The effectiveness of Park & Ride facilities in reducing negative externalities from road transportation

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Abstract:

Park and Ride (P&R) facilities have received a lot of positive, as well as negative results in terms of reducing negative externalities from road transportation, depending on the country and the types of P&R's in use. This paper conducts a large qualitative research on previously studied effects of P&R facilities toward societal and private benefits, as well as dis-benefits, after which a framework for a successful P&R policy to reduce negative externalities is discussed. The main findings show that P&R facilities are able to reduce negative externalities, but only in certain cases. These cases are (1) where the facility has an origin function (it is a remote facility), (2) it is connected to a rail-based public transport system and (3) the unintended effects are minimized by pricing methods. Other types of P&R were found to increase the negative externalities overall, but contribute to other policies, such as user comfort and cost savings, as well as profitability. With these multiple viewpoints, this paper can be used as a benchmark for initiating a P&R policy that can successfully reduce negative externalities from road transportation.

I. Introduction

In today's densely urbanized world, road transportation causes multiple negative externalities that are becoming a severe problem for the welfare of the society. As the urban sprawl continues to rise, more and more people will live in cities and the number of people living in urban areas is expected to rise to 66% by 2050 (United Nations, 2014). This will increase the amount of traffic in cities, which in turn could have severe consequences for the local communities as they will suffer from the negative externalities of transportation. The three most common externalities relating to road transport are greenhouse gas emissions, noise and congestion (Lindsey, 2011). Individual drivers cause extra costs for other drivers through these externalities, by not paying for the full social marginal cost of driving (Lindsey, 2011). As an example of the extent of the problem, congestion is the most costly externality (Small & Verhoef, 2007), and it is estimated to have a cumulative cost of $4.4 trillion by 2030 for France, UK, Germany and the U.S combined (INRIX, 2016). Additionally, in the reports from Texas Transportation Institute, the researchers discovered that congestion levels have been rising significantly each year in the largest metropolitan areas (Federal Highway Administration, 2015). It is also said that congestion typically erodes a country's GDP by 1-3% (Williams & Hammond, 2016), which clearly shows that transportation related problems need to be managed efficiently. Eventually, congestion needs to be reduced by giving the urbanization process support and in order to solve the problem effectively, transport demand management (TDM) is needed. TDM refers to any actions aimed at influencing people's travel behaviour, so that alternative mobility options are used and/or congestion is reduced (Meyer, 1997). Moreover, the focus on making urbanization work would be more productive than trying to stop it (Spence, Clarke Annez, & Buckley, 2009).

Park & Ride (P&R) facilities have been used as a TDM tool since the 1930's already and at first, the tool received a lot of positive support for being effective against traffic and congestion problems (Noel, 1988). P&R facilities typically have two roles in TDM: firstly, it allows congestion to be reduced in the city and on the routes to the city where traffic jams occur and allows the use the public transport inside the city, where driving is normally more difficult. Secondly, it promotes the use of public transport instead of driving for the whole trip from home to the central business district (CBD) (Wang, Yang, & Lindsey, 2004). P&R facilities thus help to reduce congestion occurring from car use inside the CBD, as well as other negative externalities from transportation, such as pollution and energy consumption. Further, P&R facilities share the same goals as mentioned above, but can differ in the way they are implemented. There are three different location types and two different public transport (PT) modes that can be identified for P&R facilities. Firstly, a remote P&R is one that is located close to the origin of trips, thus around the residential areas of the suburbs (Mingardo, 2013). Secondly, a peripheral P&R is located close to the destination end of trips, thus around the edge of the CBD (Mingardo, 2013). Thirdly, a local P&R can be located anywhere in between the origin and the destination, somewhere close to the main travel routes, such as highways, and further away from residential areas (Mingardo, 2013). Next, the two PT types, which are used for the end part of the trip are rail-based and bus-based. The rail-based includes train, metro and tram options, while the bus-based is solely focusing on using busses. Moving on, many studies have been conducted toward the effects of P&R facilities with both positive and negative conclusions. In North America, P&R facilities have been found to be an effective tool against the negative externalities from transportation (Noel, 1988) (Bolger, Colquhoun, & Morral, 1992). It has found to accrue many private benefits to users, such as cost and time savings, as well as many societal benefits, namely the reduction in energy consumption, car pollution and traffic congestion (Noel, 1988). P&R facilities have also received many positive results elsewhere, namely in the UK and Scotland, but the studies conducted also show potential for improvements and growth (Wang, Yang, & Lindsey, 2004), (Meek, Ison, & Enoch, 2008), (Cairns, 1997). Next to the positive results from P&R, there are also many studies that show overall negative net effects toward reduced car use and congestion (Zijlstra, Vanoutrive, & Verhetsel, 2015), (Norhisham, Sidek, Beddu, Usman, Basri, & Katman, 2012), (Seik, 1997), (Meek, Ison, & Enoch, 2011), (Parkhurst, 1995), (Parkhurst, 2000), (Mingardo, 2013). Some of these papers introduce new unintended effects, which were not considered in the older studies, thus it raises the question whether P&R facilities can successfully achieve the desired goals, without causing new negative effects. In a meta-analysis of P&R facilities, it was concluded that many unintended effects do actually counter the first observed positive effects (Zijlstra, Vanoutrive, & Verhetsel, 2015). Next, also some models to optimize profits and minimize social costs from P&R facilities have been made (Li, Zhou, Zhang, & Zhang, 2012), (Horner & Groves, 2007), which gives a good foresight into how P&R facilities should be planned and implemented in the future. This paper aims to study these previous papers by analyzing the models used and conclusions made, both positive and negative, in order to answer the research question: **To what extent do P&R facilities help to reduce negative externalities from road transportation?**

Firstly, a considerable literature review is conducted, in which the different studies are assessed with regard to each societal and private benefit as well as dis-benefits from the P&R facilities. Next, a discussion of factors for a successful P&R ride policy is considered and explained in order for policy makers to achieve the full potential of P&R facilities. After, the paper is concluded with an overall opinion of the usefulness of P&R facilities and a detailed answer to the research question is given. The conclusion also includes limitations of this paper and suggests further research possibilities.

II. Existing Park & Ride facilities in the Netherlands

In addition to the above introduction, this chapter explains the types of P&R facilities and how they fit to the urban mobility policy. Firstly, P&R facilities are in use all around the world, though they can differ in multiple ways. P&R facilities typically have the role of supporting sustainable mobility policies by reducing negative externalities and supporting PT usage, as well as improving the mobility of the city. Moreover, some policies might differ in the objectives they try to achieve through the use of P&R, as some policies are implemented to maximize private benefits to its users, rather than focusing on making sustainability work. As mentioned above, there are three different location types, which are represented below as examples from different P&R types in the Netherlands. Each P&R facility is also priced differently, according to the city and other parking options available. Below are some examples of P&R facilities that are utilized in the Netherlands, with all the three different location types in use.

In Rotterdam, P&R facilities are spread around the city, mostly using peripheral facilities and some mixed facilities that act both as an origin and a destination function. All of them are connected to the metro or train network of the city, which allows the user to access any part of the city, as well as travel all the way to other cities. Parking fees are €2 on top of the PT fee used to travel to the city. Users that do not travel with the PT, will pay a normal fee of €0,5 per 18 minutes and a maximum of €17 per day (Gemeentje Rotterdam, 2016). This P&R requires a smart card for the PT in order to receive the lower parking fee. Utrecht also has a mix of different locations, but the pricing differs from that of Rotterdam. For this P&R, the user does not need a smart card, but instead pays a fee of €4,5, which includes up to four persons travel with the PT, regardless of how many people actually travel with the PT (The European Car Parking Guide, 2016). In Den Haag, mostly remote facilities are used, and only a few peripheral locations exist. The parking fees are used in the same way as in Rotterdam. The figures below represent each city and their P&R locations.

Figure 1: Rotterdam P&R locations (The European Car Parking Guide, 2016)

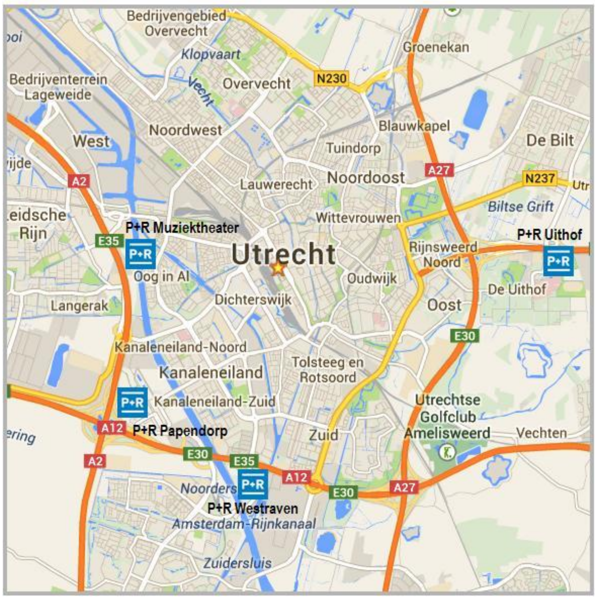

Figure 2: Utrecht P&R locations (The European Car Parking Guide, 2016)

Figure 3: Den Haag P&R locations (Gemeentje Den Haag, 2016)

III. Literature review on Park & Ride

To begin with, P&R facilities have clearly shown multiple effects benefiting the society in reducing negative externalities from road transportation. Most academic papers have focused on the effects toward main policy goals, namely reduction in energy consumption, reduction in vehicle kilometers travelled (VKT), reduction in traffic congestion, reduction in pollution and the increase in PT usage. Next to that, other papers have focused on a mathematical modelling approach to estimate the actual magnitude of effects toward VKT, pollution and energy consumption. Subsequently, some papers have also studied smaller societal benefiting effects from P&R, such as reduced parking demand in the CBD, reduced parking problems as well as an improved access to jobs. On top of the societal benefits, private benefits to P&R users have also been estimated in many papers, mainly including time and cost savings as well as a more comfortable travel experience from home to work. In contrast to the benefits that P&R facilities bring forward, there are also multiple dis-benefits identified, which according to some papers actually counter the positive effects and cause more harm than good for the society. The identified dis-benefits include breaking even with costs, traffic re-location and causing multiple unintended effects that harm the overall effect toward the main policy goals. This section will identify each above mentioned benefit and dis-benefit with regard to multiple academic papers in order to get an overview on the past and current effectiveness of P&R facilities towards reducing negative externalities.

A. Societal benefits

a. Reduced energy consumption

One of the first academic papers that studied overall effects of P&R facilities in the United States describes multiple benefits from P&R, the first one being reduced energy consumption. This is achieved by separating many single occupancy vehicles (SOV's) into high-occupancy vehicles (HOV's) and PT usage (Noel, 1988). Noel states that the energy savings per passenger mile are the largest, when the P&R is located close to the residential areas of the users, meaning a remote P&R that is further away, rather than closer to the CBD (Noel, 1988). On top of that, Noel also mentions that energy savings are the largest with rail-based P&R rather than bus-based, when nonpetroleum-based energy is used to transfer the users to the CBD (Noel, 1988). Next, in another study it was found that energy savings are less beneficial for users who travelled in high occupancy vehicles before the introduction of P&R facilities (US Environmental Protection Agency, 2012). This group of users benefit from the more convenient travel options, but do not contribute to energy savings as much as SOV users since they already used PT before the introduction of P&R facilities and are now attracted to use the car until the P&R (US Environmental Protection Agency, 2012). From this it can be seen that reduced energy consumption depends highly on where the P&R is located, which PT form is used for the end part of the trip and which modes of travel the users used before the introduction of the P&R facility. Following this further, a mathematical model was used to asses which location of P&R would contribute the most toward reducing social costs. In this study, social costs refer to time savings, as well as energy savings from switching transport modes (Wang, Yang, & Lindsey, 2004). They controlled for different levels of demand and the authors concluded that the further the location from the city centre, the more social cost savings are encountered (Wang;Yang;& Lindsey, 2004). This is consistent with the work from Noel (1988), in that energy savings are the largest when P&R facilities are located further out, because it intercepts the longest SOV travels. On the one hand, the study from Wang et al. (2004) offers important findings toward the fact that P&R can reduce energy consumption greatly. On the other hand, this model had multiple assumptions that might not hold in practice, thus lacking external validity.

Moving on, other studies from the UK have revealed that energy savings can be definitely observed from intercepting SOV users into busses (HOV) that go to the CBD in ideal conditions. However, from empirical studies, it was found that overall reductions in energy consumption are absent due to multiple unintended effects. Firstly, Parkhurst (1995) mentioned that the energy savings are absent due to additional trips made from public transport abstraction, as well as lower demand for busses that were used from the origin to the P&R, meaning the bus efficiency was lowered. Similarly, Meek et al. (2008) concluded that the energy savings are not apparent with bus-based P&R due to PT abstraction, trip generation and low load factors on the dedicated busses at P&R locations. These unintended effects are discussed in detail later on. Furthermore, a study by Bolger et al. (1992) found out that customers are more satisfied with rail-based P&R services than bus-based and also contribute more toward the goals of P&R with rail-based locations. Bolger et al. (1992) also mentioned that locations not too far from the CBD satisfied the most people in his surveys, thus these findings contradict the results from Noel (1988) and Wang et al. (2004), while they strengthen the view that bus-based P&R does not contribute to energy savings. As a final point, it can be seen that reduced energy consumption depends largely on the types of P&R used and thus the overall conclusions differ greatly.

b. Reduced traffic congestion

Notably, reduced traffic congestion is the main policy objective for P&R facilities as mentioned in a great variety of papers, in which studies have been conducted to evaluate the effect toward VKT. As mentioned above, Noel studied the effects around United States and mentioned car use reductions as the main goal for P&R facilities, measured in terms of VKT (Noel, 1988). As explained in the paper, if well located, the P&R can achieve major reductions in congestion (Noel, 1988). The author also mentioned that remote P&R showed the highest reduction in congestion levels, but that the results also depend on the existing levels of congestion experienced in the CBD as well as the remote areas (Noel, 1988). Next to Noel's work, Morrow (2005) studied the effects in the United States too and derived that car use and congestion in the CBD can be reduced, but the reduction is sensitive to the parking costs inside the CBD. Importantly, in the study by Meek et al. (2009), they enforced that traffic congestion and overall car use are different, as opposed to other papers, wherein they are seen as the same objectives. Meek et al. (2009) discussed that traffic congestion can be alleviated in the CBD, but overall car use is still not reduced, due to relocating traffic to areas of the P&R, as well as introducing new car trips from cheaper travel options. Their survey revealed that P&R facilities should be placed in smaller towns or cities that are economically buoyant and congestion is a problem, in these circumstances, major reductions can be seen in congestion levels (Meek;Ison;& Enoch, 2009). Further, in another paper from Meek et al. (2010), their surveys resulted in highly positive views upon the importance of mainly three policy goals, namely the reduction in congestion levels, the reduction of overall car use, and the reduction in car emissions (Meek;Ison;& Enoch, 2010). The reduction in congestion levels was rated as the most important policy goal, when all options were considered. The paper also showed that bus-based P&R is at least 70% effective in reducing car use, while the other 30% consist of worries about unintended effects, which are discussed in detail later on. Moving on, as Meek et al. (2009) mentioned, only in certain circumstances P&R can show major reductions in congestion. This is the same view as Parkhurst has, as he mentioned that only with 'package' policies reductions in congestion can be seen (Parkhurst, 1995). His results showed that congestion remained constant in the cities studied and he then suggested that traditional PT should be adapted to P&R locations in order for policy goals to be realised, with the help of local authorities (Parkhurst, 1995). Parkhurst also mentioned in a latter paper that traffic is not reduced, but rather re-located and thus P&R does not contribute well for its desired policy goals (Parkhurst, 2000). It is thus clearly seen that the main policy objective of P&R facilities, namely reduced traffic congestion, is very hard to achieve without causing additional negative effects somewhere else. Moreover, Cairns is of the same opinion as Parkhurst in that only some reductions in congestion are seen in the CBD, but the net effects of actual VKT travelled results to be increased due to relocated traffic (Cairns, 1997). Besides Meek et al., Parkhurst and Cairns, also Mingardo revealed interesting results from the Netherlands, in which he concluded that peripheral P&R locations do not contribute to a net reduction in VKT, but rather an increase, due to multiple unintended effects (Mingardo, 2013). On the contrast, he concluded that remote P&R locations did show overall reductions in VKT, because these locations do not cause as many unintended effects as a peripheral ones (Mingardo, 2013). Putting together, Mingardo's conclusions agree with Noel's in that remote locations do reduce traffic congestion, but also agree with Meek et al., Parkhurst and Cairns in that unintended effects can cause VKT to be larger than before the introduction of P&R. This discussion is of very large extent and thus requires more specific research on what exact policy packages can possibly alleviate unintended effects and make P&R contribute greatly toward its goals. As for now, the effects on congestion alleviation are highly dependent on the type of P&R location, the size of the city, the parking policies and the level of existing congestion in the city as well as the availability of help from local authorities in implementing such facilities.

c. Reduced automobile air pollution

In like manner of the two previously mentioned societal benefits, another important goal of P&R facilities is the reduction of automobile air pollution. Each previously discussed paper also analyzed the effect of P&R toward air pollution, with interesting results. Firstly, Noel concluded that a reduction in air pollution can be achieved in the CBD by users of P&R when significantly less cold starts are done in the CBD (Noel, 1988). He also mentioned that due to P&R users using electric rail-transit to the CBD, this is a further improvement of the air quality (Noel, 1988). Lower congestion also allows better operating speeds and less frequent speed changes, which contributes to less air pollution (Noel, 1988). Although this may be true for electric PT modes, other studies indicate that air pollution is not reduced, but rather re-located. These findings come from Parkhurst (2000) in the study of bus-based P&R services. He states that traffic is transferred from the CBD to the rural areas and with it, also air pollution, thus there is only a re-location of emissions (Parkhurst, 2000). It is important to note that this study was concentrated on bus based transit, which also contributes to air pollution, while rail-based, such as metros, do not. Be that as it may, Parkhurst did also mention that in cities where urban congestion and air-pollution are very acute, such a bus-based P&R facility can still bring forward great benefits, even though the pollution is just dispersed into different areas (Parkhurst, 2000). Moving on, as Morrow mentioned, air pollution reductions are sensitive to overall congestion reductions (Morrow, 2005) and thus are correlated similarly. Whenever congestion is managed to be reduced, so is air pollution. The two are highly similar, as reduced VKT also shows reduced CO2 emissions. Therefore, as previously mentioned by Mingardo, on the one hand, peripheral locations show additional vehicle emissions than before P&R, but on the other hand, remote locations show reductions in vehicle emissions (Mingardo, 2013). Similarly to Mingardo's conclusions, Ziljstra et al. (2015) also mentioned that remote locations contribute to more PT kilometers and reductions in VKT, as well as emissions

(Zijlstra;Vanoutrive;& Verhetsel, 2015). Whereas peripheral locations intercept the most cars travelling to the CBD, but do not contribute to more PT use nor reduced VKT. In fact, these locations in the urban fringe cause a reduction in PT use and an increase in VKT, thus also an increase in air pollution (Zijlstra;Vanoutrive;& Verhetsel, 2015). Generally speaking, each location discussed so far has its benefits and dis-benefits, but according to Meek et al. (2011), no P&R facility is actually fully beneficial, and thus he suggested alternative concepts, out of which the link and ride concept showed to be the best. This could significantly overcome the problems of traditional P&R facilities toward societal benefits, but with the price of high investments (Meek;Ison;& Enoch, 2011). This concept is discussed in more detail in the framework for an optimal P&R model. It is notable to say that reductions in air pollution and increases in PT use vary significantly depending on the type of P&R location (peripheral, remote or local), the type of PT used for the end part of the trip, as well as how well the CBD parking fees are connected with P&R fees. The current view is as if peripheral locations are only beneficial in the short run for acute congestion and air pollution problems, but in the long run, remote locations are the preferred and better choice toward reducing negative externalities.

d. Other societal benefits

So far the three most common policy objectives for P&R facilities have been explained, but it is important not to mention the other objectives that P&R still bring forward, even though these effects are not studied in all papers. Firstly, Noel mentioned that due to P&R resulting in less cars accessing the city centre, also less parking demand will be observed in that area (Noel, 1988). When parking demand decreases, also less construction and development work is needed in the CBD area, in which construction costs are the highest (Noel, 1988). This allows more financial benefits for the city and its developers, which can be further used for P&R improvements (Noel, 1988). Noel explicitly states that in order for this policy to be successful, each stakeholder (tenants, employees, property owners) must be involved in plans to discourage the use of SOV's (Noel, 1988). This means that every stakeholder in the city must take part in the P&R scheme in order for reduced parking demand to be observed. When so, the increased parking demand outside of the CBD, as well as newly introduced traffic at remote areas do not counter the benefits from urban parking construction cost savings. Following Noel's findings further, Morrow also states that fringe parking can reduce the parking demand in the urban core and thus lower the need for expensive urban parking development (Morrow, 2005). Additionally, Parkhurst also voiced a similar opinion, saying that traffic and parking capacity in the CBD is reduced, while accessibility is not (Parkhurst, 1995). Secondly, an improved transit patronage can also be seen as a societal benefit, since P&R improves the access to transit services, which gives support for the use of these fast and cost effective PT services (Noel, 1988). While transit patronage is increased, it allows for planning better services and lower fees, thus supporting more sustainable travelling and increasing user comfort (Noel, 1988). Thirdly, P&R locations also bring forward a better opportunity for ride sharing, which improves the accessibility to jobs in the urban and suburban areas (Noel, 1988). Fourthly, as P&R offers incentives not to drive to the city, this also reduces the parking problems occurring on the side of public roads or on private properties, thus also improving the usability and safety of roads inside the CBD (US Environmental Protection Agency, 2012). As seen from above, other societal benefits are also encountered on top of the three most common objectives, which altogether have a significant impact on the overall cost-benefit analysis of P&R facilities. It is therefore important to consider each possible benefit together, even the smallest ones, in order to reach sound and valid conclusions.

B. Private benefits

a) User Comfort

Besides observing possible societal benefits and the magnitude of their effects, P&R facilities bring forward multiple private benefits to their users too. Firstly, Noel (1988) recognized user comfort as one of the main private benefits accrued to users of P&R. This includes time savings for work trips, which are especially large with remote P&R locations as well as improved travel comfort (Noel, 1988). The time savings are occurred from the increased possibility of car or van pooling together with good PT connections to the urban core (Noel, 1988). The travel comfort relates to avoiding stress from travelling with a private car, namely avoiding traffic jams in congested areas, as well as not being responsible for any accidents on the way (Noel, 1988). Many users viewed the work trip during rush hours as an unpleasant chore (Noel, 1988), thus the comfort of being able to car-pool to the P&R and being able to do things while travelling in the PT, become great private benefits. Further, Bolger et al. (1992) also concluded that the rail based P&R ensures a faster and more convenient travel than a feeder bus service. Moreover, Meek et al. (2011) also noted that using P&R is seen as a higher quality travel option than others forms, thus making it relevant to take into account. Even though the users observe time savings and more comfort compared to the situation before P&R, they do not set a monetary value for these benefits, making them hard to observe and measure, thus they are not found as a benefit in all studies.

b) Cost savings

Moving on with private benefits, on top of user comfort, the users of P&R also capture cost savings, which can be very significant in the long run and are seen as the most important private benefit. According to Noel, when the private car is used less, the average yearly VKT is reduced, which correlates to a lower risk of accidents and lower insurance premiums (Noel, 1988). As the yearly driven distance is lowered, so is vehicle depreciation, which can be accounted for as a cost saving (Noel, 1988). Further, also vehicle maintenance costs and fuel expenditures are reduced, as less VKT are encountered (Noel, 1988). It is important to note that these savings only arise when actual VKT is reduced, which has been found to happen only with remote P&R locations. Peripheral locations actually increase the VKT and therefore do not contribute to private cost savings. Moving on, there is one clear private benefit that can be noticed from any P&R location, namely the reduction in travel related fees. These fees refer to lower parking costs at P&R sites as opposed to the CBD, as well as any savings in toll fees on roads leading to the CBD (Noel, 1988). Additionally, Meek et al. (2011) also said that time and monetary savings from using P&R are highly valued and are clear benefits to its users, but they also mentioned that there are acute problems due to unintended dis-benefits.

C. Dis-benefits and unintended effects

a) Break-even with costs

Of course, when assessing the effectiveness of P&R facilities, the possible dis-benefits need to be carefully accounted for in order to successfully implement a beneficial P&R policy. The first identified dis-benefit is the breaking even with costs, which has found to be very difficult according to various papers. Firstly, Noel comments that the users' out-of-pocket costs are the largest factor influencing their decision whether to use a P&R facility (Noel, 1988). Therefore the prices of parking are kept low or disregarded fully in P&R locations. This is to attract most users and through that, achieve a more socially beneficial outcome. Noel (1988) also adds that in most cases, through a well-organized and planned policy, the cost ineffectiveness can be still minimized. This is due to fewer investments needed in the CBD parking areas, which can instead be used for P&R, as earlier mentioned. Additionally, also Wang et al. (2004) noted that the most profit maximizing location for a P&R is a peripheral one, which usually captures the most demand, and therefore cost ineffectiveness can be minimized. On the one hand, peripheral locations do not contribute to the desired social benefit, but they allow achieving profits and the most user comfort. Whereas on the other hand, remote locations benefit the society the most in terms of minimizing negative externalities, but they do not capture as much revenue as peripheral ones (Wang, Yang, & Lindsey, 2004). Wang et al. (2004) conclude that for remote locations to break even, financial support is needed from the government. On top of Wang et al. (2004) and Noel (1988), also Cairns (1997) had worries of how to break-even with P&R facilities. In his opinion the largest problem with implementing a P&R facility is that the capital investments are considerable and often out of reach for smaller authorities to implement (Cairns, 1997). His view is in line with that of Wang et al. (2004), saying that without any government intervention in the implementing process, a socially beneficial P&R cannot survive. Subsequently, Parkhurst (1995) also agrees that subsidies are needed, as costs of building such a facility are very high, and high parking fees discourage the use. It is thus clear to conclude that in cities, where budgets are tight for governments, it is hard to implement a profitable as well as a socially beneficial P&R facility. Due to the tough break-even opportunities, implementing a P&R needs very accurate planning and should only be used in cities that can afford such investments and have acute traffic problems.

b) Traffic re-location

Another dis-benefit that was mentioned as to why negative externalities are not reduced in the way that was planned for is the re-location of traffic. Noel stated multiple societal and private benefits that are possible to achieve when well planned, but he also mentioned that due to less cars on highways as a result of P&R, new traffic might be induced in areas not affected before the P&R (Noel, 1988). He states that it is possible that new congestion and air pollution problems might arise around the area where the

P&R is located, as many drivers are intercepted from highways into this area (Noel, 1988). This new congestion typically arises around interchange ramps of highways and access routes to the P&R. Moreover, Parkhurst (1995) studied the effect of traffic re-location in more detail and concluded that P&R facilities do create extra travel kilometers for some users, as well as launch some new traffic from users who used PT before the P&R for the whole trip. In a latter paper, he mentioned that there are three reasons for increased travel outside of the urban area, namely the drivers intercepted detouring to the P&R site, new drivers that used PT before and drivers making additional trips (Parkhurst, 2000). All three causes for increased VKT can be seen as separate unintended effects, and thus are explained in the next paragraph. With this in mind, it can be said that P&R facilities are beneficial in reducing VKT, only if new traffic is not created outside of the city due to having P&R locations. It is important to consider the possible additional effects that P&R facilities can bring forward in order for negative externalities to be reduced. Cairns also suggested that traffic is moved from the center and highways to rural areas of the city, therefore not reducing traffic, but re-locating it with no effect to overall VKT reductions (Cairns, 1997). Meek et al. (2009) also agreed that P&R might cause a redistribution of traffic, rather than a reduction, since the generalized cost of travel is lower with the P&R than it was before. Further, Meek et al. (2011) introduced other concepts that could be used rather than P&R, in order to minimize the aforementioned increases in VKT. They explained five concepts, namely, the demand led concept, the integrated concept, the hub & spoke concept, the remote site concept and the link and ride concept (Meek, Ison, & Enoch, 2011). From these five concepts, they concluded that the link and ride concept is the most beneficial in terms of reducing negative externalities (Meek, Ison, & Enoch, 2011). In the link and ride concept, small interchange facilities are placed close to the main corridors of travel, which can be easily accessed even by walking (Meek, Ison, & Enoch, 2011). This concept is different from the current P&R and thus would require high capital investments to implement. Meek et al. (2011) believe it can be a feasible long term solution to replace P&R facilities. As a final point, it is essential to note the importance of assessing the possibility of traffic redistribution before implementing a P&R, as well as the possibility of other concepts instead of the P&R to address negative externality reductions most effectively.

c) Unintended effects of P&R

Going back to traffic re-location, as Parkhurst (2000) mentioned, there are three reasons for traffic re-location and each of them can be seen as separate unintended effects, which all lead to the same result. Firstly, drivers detour from the normal routes just to reach the P&R for cheaper and more comfortable travel (Parkhurst, 2000). This creates extra kilometers travelled, for example, if the user lives close to the urban centre, but drives toward remote areas to use P&R due to a cheaper travel option. Secondly, some people used to travel to the CBD only with PT, but now drive to the P&R and take the PT from there (Parkhurst, 2000). This unintended effect is called PT abstraction, and it creates new VKT, again due to a cheaper and easier travel option. Thirdly, some people might make additional trips, since the generalized cost of travel is lowered (Parkhurst, 2000). Putting the three together, each unintended effect causes an increase in car use outside of the urban area, which might in fact increase car dependence too, as the generalized costs are lowered and car use is made easier (Parkhurst, 2000). Moving on, Mingardo agreed with Parkhurst (2000) that multiple unintended effects are present, which make the overall net effect negative for peripheral locations. He also introduced two new unintended effects observed in the Netherlands, namely the abstraction from bike as well as park and walk users (Mingardo, 2013). Abstraction from bike refers to users that biked to the centre before, but now are inclined to use their car to the P&R and PT to the centre (Mingardo, 2013). Park and walk refers to situations in which a person uses the parking facility of the P&R, but does not use the PT to the centre, since their destination is in walking distance (Mingardo, 2013). These two effects create new traffic and also more congestion around the P&R, thus they should be considered carefully too. Mingardo (2013) offers a possible solution to minimize these unintended effects, which is adding a small parking fee to the P&R sites. This would discourage bike and PT abstraction, but at the same time, it might induce some users into switching back to driving all the way to the CBD or motivate users to search parking options around the P&R (Mingardo, 2013). More evidence would be needed to evaluate the actual effect of a P&R user fee, but should be kept in mind as a possible solution for unintended effects. Next, there are also other smaller effects that affect the overall effectiveness of P&R negatively. In the study from Meek et al. (2008) it was found that energy savings occur from further out P&R facilities, but he also stated that usually the suitable location for such remote facilities are in or around a greenbelt area, which then offsets other environmental reductions. Cairns (1997) also mentioned that some existing bus and train services have inquired expenses after the P&R facility was carried out. Furthermore, some experiences of P&R facilities from Singapore and Malaysia suggest that the effects are negative due to a lack of use. Seik (1997) mentioned that in Singapore, despite improving results, the P&R scheme lacks users and therefore the positive effects are not observed. He suggested that together with cordon pricing, the scheme might receive more attention and through that, also more positive effects (Seik, 1997). Next, According to Norhisham et al. (2012), surveys from Malaysia showed that most people are unaware of the benefits of P&R, and thus do not use it to its potential. They suggested that advertising the P&R and its benefits should lead to more usage, and thus possibly reach more positive results. As can be seen, many unintended effects have arisen in multiple studies, which clearly show that P&R schemes are not perfect and need very careful planning in order to be beneficial toward the society. The table below shows each paper that was used in the literature review with their main findings to give a better overview of the benefits and dis-benefits of P&R.

Topic of Paper	**Author**	**Year**	**Main Outcome**
Rail based P&R	Bolger et al.	1992	**Positive:** Reduced energy consumption, faster and more convenient travel option for its users
Scotland P&R	Cairns et al.	1997	**Positive:** reduced traffic congestion **Negative:** Break-even with costs and traffic relocation
Multiobjective optimization of P&R	Farhana et al.	2008	**Positive:** Multi-objective policy is possible: covering as much potential demand as possible, locating park-and-ride facilities as close as possible to major roadways, and siting such facilities in the context of an existing system **Negative:** Does not account for unintended effects
Strategies for optimal P&R locations	Horner et al.	2007	**Positive:** VKT reductions possible up to 52.52% with a combination of three remote and two local facilities. A mixture of policy objectives should be used in accordance to the network flow of existing transport systems **Negative:** Does not account for unintended effects
Bilevel	Fan et al.	2014	**Positive:** Social welfare maximizing

Programming Model for Locating Park-and-Ride Facilities			policies are achievable, where the total consumer and producer surplus is maximized and leads to a win-win situation **Negative:** Does not account for unintended effects
Bus based P&R – evaluation	Meek et al.	2008	**Positive:** Overall view is positive in terms of reducing VKT, congestion and emissions **Negative:** Increased VKT by some users and some evidence of unintended effects
Bus based P&R - Stakeholder perspectives	Meek et al.	2009	**Positive:** reduced CBD congestion **Negative:** Relocation of traffic
Bus based P&R – Local authority attitudes	Meek et al.	2010	**Positive:** reduced congestion, car use, pollution **Negative:** unintended effects
Alternative concepts to P&R	Meek et al.	2011	**Negative:** significant increase in VKT from P&R **Positive:** Link and Ride concept
Rail based P&R	Mingardo	2013	**Positive:** Remote facilities show decrease in VKT **Negative:** Peripheral facilities show increase in VKT and new unintended effects are introduced
Fringe Parking	Morrow	2005	**Positive:** Can reduce congestion, VKT, pollution and parking development in CBD **Negative:** Users are sensitive to fringe parking lot costs
P&R overview	Noel	1988	**Positive:** Reduced energy consumption, congestion, pollution, CBD parking development needs as well as increased travel comfort and cost savings **Negative:** Breaking even with costs and traffic transferral
Awareness and level of P&R use	Norhisham	2012	**Positive:** Can reduce congestion, pollution and VKT **Negative:** Awareness and use of P&R is not sufficient for overall effects to be significant
P&R increasing traffic	Parkhurst	1995	**Positive:** Reduced energy consumption, congestion, pollution, CBD parking development needs as well as increased travel comfort and cost savings **Negative:** Mostly traffic relocation and introducing new traffic which result in a negative overall effect toward VKT
P&R influence on	Parkhurst	2000	**Positive:** reduced CBD congestion and

traffic			VKT **Negative:** Detouring, PT abstraction and additional trips all contribute to overall increase in VKT
Effectiveness of P&R	Parkhurst	2014	**Positive:** Supports policies to enhance user comfort and dependence on the use of the facility. Only some remote locations support sustainability objectives **Negative:** No clear evidence to enhance sustainability objectives, as unintended effects overcome the benefits
P&R experiences	Seik	1997	**Positive:** Improving results to reduce congestion and VKT **Negative:** Low level of usage results in non-significant positive effects
P&R / Fringe Parking	US Environmental Protection Agency	2016	**Positive:** Reduced energy consumption, congestion, pollution, CBD parking development needs and private costs **Negative:** Breaking even with costs, traffic transferral
Locating and Pricing P&R facilities	Wang et al.	2004	**Positive:** Remote locations minimize social costs and show most positive social benefits **Negative:** Breaking even with costs
Meta-analysis of P&R effectiveness	Zijlstra et al.	2015	**Positive:** Remote facilities increase PT use and decrease overall VKT, also accessibility to PT is increased **Negative:** Peripheral locations reduce PT use and increase overall VKT, doubts that P&R can be a sustainable option

Table 1: Main findings of the literature review

IV. Discussion of factors for a successful Park & Ride policy

Seeing that P&R facilities have been studied in multiple countries and cases with both positive and negative conclusions, it is important to consider a framework for a successful P&R policy, aiming to reduce negative externalities from road transportation. As seen from the above literature review, on the one hand P&R facilities are not always successful in reducing negative externalities, as some facilities show overall negative effects. But on the other hand, there are multiple successful P&R facilities, which clearly show positive effects in reducing negative externalities. This framework for a successful P&R policy will examine the most crucial factors that have made each P&R either successful or not in order to introduce a combination of factors that are needed or must be disregarded for a P&R policy to succeed in reducing negative externalities from transportation. Some optimization models have already been created, mainly focusing on social welfare maximization (Fan, Khan, Ma, & Jiang, 2014), covering as much demand, locating P&R facilities as close to major roadways as possible, and incorporating facilities with existing transport systems (Farhana & Murray, 2008) as well as locating facilities according to the network flow of the city (Horner & Groves, 2007). Each model is very useful when considering these objectives, but they lack the consideration of unintended effects, which in many cases show to be very necessary for a successful P&R policy. This framework will solely focus on the policy objective to reduce negative externalities, namely energy consumption, congestion, VKT and air-pollution. The study of literature showed that the most crucial factors are the location, PT type and availability, investment costs and lot pricing, minimization of unintended effects and the awareness of P&R. These factors will be evaluated further and the best combination of each factor in terms of reducing negative externalities is presented for policy makers to be able to consider whether P&R can be a successful TDM measure in the city in question. The Figure below represents to three most important factors to reduce negative externalities of road transportation.

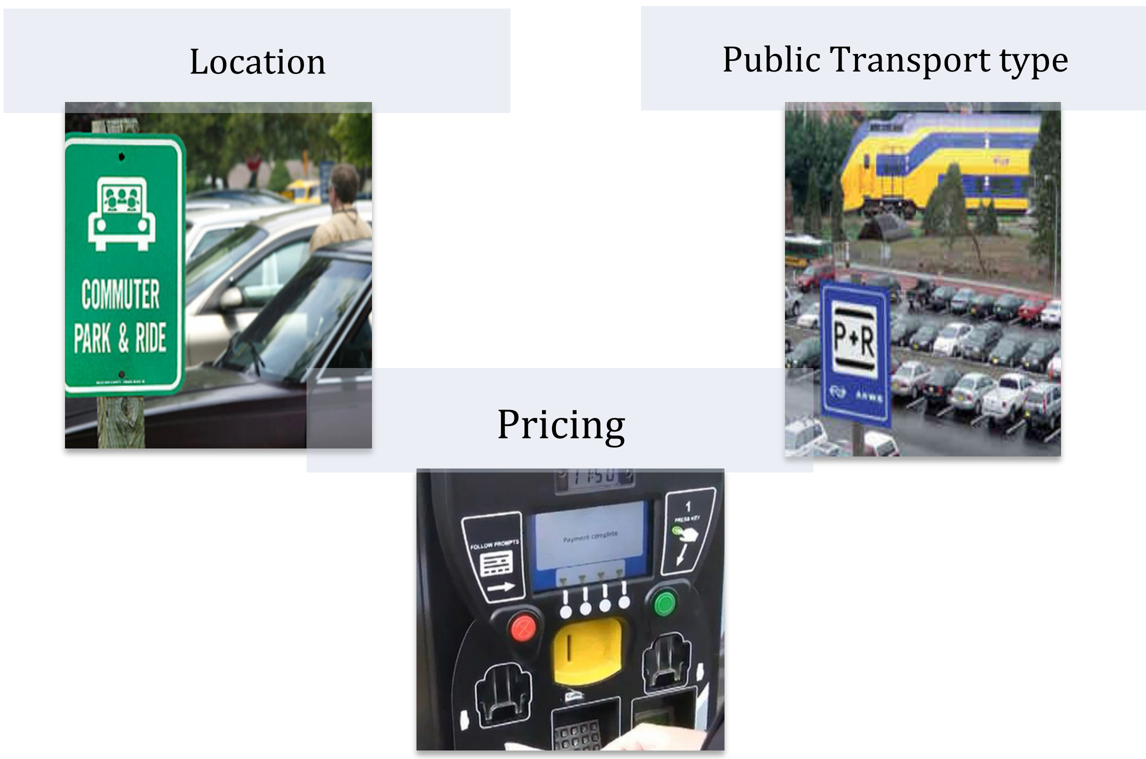

Figure 4: Framework for a successful P&R in reducing negative externalities

A. Location

To begin with, the first crucial factor that has shown clear differences in the successfulness of P&R facilities in reducing negative externalities is the location of the site. As mentioned above, there are three different location types considered, namely peripheral, local or remote sites. From the study of literature, it is clearly seen that remote locations show a positive net effect in reducing congestion and VKT in all academic papers that studied the effect, as well as promote the use of PT, as Zijlstra et al. (2015) mentioned in the meta-analysis. Remote locations were also found to reduce vehicle emission the most out of all cases (Mingardo, 2013). Thus, when looking at all the social benefits, remote locations offer the largest positive effects. Moreover, remote locations offer the highest time savings and user comfort (Noel, 1988), thus also the largest private savings. Only one paper mentioned that peripheral locations satisfy the most people from surveys in terms of comfort (Bolger, Colquhoun, & Morral, 1992), but this might be due to the higher demand and thus higher survey rate than in remote locations. The only problem with remote locations is the breaking even with costs, because these locations usually do not capture enough demand to be profitable on their own. Peripheral locations on the other hand capture the most demand and thus can be profitable, which allows breaking even with costs. Other than that, the results for peripheral locations showed negative net effects in all papers studied, as VKT is increased and the use of PT is decreased in some cases. Further, Horner & Groves (2007) concluded in their optimization paper, that a combination of three remote sites and two peripheral sites lead to the largest possible VKT reductions. They found that different sectors of a city have different demands, and thus some sectors need a peripheral location, since not many people live in the remote areas and the busy remote areas should have a remote location. This paper did not control for unintended effects that might arise as explained before, thus the optimization solution might not hold as planned. It can be thus concluded that remote locations should be considered as the most successful facility when reducing negative externalities is the main policy objective. Even though remote locations are the optimal choice as a location, it is important to make sure no greenbelt areas are damaged when implementing them into a city.

B. Public Transport type

Moving on, the second crucial factor that has been identified in the review of literature is the PT type. Many papers have analysed the effect on energy consumption, pollution and user comfort from different PT types available to use from the P&R. The results indicate that energy savings are the largest with rail-based P&R rather than bus-based (Noel, 1988) (Bolger, Colquhoun, & Morral, 1992). Also, due to P&R users using electric rail-transit to the CBD, this is a further improvement of the air quality (Noel, 1988). Further, customers are also more satisfied with rail-based P&R services than bus-based, as well as they offer a faster and more convenient travel than bus (Bolger, Colquhoun, & Morral, 1992). Next, some bus based P&R has shown to lower the bus efficiency and low load factors result in negative effects overall (Meek, Ison, & Enoch, 2008). Putting these findings together, it can be seen that rail based P&R contributes better toward reducing negative externalities, thus P&R sites should be implemented in cities which have an existing metro or train connection to the CBD, instead of using busses.

C. Pricing and minimization of unintended effects

Besides the location and PT type, also the pricing of a P&R lot affect its effectiveness to reduce negative externalities. It is said that the users' out-of-pocket costs are the largest factor influencing their decision whether to use a P&R facility (Noel, 1988), so in order to attract users, the parking costs must be kept low or disregarded fully. Morrow (2005) commented that the amount of demand is dependent on the relative pricing between CBD and the P&R. As prices increase in the CBD or decrease at P&R lots, more demand is created and vice versa (Morrow, 2005). In some modelling papers, like Wang et al. (2004), pricing of P&R was set to zero, which resulted in a great success of the facilities. From this it can be seen that parking fees should be optimally set very low, in order to capture enough demand and through that, effectively reduce negative externalities. Next, since parking fees are very low and demand is high, this has caused unintended effects of PT and bike abstraction, detouring drivers, additional trips made and Park & Walk. Due to the unintended effects, traffic re-location happens and new congestion and air pollution problems might arise around the area where the P&R is located. Moreover, each unintended effect might in fact increase car dependence too, as the generalized costs are lowered and car use is made easier (Parkhurst, 2000). This shows that these unintended effects need to be minimized, if effectiveness to reduce negative externalities is the main policy goal. Mingardo (2013) offered a possible solution to minimize these unintended effects, which is adding a small parking fee to the P&R sites. It is important to keep in mind that this parking fee must still be low enough to not discourage users to drive all the way again, thus it should be much cheaper than that in the CBD. A solution to minimize the effect of Park & Walk users would also be to set a high parking fee for users that do not use the PT for the end part of their trip, and a large discount for users that used the PT. This would make the fee small to normal users and high to the people who misuse the facility. The Kralingse Zoom P&R facility in Rotterdam utilises this type of pricing, where the user that travels with PT smart card will pay a €2 parking fee and the PT fee and users that do not travel with the PT, will pay a normal fee of €0.5 per 18minutes and a maximum of €17 per day (Gemeentje Rotterdam, 2016). Moreover, the awareness of P&R facilities plays a huge role in the decision to use it, as some experiences of P&R facilities from Singapore and Malaysia suggest that the effects are negative due to a lack of use. Thus, advertising the P&R and its benefits should lead to more usage, and thus possibly reach more positive results. Together in the advertisement, parking fees should be mentioned, so that users are aware of the possibility of monetary savings from the use of P&R too. In brief, a successful P&R facility to reduce negative externalities should have considerably lower parking fees than in the CBD, but still keep a small fee so that unintended effects of PT and bike abstraction can be avoided and that drivers are still attracted to use it.

V. Conclusion

In conclusion, this paper aimed to analyze the effectiveness of Park and Ride facilities in reducing negative externalities from road transportation by studying previous literature from many different countries. After this, a framework of the most crucial factors needed to achieve reductions in externalities was presented. Firstly, the use of P&R facilities in the urban mobility policy was explained and some examples from the Netherlands were presented. After, each societal and private benefit, as well as dis-benefit from the use of P&R was evaluated from multiple theoretical and empirical academic papers. In detail, this qualitative research covered the effect toward energy consumption, congestion, air pollution, CBD parking demand, CBD parking problems as well as the access to jobs. On top of that, it also covered the effect toward user comfort and travel costs as well as the breaking even possibilities, traffic re-location and other unintended effects, including detouring, PT abstraction and making additional trips. Next, a framework for a successful P&R policy aimed at reducing negative externalities from road transportation was introduced according to the results obtained from the study of multiple academic papers. From the study of literature, it was seen that remote P&R facilities do reduce all of the previously mentioned externalities, as well as improve the user comfort and cut travel costs, whereas peripheral P&R facilities were found to lack the capability of reducing those externalities. This was due to it causing multiple unintended effects and thus increasing the overall level of those externalities. Peripheral facilities do on the other hand also contribute to user comfort and cost savings, which is why they are still considered useful. It was also clear that rail-based P&R facilities contribute the most toward reducing negative externalities, as well as improve the user comfort, whereas bus-based facilities did not. Further, the unintended effects caused overall negative results in multiple studies, which can be minimized by the use of pricing, but more evidence is needed to fully say this holds in every case. Ultimately, from the previously mentioned factors that affect the successfulness of a sustainable P&R policy, it can be said that the P&R facilities should be located in remote areas, they should be connected to rail-based PT and they should include a large fee for parking, with a possibility to a large discount if PT was used. Other location and PT types do not successfully reduce negative externalities, but rather contribute toward other policies, such as profitability and improving the users' access and comfort. It can be then said that P&R facilities differ in the extent they reduce negative externalities, depending on the three aspects of the facility, namely location, PT type and pricing. Overall, P&R facilities do not reduce negative externalities to a large extent, but can do so, when the three aspects are used together. Thus the research question: **To what extent do P&R facilities help to reduce negative externalities from road transportation?** is answered.

Further, this paper has multiple limitations to it, which limit the significance of the results. Firstly, the effect of P&R facilities to reduce negative externalities depends on the city it is utilised in, and thus the results from multiple papers differ even though the facilities were used in the same way. For example, in Singapore and Malaysia, the P&R facilities were used in like manner with the Netherlands, but the results differed due to the different awareness levels about P&R in those countries, thus making it hard to evaluate the effectiveness of such P&R's. Secondly, pricing differs in most cities, as well as the ownership of the P&R facilities, thus making it difficult to assess the decision making process, which affects the breaking even possibilities, as well as the level to which pricing can be used to minimize unintended effects. In order to overcome these limitations, detailed information of specific P&R facilities, such as the ownership as well as policies behind each P&R need to be known. This requires interviewing those specific parties involved, thus only allowing focusing on a certain city, but not to get an overall picture of the effectiveness of P&R's. For further research, specific questionnaires should be conducted for specific P&R's to assess the different effectiveness of each possible location type, PT type and pricing system. This would allow the correct policies to be placed in cities that are in acute need of travel demand management, making the effectiveness of P&R as successful as possible.

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