on the number of participants. Also, most initiatives have a specific range of eligible travelers, as some participation conditions are very specific. As many people are ruled out, they will not voluntarily change their traveling behavior. This might interfere with the possible success of the program.

Thus, Spitsmijden is a clear TDM strategy as it tries to alter the behavior of travelers without altering the characteristics of the roadways. As mentioned earlier, TDM and TSM strategies complement each other and will not be successful without each other. As an example, Spitsmijden and HOV-lanes complement each other as they both encourage travelers to travel by bus or carpool. The impact of both programs will likely be higher if implemented together at the same time.

2.3.2 Promotion of public transport

The next TDM strategy that will be discussed is the promotion of public transport (Stopher & Stanley, 2016). Public transport is available at all major cities across Europe but often not optimally used. Public transit can reduce the number of vehicles on a road, which will reduce the chance of congestion and reduce air pollution and noise. As public transit will be on the road no matter how many passengers it carries, it is socially efficient to ensure the capacity of the bus is fully used. This can be done by marketing and promotions or by making public transit free of charge.

Free of charge public transport can impose social welfare loss. It is expensive to facilitate free public transit and implementation may have negative influences on those already using public transport. As more people will use public transport, current users will experience congestion. It can also be expected that not all of the new public transit users were car users, rather they used to walk or cycle. As travel is a derived demand and provides no utility on its own, travelers will choose the mode of travel that cost them the least amount of utility. In this case, the government will not get the results they were hoping for as public transit will get congested and the drivers are not altering their travel behavior. In this case, it should be studied what the considerations of car users are and analyzed why they keep using the car. One explanation may be the existence of symbolic-affective motives which appeal to feelings such as sensation, power, superiority control and independence (Steg, Vlek, & Slotegraaf, 2001). In the end, the offering of free public transport will result in a decline of road congestion and will encourage economic activity.

In terms of marketing and promotions, much can be done. First of all, the supply of information is crucial. Many people are biased against public transit as they did not experience themselves what it really is and hear a lot of stories from hearsay. Many of these stories include some criticism on the public transport options without experiencing the upside of it. The public opinion should be boosted. In the Netherlands, for example, the Dutch Railway company (NS) tries to achieve this using posters and ads on the internet and television. Also, it now is common to share any updates about possible limitations on the public transit lines via the internet. This way, people have access to up to date information about any delays or reroutes they might encounter.

2.3.3 Road Pricing

Road pricing is a common used TDM strategy and follows the user pays principle, because, among traffic engineers and transport economists, road pricing refers to policies that impose direct charges on road use (Jones & Hervik, 1992). Road pricing is most commonly associated with congestion reduction. In addition, road pricing will have positive effects on air quality as road users will change their mode of transport to more environmentally friendly ones. On the other side, accessibility will be negatively influenced as generalized transport costs are expected to increase (Condeço-Melhoradoa, Gutiérrez, & García-Palomares, 2011). Overall, the largest gains for road users are expected to be in travel times, as road pricing will decrease the number of users on the priced road, which will reduce the level of congestion (Condeço-Melhoradoa, Gutiérrez, & García-Palomares, 2011). As mentioned, road pricing is mainly associated with the reduction of congestion. Vehicle pollution is also expected to be reduced but only as a side effect, as the choice for alternative and more environmental friendly travel modes will not be available for everybody. The effects on accessibility will be perceived differently by different road users (Condeço-Melhoradoa, Gutiérrez, & García-Palomares, 2011).

Road pricing is easy to implement, as it is easy to charge users of the particular section of the road infrastructure. It will reduce congestion on the priced road as the users whose willingness to pay is lower than the imposed charge will change their mode of travel or choice of route. As mentioned by Condeço-Melhoradoa, Gutiérrez, & García-Palomares (2011), the effects of the implemented road pricing will differ among travelers, as some will pay the charge and experience the gains in terms of travel times, while others have to change their travel habits which might lead to longer travel times and/or costs of travel. Trips to locations inside the priced area might also be foregone. This might have social as well as economic implications. The possible implementation of a road pricing policy should therefore be thoroughly evaluated and analyzed, as it should aim to increase social welfare and thus all travelers concerned should be included in evaluation.

2.3.4 Congestion charges

The next TDM strategy that will be discussed in this paper is congestion charging. Congestion charging is one of the many ways to implement road pricing and is recommended by economists as it is cost-efficient and raises revenue for the government. In general, political and public support for congestion charging schemes are low and interfere with possible implementations (Börjesson, Hamilton, Näsman, & Papaix, 2015). London and Stockholm are two well-known cities in Europe where this measure was eventually implemented, to great success. Milano followed the example set by London and Stockholm in 2008.

The initiative started in 2003 in London. Vehicles driving in the city center between 7:00 and 18:00 were obliged to pay a 5 pound congestion charge (Mingardo, 2017). In the meantime, the charge has gone up to £11.50 a day. The charge is levied by using number plate recognition software. The net profit of the congestion charge is invested in the London infrastructure (Platform31, sd) and was approximately 137 million pounds in 2007/8 (Mingardo, 2017). Stockholm followed the initiative with a trial in 2006 and permanent implementation in the first half of 2007. The Stockholm Congestion Charge system also uses number plate recognition. In addition, electronic tags are loaned out to drivers so that direct debit is also possible. Furthermore, the Stockholm Congestion Charge fee varies in time, making it more expensive during peak hours. The profits made by the initiative are used to improve infrastructure around Stockholm (Roadtraffic-technology.com, sd).

The congestion charge initiative aims to reduce the number of cars in the city center during daytime and has as priority to reduce congestion. The initiative in London had an initial effect as congestion levels decreased. The decrease has however been offset by infrastructure changes. The money raised by the congestion charge initiative was used to remove road capacity for motor vehicles and improve infrastructure for cyclists and pedestrians. Therefore, the gains in terms of congestion reduction were offset by the infrastructural changes (Wilson, 2013). Also, reductions in traffic were found all over the UK in recent years, so it is unclear if and how much the congestion charge contributed to a decline of congestion in London (Wilson, 2013). Transport for London (TfL) has used the profits from the initiative not to improve conditions for congestion charge payers, but instead used the profits to enhance the alternative travel mode options. For example, in 2007/8, the largest investment was conducted in bus improvements (Mingardo, 2017). This means that the person who pays and keeps using the car in the congestion zone does not benefit from the improvements directly. Only if this person would change his mode of travel he might experience the benefits that he paid for. This can be seen as an unfair allocation. Suppose a person who lives an one hour drive away from London commutes to his work location in the CC zone every day. Every day this person pays the charge but never reaps the benefits of the program. Instead, road capacity declines in favor of dedicated bus lanes or broader pedestrian areas, from which the payer will not experience the benefits. In the extreme case he will even experience a deficit which is caused by the removal of road capacity. The question that follows from this is if the beneficiary should pay, or the user. It can be argued that a larger portion of the profits should be invested in vehicle capacity which leads to a fairer distribution from the view of the payer. On the other hand, the payer does not suffer from the bad air quality all day, while local residents do. It is therefore almost impossible to find a “fair” allocation of investments. TfL should take all stakeholders into account while deciding how to allocate their revenues.

In 2006, Stockholm followed the London example and implemented their own environmental zone. It is very much the same as the London congestion charge, but also shows some differences. Where the London congestion charge zone charges every vehicle that drives in the city center, the Stockholm congestion charge only charges vehicles that pass a control point, either in or out of the congestion charge zone (Roadtraffic-technology.com, sd). This means that in the Stockholm congestion charge zone, you have to pay each time you pass a control station, with a maximum daily fare (Eliasson, 2014). In contrast, the London congestion charge is only paid once a day, irrespective of how many times a vehicle enters and leaves the congestion charge zone (Platform31, sd).

The Stockholm congestion charging zone was implemented after a referendum held after a trial period was held. Before the trial, public opinion was negative and a referendum at that time would result in a no-go for the congestion zone. However, as the trial yielded the first results, which included a 30-50% drop in congestion levels due to a 20% reduction of traffic volume, public opinion shifted in favor of the congestion charge. At the referendum, the majority voted in favor, leading to the implementation in 2007 (Eliasson, 2014). After the trial, traffic volume did not rise to its old level, implying that there were residual effects, which can be explained by the change in travel behavior of some road users. After the charge was re-introduced, traffic volume decreased and stabilized at around -20% (Eliasson, 2014). In addition, CO_2 emissions fell by around 10% in the zone and 2% in the hinterland (Mingardo, Content Introduction to Transport Economics, 2017). In terms of costs, the congestion charge zone in Stockholm tends to be profitable. At first, a 760 mkr benefit was expected each year, which would offset the initial costs in only four years, which is relatively short for an infrastructure initiative (Mingardo, 2017). More recent calculations show that the initiative produces a net social benefit of 654 mkr a year, excluding the costs of investments made to the infrastructure (Eliasson, 2014).

Congestion charging has proved to be successful in two major European cities in terms of both congestion reduction as well as pollution reduction, although the reduction in London is not significant. In London, revenues have been used to improve conditions for pedestrians, cyclists and public transit, where the Stockholm CC made investments possible in a bypass around the city. Both initiatives incurred a deficit in their starting year which was earned back in a relative short period of time in following years. In both areas, initial attitude towards a congestion charge was negative. Attitude changed over the first years of the charge, as it is believed that familiarity breeds acceptability (Börjesson, Hamilton, Näsman, & Papaix, 2015).

2.3.5 Low Emission Zones

The Low Emission Zone, also called LEZ for short, is another TDM strategy that deals with congestion as well as pollution. This measure is implemented in a large number of cities across Europe. The first LEZs were found in Sweden in 1996, where they were called “Miljözon” and banned only old Heavy duty vehicles (HDV’s) and required middle aged HDV’s to replace their engine or install an emission control device. In 2002, the first LEZ outside of Sweden was found. (Holman, Harrison, & Querol, 2015). LEZs are currently employed by at least 200 cities in 10 countries across Europe in 2014. The rules of these LEZs differ from only affecting heavy-duty vehicles or lorries to all vehicles including mopeds (The AA, 2017). LEZs in Germany, which included HDV’s as well as passenger vehicles, showed positive results in terms of pollutant reduction. However, in other countries the results were mixed if any result was observed at all (Holman, Harrison, & Querol, 2015).

Where road pricing has its main purpose in battling congestion, the LEZ focusses on improving air quality inside its borders. In general, it is the most effective measure a municipality can take to reduce pollution (Sadler Consultants Ltd, sd). As cities should comply to the Clean Air Act of 1970, they look for initiatives to decrease the exhaust of pollutants by vehicles. A LEZ, in contrast to the congestion charge zone, does not impose a tariff on driving in the city center, but entirely bans out old and exhausting vehicles (Gehrsitz, 2017). This means that the city center of various European cities cannot be reached with a polluting car or lorry. Similar to the effects of road pricing, this might impose social exclusion or a decrease in mobility and accessibility for individuals that are affected by the ban. Alternative travel modes will not suffice for all affected travelers or might not be available to the needed extent. Affected travelers might not be able to replace their polluting vehicle and thus have to re-mode, re-route or forego the trip. This negative effect of LEZs should be minimized, as, like every TDM strategy, the aim of the measure should be to increase social welfare by decreasing negative externalities associated with transport. A LEZ creates a trade-off that decreases pollutants at the expense of travel costs or mobility and accessibility. The municipality can minimize the costs incurred for affected travelers by facilitating a strong public transit network in combination with park and ride (P+R) places just outside the LEZ.

In the above section, various TSM and TDM measures and strategies have been explained and briefly discussed. In particular the concepts of congestion charging zones and LEZs were discussed, as they make it possible to understand the empirical assessment later on. The next section will first present a case study of two LEZs implemented in the Netherlands. The first LEZ that will be discussed is the Utrecht LEZ, which is the oldest in the Netherlands. The emphasis however will be on the discussion of the Rotterdam LEZ. This case study will be followed by the empirical assessment of the LEZ.

3. Case study: LEZs in the Netherlands

As in many European countries, cities in the Netherlands followed the initiative of the LEZ. In 2007 the first two LEZs were introduced. In 2014, the amount of LEZs in the Netherlands had grown to 15. These LEZs included only HDV's and low duty vehicles (LDV's). Research shows that the implementation of LEZs did not significantly reduce vehicle related pollutants. It was found however, that the level of air pollution was lower in the post-implementation year than in the pre-implementation year (Holman, Harrison, & Querol, 2015). The level of pollution thus returned to its original level, after a temporary decline in vehicle related pollutants. Most of the LEZs in the Netherlands still only ban HDV's and LDV's, although experiments are conducted in Amsterdam, Leiden and Nijmegen that ban out polluting mopeds. In Utrecht, only full electric mopeds will be allowed from 2020 onwards (ANWB, 2017)

3.1 Utrecht

The first city in the Netherlands that implemented a LEZ that also banned passenger cars was Utrecht. Starting 2015, the municipality of Utrecht started fining all diesel vehicles that were first registered before January 1st, 2001 (Municipality of Utrecht, 2017). The implementation of the Utrecht LEZ was heavily challenged as opponents of the LEZ pled that the LEZ would have a reverse effect as banned vehicles had to drive more kilometers and the LEZ would cause dangerous situations as people would get confused by the LEZ. In 2017, the "Raad van State" ruled in favor of the LEZ, making its existence permanent (Remmers, 2017). Also, a political debate emerged upon implementation of the Utrecht LEZ, which resulted in a motion issued by the VVD (liberal party) that would make an end to LEZs in the Netherlands. Although a majority was reached, an independent judge ruled that municipalities are free to implement LEZs as they see fit, as long as its motives are clear. Also, arguments about the minor influence of the LEZ was invalidated by the fact that the municipality of Utrecht employed a package of environmental measures, of which the LEZ was just a small part (Remmers, 2017).

In order to keep their city center as congestion-free as possible, the municipality of Utrecht defined some rules for supply trucks. In the inner city, suppliers have to follow one of the predefined main roads. From these main roads loading areas throughout the inner city can be reached (Municipality of Utrecht, 2017). This strategy focusses solely on delivery trucks and can therefore be expected to facilitate a small decline in congestion. As delivery trucks are obliged to use one of the main roads, they are kept away from the smaller roads where they might cause more trouble. Downside of this strategy is that there might be a moment where there are multiple delivery trucks on one head road which may lead to the congestion of a major arterial road which can lead to even more delay. Overall, the restriction of available roads for supply trucks will reduce congestion as automobilists can anticipate on this when choosing their route.

3.2 Rotterdam

The second city in the Netherlands to implement a LEZ that targets all motor vehicles was Rotterdam. Starting the first of January 2016, strong polluting cars were no longer allowed in the city center. However, until the 30th of April 2016, no fines were imposed on perpetrators. Starting the first of May 2016, perpetrators are fined €90(excluding administration costs) per violation (Gezonderelucht.nl, 2017). The alderman of port, mobility and sustainability, Pex Langenberg, explained the goal of the LEZ is to reduce the emission of soot particles by 40% (ANP, 2015).

The allowance of vehicles is based on the Date of First Admission (DFA), which is the date a vehicle first received a number plate in the European Union. The DFA's used to define the boundaries correspond with Euro norms of vehicles. At this moment, vehicles that use diesel as fuel are only allowed if their DFA is later than the first of January 2001. Vehicles that use gasoline or LPG as fuel are allowed if their DFA is later than July 1st, 1992. These DFA's correspond with respectively the Euro III and Euro I standards. Oldtimers (cars that are 40 years or older) and 100% LPG vehicles are exempted from the LEZ requirement. For HDV's the minimum requirement to be allowed in the LEZ is Euro IV (Gezonderelucht.nl, 2017).

In order to compensate the inhabitants of Rotterdam whose car did not meet the requirements of the LEZ, the municipality offered a demolition schedule for their cars. Residents were able to demolish their car for free and be subsidized for doing so. The minimum amount of compensation was €1000, with a maximum of €2500. This way, the municipality tried to compensate owners of old cars and help them to get a car that did meet the LEZ requirements. The subsidy would be even higher when one replaced their demolished car by an electric one, or one that drove completely on green gas(CNG). The program ran until the 30th of June 2017 and exceeded 5000 demolitions (Gezonderelucht.nl, 2017).

Travelers from outside Rotterdam whose vehicle does not meet the requirements of the LEZ are not eligible for the demolition scheme and thus have to find another way to make it to their destination. The easiest way would be to buy a car that does meet the requirements. As can be imagined, not everyone will be able to make such an investment, so alternatives should be sought. These alternatives also apply to inhabitants of Rotterdam who did not make use of the demolition scheme.

If the destination is outside the LEZ, rerouting might be possible. In this case it is possible to drive around to the place of destination. In the case of a destination inside the LEZ, rerouting will not be one of the options as the car will not be allowed. The following possibilities are then available. First, it is possible to change the mode of travel to public transport. Rotterdam has a strong public transport infrastructure, including, bus, tram and subway lines. Also, with train stations in the center of the city, the center is made easily accessible. The use of public transport can be combined with the usage of designated P+R areas, located just outside the city center, where travelers can park their car against a large discount. For the people living in the suburbs, biking to the city center might also be a possibility. If these measures will not suffice, exemptions can be applied for. Short term exemptions can be bought for €24,90 per 24 hours, for a maximum of 12 days per year. Long term exemptions can be applied for if certain requirements are met (Gezonderelucht.nl, 2017).

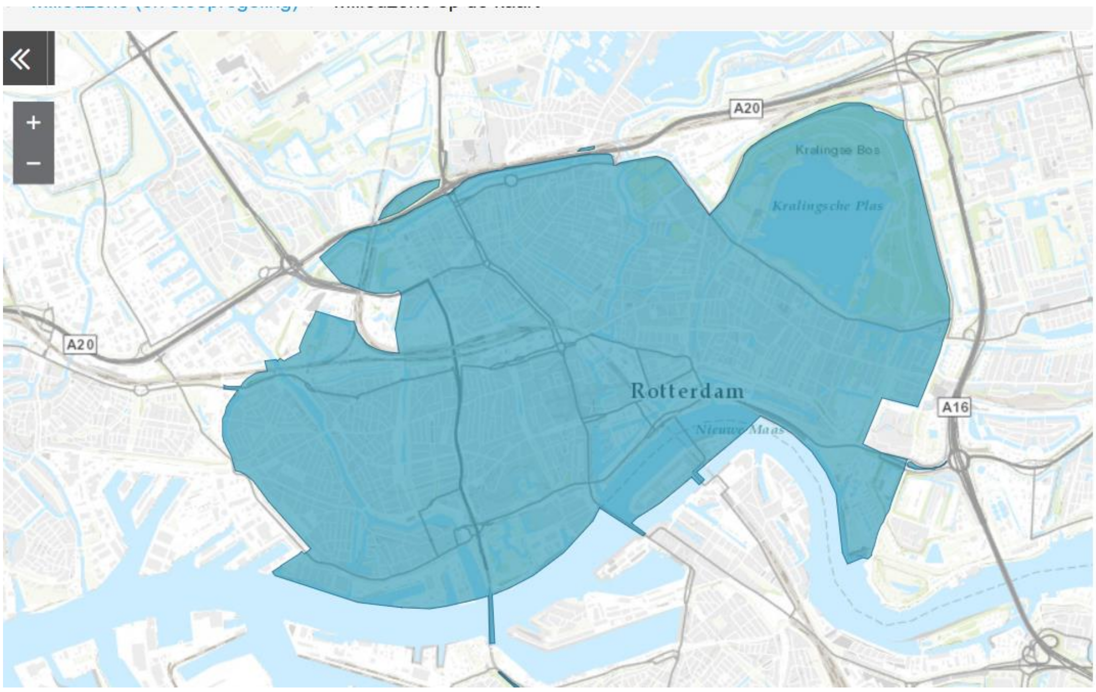


Figure 1. Location of the Rotterdam LEZ (Gezonderelucht.nl, 2017)

The Rotterdam LEZ is located on the northside of the Maas and covers a large part of the central and northern area of the city. It roughly covers the area between Spangen in the west, the "Kralingse Plas" in the east, the Northern Island in the south and the highway A20 in the north, as shown in Figure 1. The Erasmubrug, Willemsbrug and Maastunnel are also part of the LEZ. The terrain of the Erasmus University Rotterdam is not part of the LEZ and clarifies the exempted square on the righthand side of the city, near the exit of highway A16 (Gezonderelucht.nl, 2017).

Vehicles are checked by 33 monitoring and enforcement cameras across the city. As mentioned earlier, perpetrators are fined with a €90 fine when driving in the LEZ. As the cameras cannot monitor the whole area, city wardens are employed with enforcing the requirements of the LEZ (Gezonderelucht.nl, 2017).

Figure 2. Entrance to the LEZ at the Erasmus bridge (Nu.nl, 2016)

The LEZ is not the only measure the municipality of Rotterdam takes to battle congestion and pollution. One of these measures is the promotion of biking and the enhancement of bicycle lanes in the inner city. This means among other things that bicycle lanes are widened and traffic lights are programmed more biker-friendly. Also, an online platform to share experiences and tips was founded (Gezonderelucht.nl, 2017). The promotion of bike use contains some TSM as well as some TDM measures that complement each other as well as the LEZ. Especially the residents of Rotterdam who can easily change their mode of travel to biking will benefit from better cycling lanes and priority at traffic lights. As can be expected, if more residents change their mode of travel to the zero-polluting alternative, the exhaust of pollutants will decline. In addition, congestion in terms of the number of vehicles in the inner city will decline as well.

On May 27th, 2017, an interview with Pex Langenberg was published in which the effectiveness of the LEZ was discussed. Results showed that the share of vehicle emissions on the overall level of pollution declined. He also underlined that the demolition scheme refreshed the vehicle fleet of Rotterdam which decreased the amount of heavy polluting cars in Rotterdam (De Kruif, 2017).

A preliminary report of the DCMR and TNO in November 2016 found that the Rotterdam LEZ was already a success, as the exhaust of soot already declined with 20% (Nu.nl, 2016).

Another press release that was published in June 2017 concerned a court sentence that invalidated the imposed ban of old gasoline vehicles in the LEZ. The court judged the municipality did not take the minority of old-car users into consideration. The municipality of Rotterdam appealed against this sentence (Van Vliet, 2017). The Rotterdam LEZ thus is an heavily discussed topic. Its form and requirements are heavily criticized by some parties which even lead to an appeal in court. The LEZ is particularly contested by associations of old-timer owners, as they believe vehicle pollution is not the main factor in the total air pollution in Rotterdam.

4. Survey Environmental zone Rotterdam

4.1 Methodology

As follows from the available literature, congestion charging and implementation of LEZs are commonly used TDM strategies used by municipalities to decrease pollution and congestion. Both measures are heavily discussed though, as some minor groups feel neglected and not taken into account. As discussed in the case study, the municipality of Rotterdam decided to go through with the implementation of a LEZ, with as its primary objective to decrease the exhaust of vehicle pollutants.

The effects on minor groups is hard to assess as they often concern a small proportion of the population. In case of the LEZ, this are owners of old cars and small businesses that make use of older delivery vans. Irrespective of the size of these groups, the consequences the LEZ has on them has to be taken into account while evaluating the effects of implementation. In order to do this, empirical research will be presented that aims to find behavioral effects of travelers that might have been affected by the implementation of the LEZ in 2016. Also, a hypothetical scenario was tested, in which respondents were asked what they were to do in case their car did not meet the LEZ's requirements anymore. This way, respondents are asked to put themselves in the shoes of the affected parties and behave like they would. The results can be analyzed and give a representation of the consequences the minor groups experienced.

The method of research used was an online survey which was rolled out over social media. The main channels of distribution were Facebook, LinkedIn and Facebook, as well as possible word-of-mouth sharing by respondents. The survey consisted of 15 questions. Most questions were multiple choice and thus had predefined answers. This was done to limit the range of possible outcomes and keep the survey comprehensible. In addition, two questions were open. In one of these questions, the willingness to pay of respondents was asked, in the other question the open part was an explanatory field in case a respondent had another reason of travel than the predefined options stated. A schematic overview of the structure of the survey is presented in table 1.

Question ID	Question (Dutch)	Question (English)
1	Woont u in Rotterdam?	Do you live in Rotterdam?
2	Bent u in het bezit van een auto?	Do you own a car?
3	Reist u weleens met een auto (eigen of geleend) door Rotterdam?	Do you drive throough Rotterdam (own car/borrowed)?
4	Hoe vaak rijdt u door Rotterdam?	How often do you drive through Rotterdam?
5	Voor welke activiteit gebruikt u meestal de auto?	For what activity do you use the car the most often?
6	Bent u bekend met de milieuzone in Rotterdam?	Are you familiar with the Rotterdam LEZ?
	De milieuzone is een gebied in de binnenstad van Rotterdam waar sinds 1 mei 2016 oude auto's die veel uitstoot hebben niet worden toegestaan. Hierbij wordt gekeken naar het productiejaar .Op basis van het productiejaar wordt bepaald of een auto toegestaan is in de binnenstad. Bij invoering was dit 1 januari 2001 voor diesels en 1 juli 1992 voor benzinewagens.	The LEZ is an area in the inner city of Rotterdam where from the first of May, 2016 old, polluting cars are not allowed anymore. Admission is based on the year of production. Upon implementation, gasoline cars were not allowed if they were produced before the first of July, 1992. Diesels were not allowed if they were produced before the first of January, 2001
7	Voldeed uw auto aan de milieueisen bij de invoering op 1 mei 2016?	Did your car comply to the LEZ's requirements the firts of May, 2016?
8	Wat waren de consequenties van de invoering van de milieuzone voor u?	What were the consequences for you?
	Op dit moment houdt de milieuzone 6% van de ingeschreven auto's in Rotterdam buiten het centrum.Stel: De gemeente Rotterdam overweegt de eisen van de milieuzone aan te scherpen. Hierdoor hoopt de gemeente Rotterdam de luchtkwaliteit nog verder te kunnen verbeteren. Deze maatregel zal impact hebben op het aantal auto's dat is toegestaan binnen de milieuzone.Ga er bij het restant van deze vragenlijst van uit dat uw auto niet meer voldoet aan de milieueisen en dus niet meer binnen de milieuzone mag rijden.	At ths moment, the LEZ bans 6% of the registered cars in Rotterdam out of the environmental zone. Now suppose the municipality of Rotterdam considers tightenining the requirements of the LEZ. This way, the municipality hopes the air quality will improve even more. This measure will impact the amount of vehicles that is allowed to drive in the LEZ. Assume the new measure implies that your car does not comply to the requirements of the LEZ anymore for the remainder of this questionnaire
9	Wat zouden de consequenties voor u zijn?	What would be the consequences for you?
10	Waarom zou u geen auto aanschaffen die voldoet aan de eis?	Why would you not buy a complying car?
	In Londen en Stockholm is een aangepaste variant van de milieuzone actief. In deze steden mag je alleen de binnenstad in als je een zogenoemde Congestion Charge (congestiebijdrage) betaalt, ongeacht hoe oud de auto is. In Londen is dit op het moment 11,50 pond per dag, in Stockholm hangt de prijs af van het moment van de dag.Stel dat de gemeente Rotterdam overweegt de aangescherpte milieuzone te vervangen door een Congestion Charge gebied. Dit houdt in dat alle auto's mogen rijden tegen betaling van een dagelijks tarief. Elke auto betaalt dus.Ga er nog steeds van uit dat jouw auto niet aan de verscherpte milieuzone-eis voldoet.	In London and Stockholm an alternative to the LEZ is implemented. In these cities, you are only allowed in the inner city if you pay the congestion charge, irrespective of how old your car is. In London this charge is set on 11,50 per day, in Stockholm the charge depends on the time of the day. Suppose the municipality of Rotterdam considers to replace the earlier propossed tightened LEZ with a congestion charge zone. This means every car is allowed in the inner city if they pay the daily charge. Still assume your car does not meet the tightened LEZ requirements mentioned before.
11	Wat zou u bereid zijn per dag te betalen om de stad in te mogen?	What would be your maximum willingness to pay to enter the city center?
	Stel dat de dagelijkse bijdrage op €5 per dag wordt vastgesteld. Iedereen die het centrum inrijdt betaalt dit bedrag aan de gemeente.	Suppose the daily charge is set on €5. Everyone that drives into the city center has to pay this charge to the municipality.
12	Wat zou u doen?	What would you do?
13	Wat is uw leeftijd?	Whats your age?
14	Wat is uw geslacht?	Whats your gender?
15	Wat is uw inkomen?	What is your income?
16	Heeft u nog op of aanmerkingen betreffende deze survey of de milieuzone?	Do you have other remarks concerning this survey or the LEZ?

Table 1. Overview of the survey

Questions 1 up until 3 asked the respondents about their city of residence, car ownership and if they drove through Rotterdam by car. Questions 4 up until 9 questioned the respondents about their usage of a car in the LEZ, their familiarity with the LEZ and the possible consequences the LEZ has had on them in 2016. The, questions 10 up until 13 put a hypothetical scenario on the respondents. Respondents were asked to pretend their car was not eligible anymore for the Rotterdam LEZ. The purpose of the questions was to see how respondents would react to such a scenario. Questions 12 and 13 introduced the alternative of a congestion charging zone instead of the LEZ. The answers were used to find the willingness to pay of a non-complying car owner to be allowed in the inner city and test their willingness to pay against a fictional fee. At last, questions 14,15 and 16 asked some demographics of the respondents that could be used to distinguish different demographic groups based on gender, income and age. Also, a comment section was provided in which respondents could give their opinion about the survey and/or the Rotterdam LEZ.

After completion, the results were analyzed using pivot tables in Microsoft Excel. The aim was to formulate an answer to the research objective and sub questions. They were formulated as follows:

RQ. What are the effects of the LEZ on the city of Rotterdam?

SQ1. What are the technical effects of the LEZ?

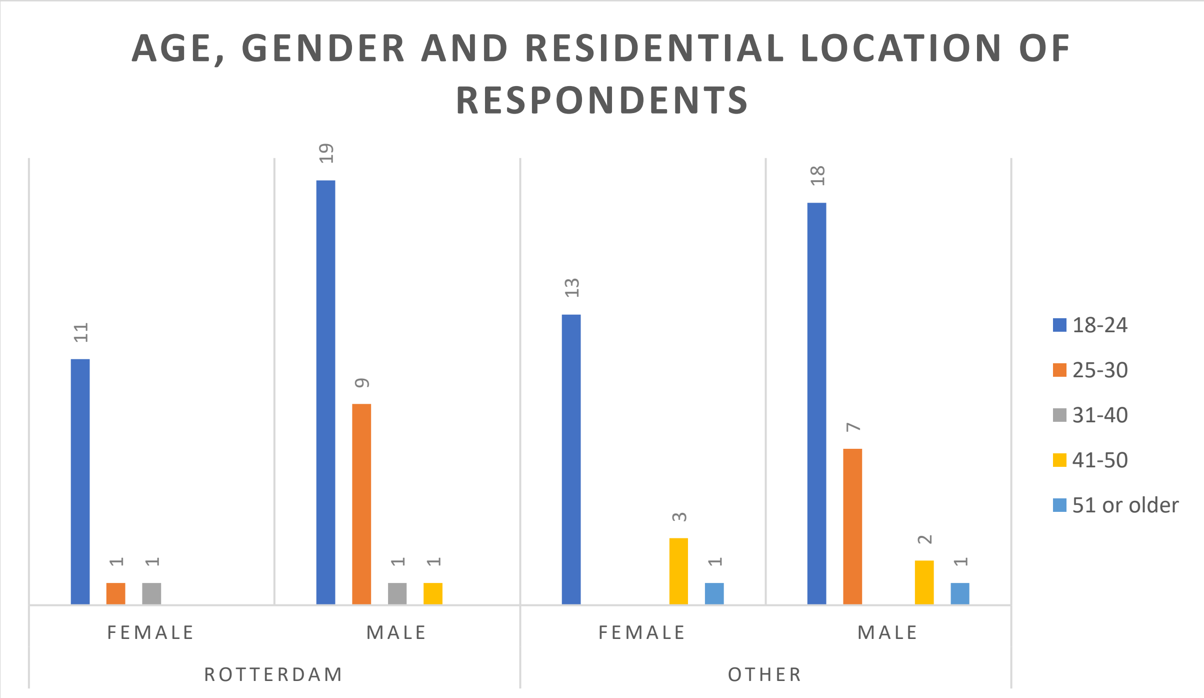
SQ2. What are the social effects of the LEZ?

4.2 Results

The survey was completed by 114 respondents in total. 17 of them stated they never drove through Rotterdam and were therefore not taken into account though politely thanked for their participation. Of the 97 remaining respondents, 9 did not finish the entire survey and were therefore kept out of the analysis. The total dataset thus consisted of 88 eligible respondents.

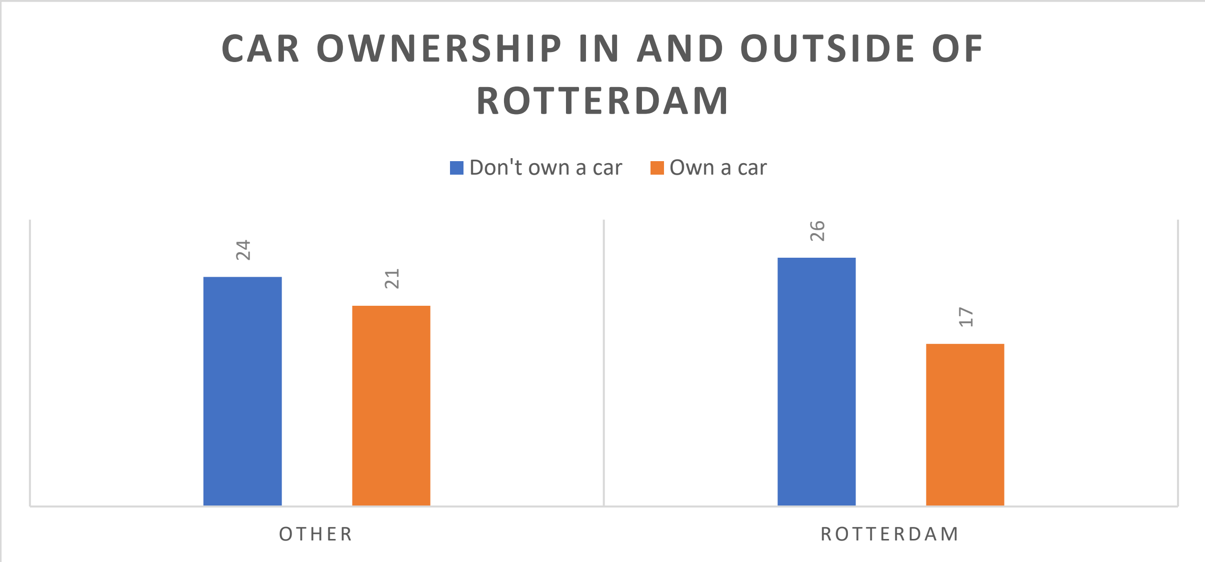
4.2.1 Demographics

Out of the 88 eligible respondents, 43 are inhabitants of Rotterdam. 45 have a residential location outside of Rotterdam. The dataset consists of 58 male and 30 female respondents. The age, gender and residential location of respondents are summarized in Graph 1. It was found that the majority of the respondents earn a below modal wage.



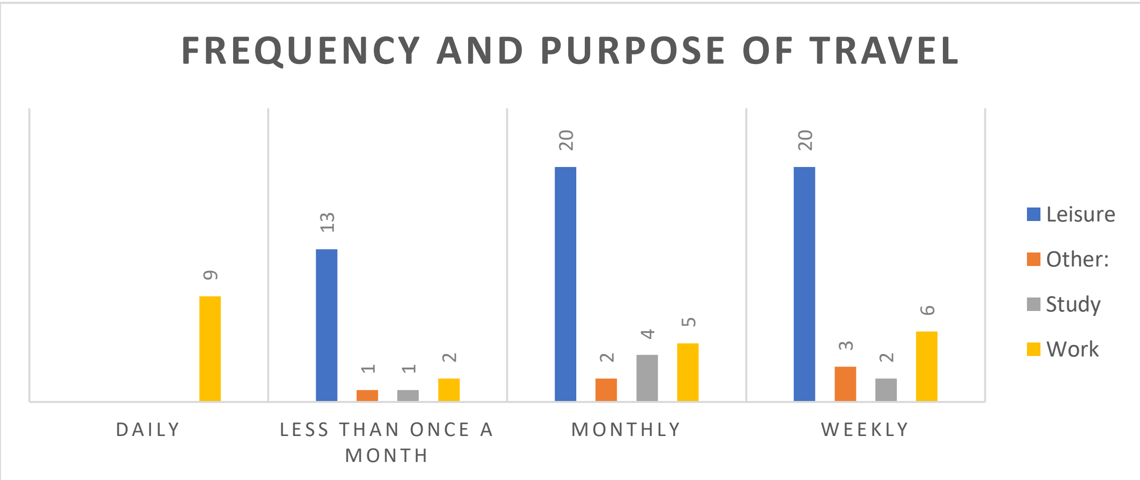
Graph 1. Demographics of respondents (Questions 1, 13 and 14)

The survey also collected information about the travel behavior of respondents. Data was collected about the frequency of car travel inside the LEZ and the main purpose of car usage. It was found that the majority of the respondents did not own a car. Statistically put, 57% of the respondents did not a car, which leaves 43% car owners. Analyzing further, only 40% of the respondents that live in Rotterdam own a car, compared to 47% of the respondents that live somewhere else. 26 respondents stated they did not own a car at the time of the LEZ's implementation, a score of 30%. This amount is less than the currently stated percentage of car ownership and is explained by the fact respondents may use a car from friends or family.



Graph 2. Car ownership of respondents by residential location (Questions 1 and 2)

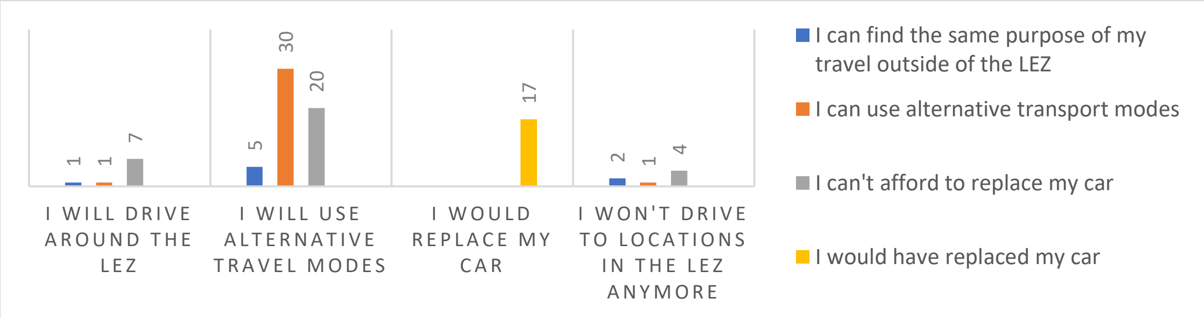
The next analysis concerns the main purposes of car use and frequency of travel through the LEZ. None of the respondents stated that their main purpose of car use was for shopping. Another interesting finding is the relation between frequency of travel and purpose of travel. It was found that the daily travelers in the LEZ all used their car mainly for work, while of the less frequent drivers in the LEZ, leisure is the main purpose of travel. Graph 3 summarizes the data on frequency and main purpose of travel.



Graph 3. Main purposes of travel and frequency of travel through Rotterdam (Questions 4 and 5)

4.2.2 Social Exclusion

One of the key subjects that will be discussed later on is the matter of the possibility of social exclusion. Out of the 88 respondents, 3 respondents stated that their car did not meet the LEZs requirements at implementation in 2016. One of them stated that they don't go to the LEZ anymore, one uses alternative travel modes and one replaced their car. Question 7 then tested the actions respondents would take if a tightening of the LEZs requirements would disallow entrance to the center for them, while question 8 looked for the reason why respondents did not replace their car. It was found that 7 respondents will not travel to location inside the LEZ anymore. 2 of those 7 stated they will shift the location of their destination outside the LEZ, 1 stated he or she will use alternative travel modes. 4 out of 7 stated they are not able to afford to change their car. Graph 4 shows the actions respondents will



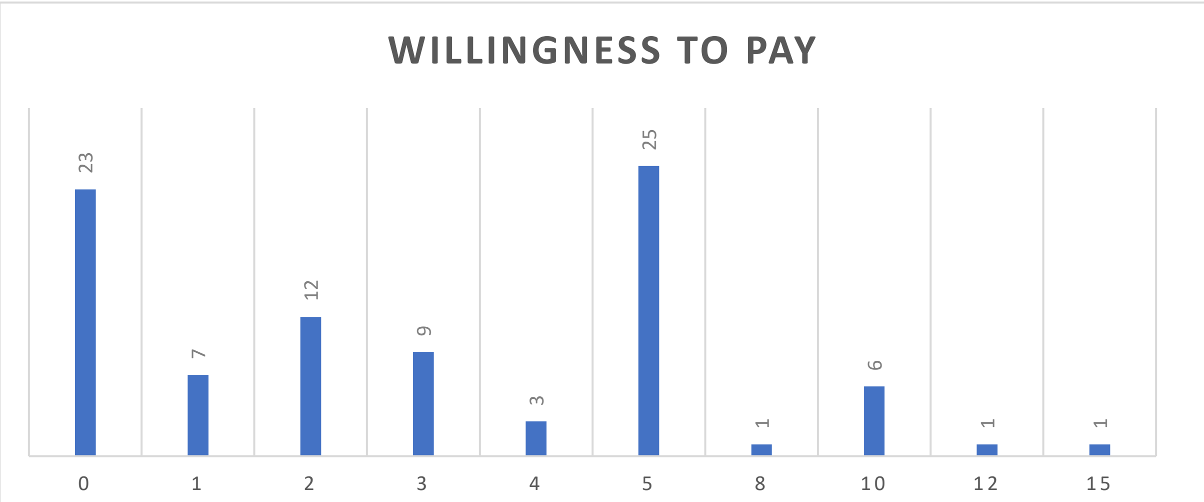
Graph 4. Consequences and motivation for respondents' actions(Questions 9 and 10)

take on the X-axis and states their main reason for not replacing their car on the Y-axis.

As can be derived from this graph, the main reason for respondents to change their mode of travel is because of the lack of sufficient funds to replace their car. In total, 31 people stated they will not be able to replace their car, of which 11 live in Rotterdam. 17 respondents would replace their car, which is only 19% of the respondents. Of the remaining 71 respondents, 32 stated the main reason for not replacing their car is that they are able to change their mode of travel. The people who stated they will drive around the LEZ can be seen as passer-byes as their destination will likely be outside of the LEZ.

4.2.3 An alternative for the LEZ

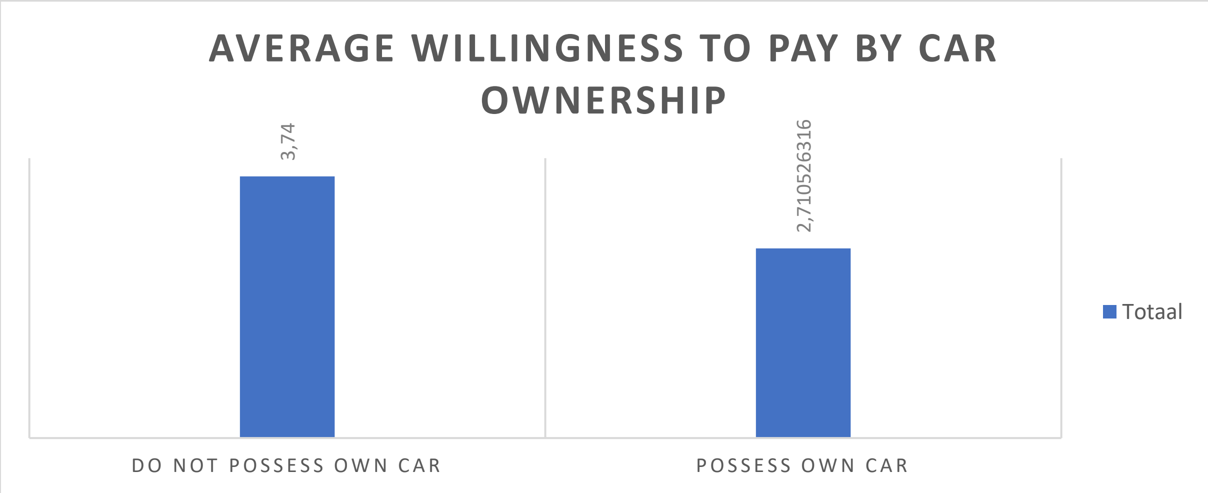
The last part of the analysis will concern the questions regarding a comparison between a congestion charging scheme and a LEZ. Questions were asked about the monetary value respondents would pay to be allowed into the LEZ, irrespective of how old the vehicle was they drove. Results varied between a WTP of zero and 15. As can be seen in Graph 5, two peaks are found.



Graph 5. Willingness to pay of respondents(Question 11)

The first peak is located at a WTP of zero and implies this section of the respondents is reluctant to pay for admission in the zone. The other peak is located at 5 euro per day. Overall, the stated average WTP of respondents is €3,30.

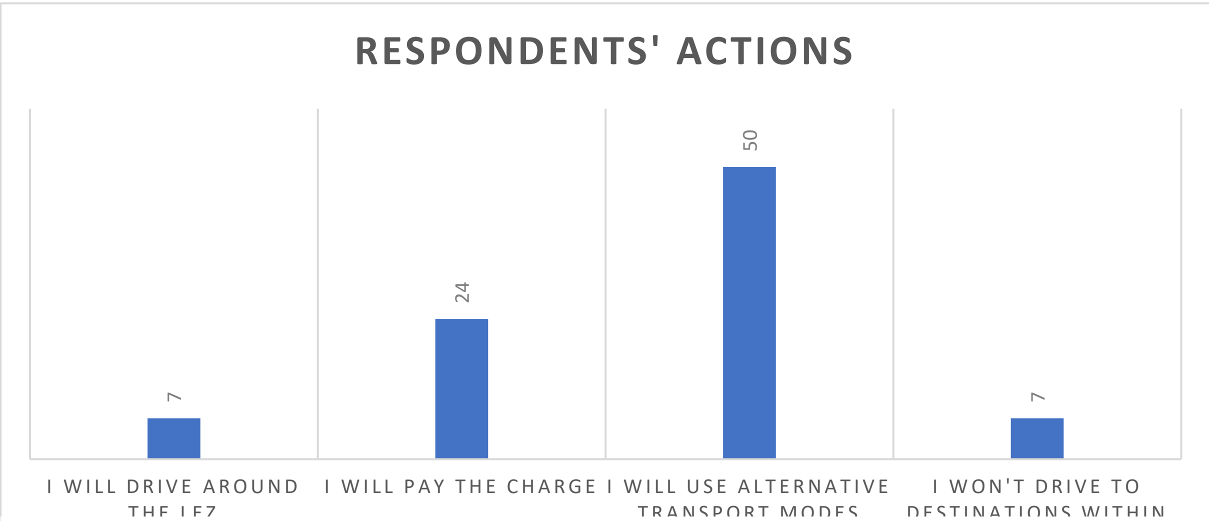
Crossing the WTP statistics with car ownership and residential location, it is found the average WTP of car owners is about 1 euro per day higher than the WTP of non-car owners. This is shown in Graph 6. Also, Residents of Rotterdam will be willing to pay more on average to get admitted into the LEZ than respondents that live outside of Rotterdam. The WTP was also analyzed by frequency of travel, where it was found that respondents that travel only less than once a month were willing to pay the most. This is shown in Graphs 9, 10 and 11 in Appendix A.



Graph 6. Average willingness to pay by car ownership

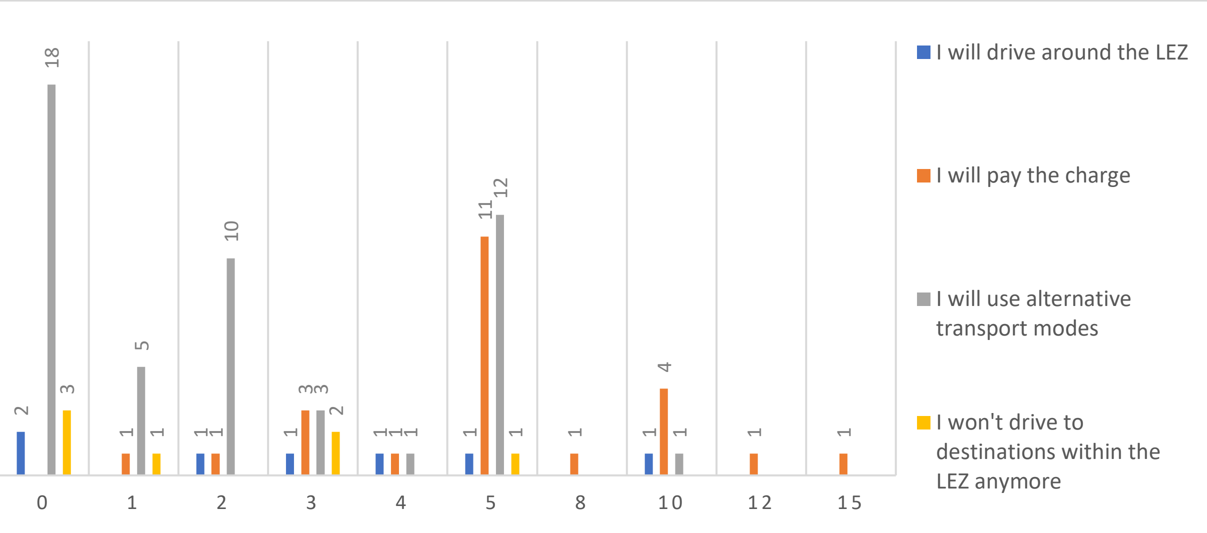
Analyzing the demographic values in combination with the WTP, it was found that the average willingness to pay is highest among the respondents between 31 and 40, as they were willing to pay €6,5 on average for admission. Also including income, it was found that all respondents in this group earned above modal wage. The lowest willingness to pay was found among respondents between 41 and 50. They all earn at least modal wages. These findings are graphically shown in Graphs 12 and 13 in Appendix A.

In the last question, the stated WTP was tested against a hypothetical charge of 5 euros. Respondents were asked to state their course of action in this case. The results are shown in Graph 7.



Graph 7. Actions taken by respondents given the hypothetical charge of €5(Question 12)

As can be derived from Graph 7, 50 respondents state that they will use alternative transport modes instead of paying the €5 charge. 24 respondents will pay the charge, 7 will drive around the LEZ and 7 will not drive to destinations in the LEZ anymore. The stated actions in case of a €5 daily charge was compared to the willingness to pay per group to facilitate further discussion. The results of the



Graph 8. Stated willingness to pay compared to actions taken

comparison are shown in Graph 8. As can be derived, respondents did not always follow up their stated maximum WTP. For example, one respondents stated its maximum willingness to pay was 1. With the daily charge set on €5, this person's revealed WTP differed from its stated WTP. This also applies for the case where the stated WTP was €5. Here, 12 respondents would rather change their mode of travel than pay the charge, while they stated they were willing to pay €5 to be admitted.

Now that the results of the survey are analyzed, the next part will discuss their implications and relate to earlier findings.

5. Discussion

The discussion will be divided in two parts. First, the case study will be discussed and matched to the available literature. Second, the survey results will be discussed.

5.1 Technical results

The case study provided an overview of the LEZ and what actions are taken by the municipality. As mentioned, the LEZ is not the only measure that has been taken in improving the air quality. As mentioned by Stopher and Stanley (2016), a TDM and TSM strategy need to be paired if optimal results are sought after. The LEZ is a clear TDM strategy as it tries to alter the behavior of travelers. The TSM part will be covered by for example the improvements made for cyclists. In addition, the public transport infrastructure is strong, but could be further enhanced. One possibility in this case would be the usage of dedicated and priority bus lanes.

The LEZ has had positive effects on the exhaust of vehicle related pollutants. Research found that the level of soot had already decline by 20% in the first 7 months, while the final target was a 40% reduction. Also, the demolition scheme has been used over 5000 times, resulting in a cleaner vehicle fleet in the city of Rotterdam. With 5000 polluting vehicles taken out of the equation, and the probability of not every car replaced, reductions in pollutants are expected.

The Rotterdam LEZ and LEZs in general are often criticized as opponents believe vehicle related pollutants only make a small percentage of the overall pollutants. They believe the other factors, like factories and cruise ships, have a much larger contribution to the level of pollution and should be addressed first. This leads to constant debate and even lawsuits. In the end, municipalities often stick to the LEZ. Municipalities face certain pollution goals set by national and international governments and therefore look for the best suited measure that will achieve this goal. As stated by Sadler consultants (sd), a LEZ is the most efficient measure a municipality can take to improve air quality of polluted areas. This motivates municipalities to start their pollutant-reducing programs with a LEZ. As each TDM strategy should be complemented with a TSM strategy, implementation of a LEZ is often followed by infrastructural changes.

It may also be argued that a congestion charge system might work in order to achieve a reduction of pollutants. This would impose a charge on every user of the LEZ and will, like with the congestion charge zones, reduce the number of cars on the road infrastructure. As can be imagined, less cars means less exhaust fumes and thus less pollutants. On the other hand, also old, polluting cars can buy themselves admission into the zone, which will have negative influences on the exhaust of pollutants. Therefore, an “environmental charge” will not have the desired effects and is not suited to reduce pollution.

The implementation of the LEZ is expected to only have an effect once and can therefore be seen as a one-shot measure. Upon implementation, the LEZ will have positive effects on the level of vehicle related pollutants as it sweeps all polluting cars out of the city at once. The demolition scheme that was implemented among the LEZ resulted in 5000 polluting cars taken out of the equation. This was in the case of 6% cars that did not comply the LEZs requirements. The LEZ will only keep having an impact on pollution if the requirements would be periodically tightened. The costs of the demolition scheme in case of a tightening are expected to rise as increasingly more cars will not meet the set requirements and therefore will become too expensive and eventually outweigh the benefits.

5.2 Social results

The first observation made by the survey was that only a small portion of the respondents was directly affected by the LEZs implementation. 3 out of 88 stated that their car did not meet the requirements in May 2016 and therefore had to either replace their car or look for alternatives in terms of mode of travel or destination of travel. One of these respondents even stated that he or she will not travel into the center of Rotterdam at all anymore. This might have various reasons that were not tested in this survey. One of the possibilities can be that his person still wants to enter but simply is not able anymore. In this case, social exclusion may well be a negative effect that the LEZ imposes on road users. Small groups of affected did make a case against the LEZ and won the lawsuit, as a judge ruled that the municipality did not took the effects on this minor groups into account enough.

This notion is strengthened by analysis of the hypothetical case. Here, 7 respondents stated that they will not enter the LEZ anymore if their car is not admitted into the LEZ anymore. The main reason for this, in 4 of the 7 cases, is that respondents are not able to replace their car. Residents of Rotterdam are compensated by being able to use the demolition scheme, but respondents outside of Rotterdam are not eligible for this scheme and thus face the decision to re-mode, re-route or alter their destination. The second-best motivation to not enter the LEZ anymore was that the purpose of their travel could also be satisfied somewhere outside of the LEZ. In other words, respondents altered their destination. Especially In the case of re-routing and alteration of destination, travelers will not drive in the LEZ of Rotterdam anymore, also foregoing any possible economic and social activities that they might have taken otherwise. Although the affected group is small, these effects should be taken into account when assessing the implementation of a LEZ measure as unlikeable social and economic effects will lead to resistance from the population.

The main reason for not replacing a car, irrespective of the action respondents would take, is that respondents lack the necessary funding to replace their car with a complying one. Most respondents that wo not replace their car state that they will use alternative travel modes to get to their destination in or through the LEZ. Among other small effects, this can have two major effects on affected travelers. The first is a lengthening of travel times, as often alternative travel modes will not provide the mobility that a car provides. Closely related to this effect is the uncertainty of travel time that public transport brings. The second major effect would be the decline of accessibility of travelers, as alternative modes may influence the travel range commuters experience. For example, commuting to a destination inside the LEZ might be too far to reach by bike on one side and be out of reach of public transport on the other hand. In this case, not being able to replace a car might lead to decreased accessibility and mobility. The municipality of Rotterdam does try to minimize this negative effect by facilitating “Park and Ride” parking zones at the borders of the LEZ in combination with strong public transport infrastructure and up-to-date information about the public transport.

Respondents were also presented a case in which they were able to buy themselves admission to the LEZ, no matter how old their car was. The technical ineffectiveness of this “environmental charge” was already discussed in section 5.1. Socially, the implementation of an “environmental charge” also was deemed ineffective. Respondents first stated their WTP to be admitted and secondly tested their stated WTP against a fictive charge. The first observation that was made was that the WTP of car owners was higher among the respondents that do not own a car of themselves. This can be explained by the fact that they are likely to travel less often by car and thus do not pay the charge often. This is confirmed by the analysis of WTP and its relation to frequency of travel, where it was found that respondents that only traveled less than once a month were willing to pay more on average than any other group. Still, all groups have an average WTP that is lower than the fictively proposed 5 euros. This implies that the “environmental charge” will not be paid in most cases. It is therefore interesting that respondents divert from their stated WTP in case of the proposed 5 euros. For example, as shown by Graph 8, 12 respondents who stated their WTP was €5 also stated that they would use alternative modes of travel in case of a €5 charge. On the other hand, there were respondents that stated their WTP was less than €5, but would pay the €5 if the charge was imposed. Because both questions were asked in a survey setting, it is not correct to speak of the stated versus revealed preferences principle, but the results might give an indication that the principle applies.

In the end, using the results obtained from question 12, it can be derived that only 24 out of 88 respondents would pay the “environmental charge”. 50 will change their mode of travel, 7 will drive around the LEZ and 7 will not go to destinations inside the LEZ anymore. In terms of reducing the number of cars in the LEZ, the “environmental charge” results in 24 out of 88 cars still entering the LEZ, which also includes polluting vehicles that the LEZ would keep out of the center. In case of the LEZ, only 17 respondents will replace their car. This means that a LEZ will in general keep more vehicles outside than an “environmental charge” would. The “environmental charge” can be seen as socially preferable, as more mobility and accessibility is preserved and there are less respondents that would not drive in the LEZ. On the other hand, average WTP lies below the proposed amount of €5 which implies the charge should be lower for society to not experience a loss in welfare incurred by the payment of the “environmental charge”. Therefore, the available data cannot provide an answer on which measure would be socially preferable, if any, as both measures do have socially negative effects in terms of possible social exclusion and decreases in accessibility and mobility.

5.3 Limitations of the survey

The conducted survey has its limitations. As it was dispersed using social media, many respondents were of the same age which might bias the results. Also, not all respondents own a car of themselves or drive through the city center regularly, which also may have had an influence on the obtained results. Last, respondents were provided with a fixed list of answers at many questions, where there might have been more answers reasonable or where more answers were applicable.

6. Conclusion and policy recommendations

In this section, the discussed results will be concluded and policy recommendations based on those conclusions will be formulated.

6.1 Conclusions

This part will first provide the conclusions that are derived from the discussion to enable the formulation of policy recommendations for the municipality of Rotterdam. The first sub question was formulated as follows:

SQ1. What are the technical effects of the LEZ?

Using available literature combined with the presented case study, it was found that the LEZ is an effective one-shot measure that can be used to cleanse the vehicle fleet and reduce the vehicle related exhaust of pollutants at once. However, in order to stay effective, requirements have to be tightened periodically which will lead to increasingly more compensational costs. as compensational costs will eventually outweigh the benefits of the measure and becomes too expensive for the municipality to follow through. Also, tightening of the LEZs requirements will increase the level of resistance among the affected. This means that the LEZ provides technical results in the short run, but will not continue to show positive results in the long run. In the end, the one-time results are desirable and therefore the implementation of a LEZ shows positive technical results.

The second sub question was formulated as follows:

SQ2. What are the social effects of the LEZ?

Social effects are undervalued as the negative effects imposed by implementation of the LEZ are often only found in a small group of the total population. However, this does not mean these negative effects should not be taken into account. The main effects that are associated with the LEZ are the risk of social exclusion, and declines of both mobility and accessibility. The results of the survey stated that there indeed is a small group that faces the risk of social exclusion caused by the LEZs requirements in the case of the Rotterdam LEZ. In addition, the LEZ might negatively influence the mobility and accessibility of affected individuals. Socially undesired effects may thus occur and should also be taken into account while analyzing the efficiency of the LEZ. Analysis of the conducted survey concluded that only 19% would replace their car in case the LEZ would affect them. This means that 81% of the respondents had to re-route, re-mode or choose an alternative destination. For these respondents, there is a chance their mobility or accessibility declined. For the respondents that had to choose an alternative destination, social exclusion might be a real risk. A LEZ thus comes with social issues that might lead to negative effects for affected individuals. Among these social effects, decreases in mobility and accessibility are possible, as well as social exclusion. The “environmental charge” is expected to have a smaller effect on mobility and accessibility and is expected to have minimal effects on social exclusion. However, as it was found that only 27% of the respondents would pay the charge, decreases in mobility and accessibility are likely to occur. In addition, the charge will be valued as a deficit by many respondents when the charge is set to €5, as the average WTP was substantially lower (€3,30). This means that an “environmental charge” would not have enough public support to be successful. In the end, the LEZ is expected to impose some negative social effects, irrespective of the variation of the measure that is used.

The conclusions to the sub questions enable the formulation of an answer to the research question. The research question was defined as:

RQ. What are the effects of the LEZ on the city of Rotterdam?

Combining the conclusions to the sub questions, the following answer was formulated.

The LEZ has positive effects on the air quality in the LEZ in the short run but will not keep on improving the air quality as it is impossible for the municipality to keep tightening the LEZs requirements, both financially and socially. However, the measure could be repeated in several years when the number of affected individuals is again small and when good arrangements are made with affected individuals. Social effects are expected to be negative as the LEZ decreases mobility and accessibility of affected individuals and has a chance to socially exclude a small part of the population. The outcome of the survey backs up this notion as it found that there were indeed respondents that faced the risk of social exclusion, as well as respondents that faced declines in mobility and/or accessibility.

6.2 Policy recommendations

From these conclusions, a few policy recommendations can be drawn.

The first policy recommendation for the municipality of Rotterdam is to repeat an implementation of a LEZ in 10 years from now. As mentioned, the costs for the municipality are too high to keep tightening the LEZs requirements over time. However, when done in ten years, the size of the affected group will again be small, so the costs of compensating this group will also be bearable. Effects on air quality are expected to be positive following implementation as the vehicle fleet will be refreshed again and cars below certain environmental standards will again be dropped.

The second policy recommendation is based on the experience of the implementation in 2016. As certain minor groups were able to issue a lawsuit that got the LEZs requirement for gasoline cars removed. In order to prevent such actions in the future, the municipality should consider all stakeholders before implementation and make clear arrangements with the small groups that will be affected. Only then will the LEZ obtain optimal results.

The third policy recommendation can be stated as a spreading of measures. As vehicle related pollutants are not the only pollutants in the city center, other sources of pollutants should also be decreased. One of the examples is the traffic on the river Maas, where freighters and cruise ships also exhaust pollutants. Another source that might have an influence on the air quality in Rotterdam is the port area of Rotterdam, where refineries are located. The municipality of Rotterdam can invest in green alternatives to reduce emissions in the hinterland that spill over to the city.

Finally, the municipality of Rotterdam should continue implementing measures that promote alternative modes of travel by improving public transport and bicycle infrastructure. This will likely improve the effects of the LEZ now and possibly in the future.

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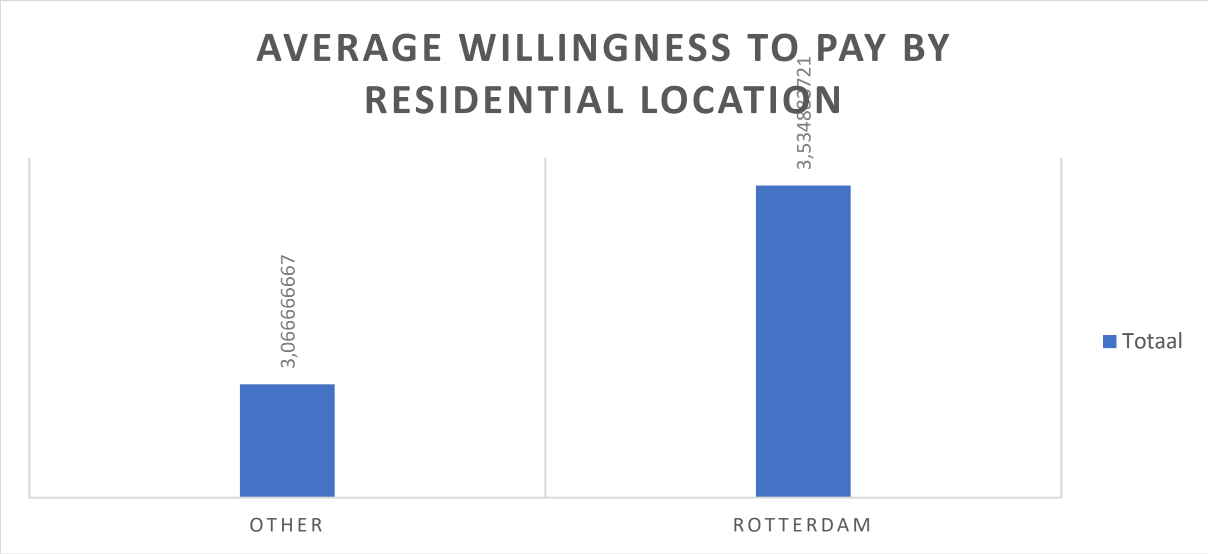
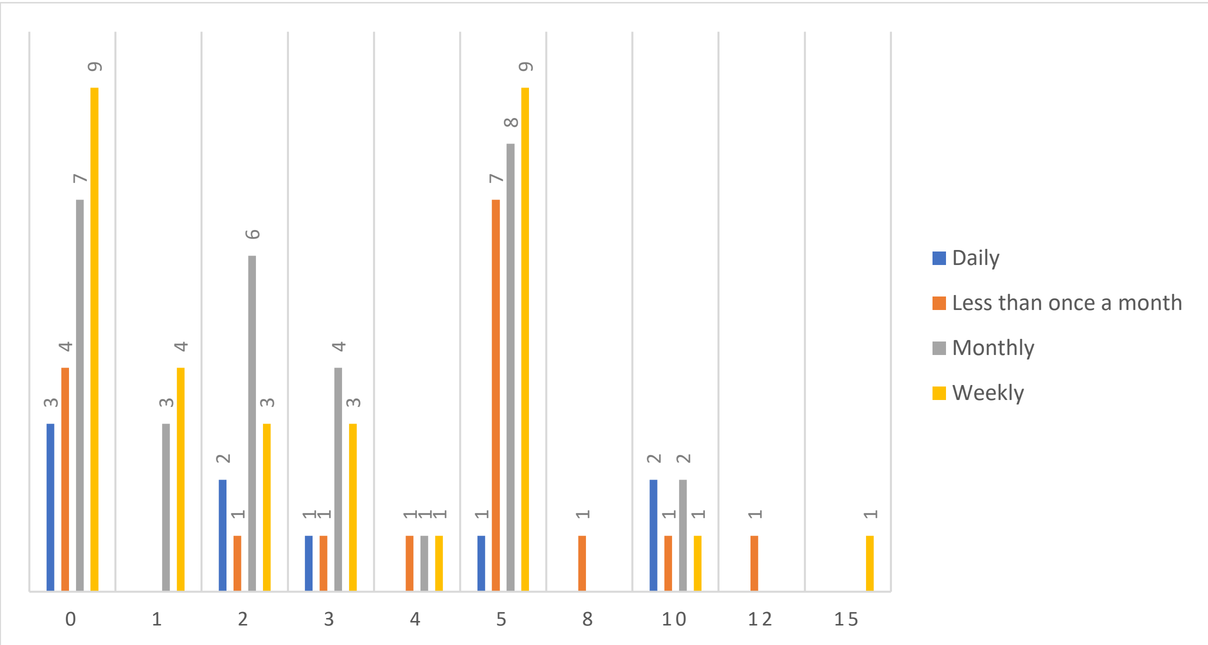
Appendix A

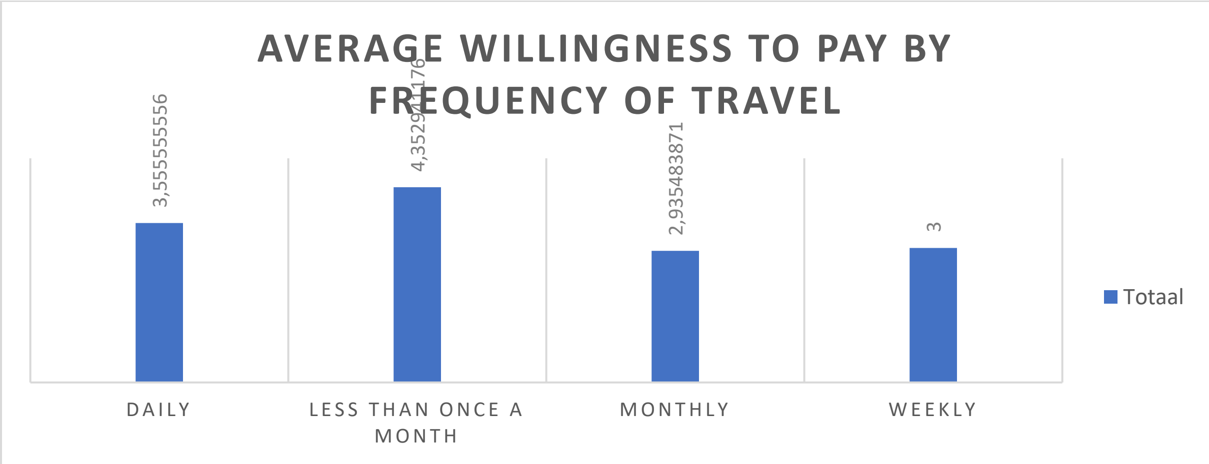
Appendix A will show some additional graphs which were discussed in 4.2 and 4.3.



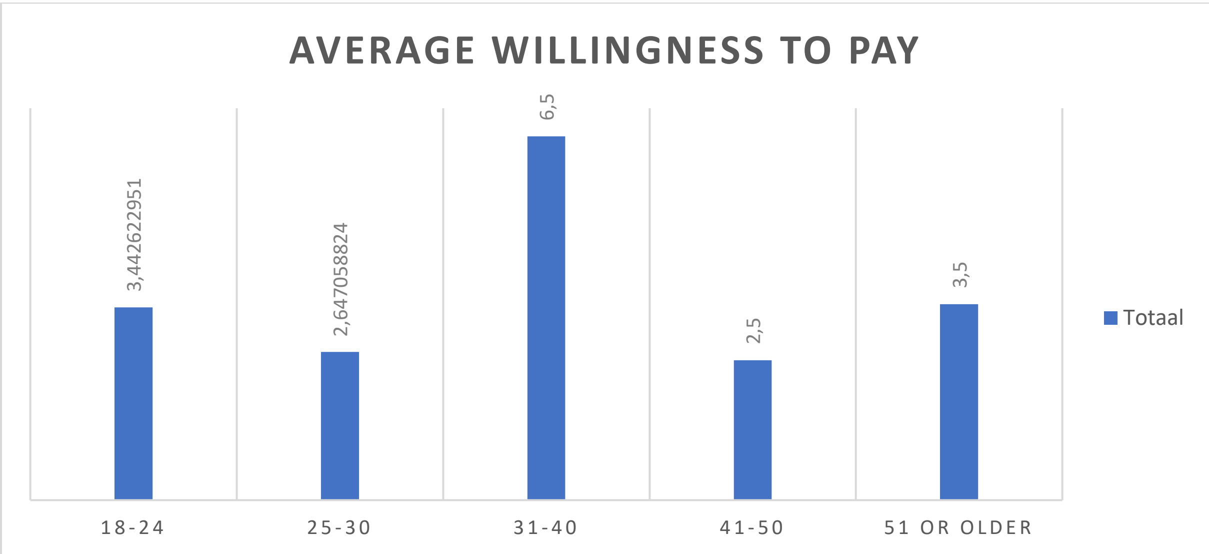
Graph 9. Average willingness to pay by residential location



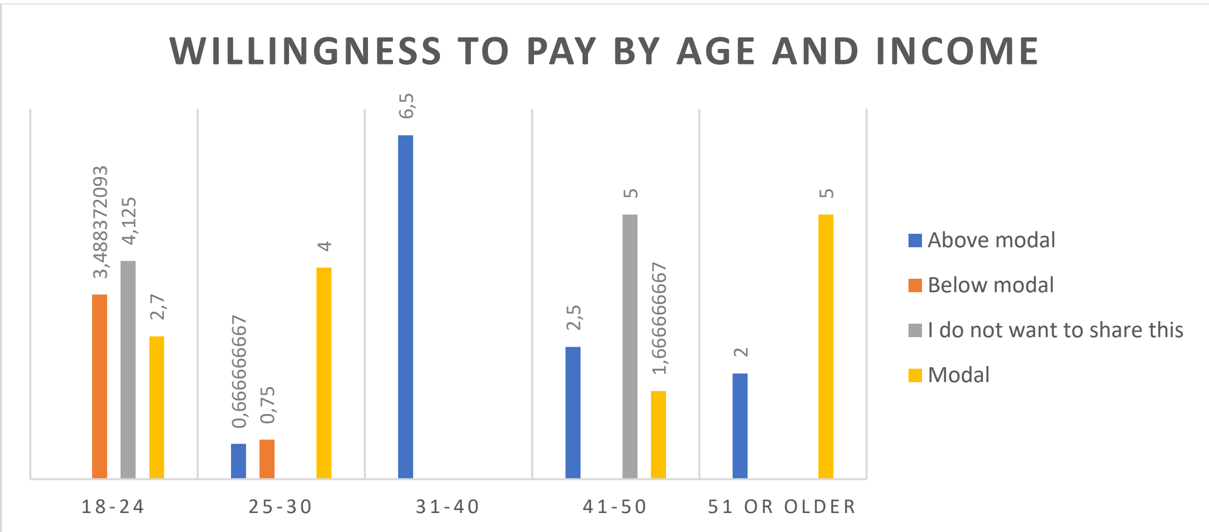
Graph 10. Willingness to pay by frequency of travel



Graph 11. Average willingness to pay by frequency of travel



Graph 12. Average willingness to pay by age.



Graph 13. Average willingness to pay by income and age