EJTIR

Issue 15(4), 2015
pp. 597-612
ISSN: 1567-7141
tlo.tbm.tudelft.nl/ejtir

A meta-analysis of the effectiveness of park-and-ride facilities

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In this paper we present a meta-analysis of Park-and-Ride (P+R) facilities. Our goal is to identify the determinants of effective sites and to assess their contribution with respect to various transport policy objectives. An effective facility predominantly attracts target group users, i.e. users who without the P+R would use the car for the entire journey. Our meta-analysis is based on the results of 40 studies and a total of 180 evaluated P+R sites, mainly from European countries. Linear regression analysis is used to estimate the influence of seven explanatory variables. Public transport mode and point of intercept are identified as the most important factors. The share of commuters, weekday or weekend use and the number of parking spaces have a significant, but limited influence on the effectiveness. The statistics from the dataset and the linear regression results are used to calculate the effects on three main policy objectives. Our analysis indicates that P+R facilities with a destination function intercept about 47 cars per 100 parking spaces provided. Public transport use drops slightly and private car kilometres (to reach the P+R) increase. Facilities with an origin function intercept about 21 cars per 100 parking spaces, private car kilometres are slightly reduced and kilometres in public transport use increases. Our results are useful to assess the impact of future P+R interventions and to formulate regional P+R policies.

Keywords: *commuting, intermodal passenger travel, meta-analysis, park-and-ride, public transport, urban mobility*

1. Park-and-Ride as a transport planning tool

Many West-European cities and regions are currently involved in the design, implementation and exploitation of Park-and-Ride (P+R) schemes (Runkel, 1993; Dijk and Montalvo, 2011). For example, the region of Paris has about 550 facilities providing over 100,000 parking places (STIF, 2009). In the Munich region we observe more than 26,000 users of P+R sites on a daily basis (Meek et al., 2008). In the Netherlands there are 446 facilities providing 70,600 parking spaces (KpVV, 2013). The region of Antwerp in Belgium already has tens of P+R sites, meanwhile further expansion is at hand, with among others the development of a new P+R facility with 1,500 parking spaces (Dickins, 1991; Jacobs and Borret, 2013).

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P+R schemes are implemented in support of a range of policy goals. Urban fringe lots and other types are often promoted as a measure to reduce the number of cars entering a city. This, in turn, has the potential to lower congestion levels and improve urban accessibility. Since most P+R facilities are located outside a city, it is hoped that P+R schemes lead to a reduction in vehicle kilometres travelled (VKT), pollution and parking pressure in city centres. Furthermore, P+R is regarded as a way to promote public transport (PT) use (Hamer, 2010; Runkel, 1993). Apart from these goals, the construction of facilities is justified as a means of meeting demand (Runkel, 1993). Evaluations of the effectiveness of P+R show divergent results. For instance, regarding the changes in VKT, Rutherford and Wellander (1986), Muconsult (2000) and Atkins Planning Consultants (WSA, 1998) are rather positive, they report reductions ranging from 1 up to 16 kilometres per P+R traveller, while Wiseman et al. (2012) and Meek (2010) both state there is an increase in the VKT of 5 to 6 kilometres per P+R user.

In order to make a sound judgement on the transport-related effects of a P+R facility one has to overcome two obstacles. On the one hand, the typical P+R facility does not exist. Therefore we need to categorize different types of P+R facilities. On the other hand, many existing studies and reviews on the effect of P+R schemes have a limited scope. They cover only one P+R site, one type of P+R facility or a certain policy objective. Current knowledge regarding P+R effects is fragmented. By systematically categorizing P+R facilities and combining existing studies we hope to provide more general conclusions regarding the effects of P+R. The aim of our research is to examine the effectiveness of P+R facilities in contributing to the most relevant policy goals. These goals are: reducing the number of cars entering the city, promoting PT use, and reducing VKT (and related emissions).

The structure of the paper is as follows. We start with a brief literature review where we discuss various effects and types of P+R facilities. Thereafter, we outline the method used. Data gathering, processing and analysis are covered in this part. Next, the results are presented in two steps. In the first step we provide and discuss the results from the regression analyses we performed in order to estimate the share of target group users on various sites. In the second step we estimate the effects on the reduction of cars entering the city and changes in VKT and PT use. We finish with a discussion and the main conclusions.

2. Literature review

P+R is promoted as *an alternative to car use from door to door*. The reason why a P+R scheme works in theory is because travellers shift from car use to a combination of car and public transport. As a result the PT patronage will rise, VKT will drop and the number of cars entering the city is successfully reduced. This in turn has positive effect on parking pressures, congestion and emissions. The travellers who use the P+R site as intended by policy makers are called *'target group users'* in this paper.

In practice we observe several *unintended effects*. [1] Not all users on the P+R facility did or would travel all the way with their car without the P+R. Some travellers used to walk or cycle to the PT node, others used a bus as feeder mode (e.g. Mingardo, 2008; Wiseman et al, 2012). When these users switch to a combination of car and PT there are more VKT, instead of less. [2] We also observe typical P+R users on the site (Becher et al., 1989; Parkhurst and Stokes, 1994). These people used another P+R facility before the new one became available, or parked their cars near the new facility in an adjacent street. Up to one third of the total P+R users can be P+R veterans. In these cases the transport effects are probably limited. The new facility is a institutionalisation of 'informal' P+R behaviour (Pickett and Gray, 1993). [3] The P+R facility might be used by non-P+R travellers, namely people that use the facility to park their car, truck or mobile home on the P+R facility, without any intention to use PT (TfL, 2010; Lindström Olsson, 2003). Some people on the P+R facility are not even aware they park on a P+R facility (Mingardo, 2003). The highest share of non-P+R travellers we encountered was more than 80% of the parked cars on the site (Mingardo, 2009). This affects the availability of parking spaces for real P+R users. Moreover, since the effectiveness of most P+R facilities is assessed by counting cars on the facility, this creates a bias in policy evaluations. The P+R might be popular because of its location, the limited costs or on site surveillance and facilities. [4] To reach the P+R facility many users make a detour, in some cases the total vehicle kilometres travelled are even higher than if the one had just driven directly to the actual destination (Parkhurst, 2000; Rutherford and Wellander, 1986). [5] P+R facilities can create new opportunities and lower transport costs. As a consequence new trips might appear. Many users state they would not have made the journey without the P+R facility (WSA, 1998). Moreover, the success of the P+R can be self-undermining as the stimuli for P+R use are mitigated by P+R use itself. Research shows that parking pressures and congestion are main reasons to travel via P+R (Becher et al., 1989; Guillaume-Gentil et al., 2004; Meek, 2010; MuConsult, 2000). If a system of the P+R schemes turns out to be successful, parking pressure and congestion levels will drop and subsequently this might attract new or former car drivers. [6] In order to make a P+R scheme competitive often high-frequency bus services are offered, while a bus has a more negative impact on the environment than a regular car (Parkhurst, 2000). All in all we can conclude that, on the one hand, the concept of P+R is straightforward and rather enticing, and on the other hand, P+R practices are rather complex.

There are additional reasons why the P+R facility can be controversial among stakeholders. Urban planners state that the construction of large-scale car parks near public transport nodes conflicts with the goals of transit-oriented development. The facilities located at the urban fringe have a possible negative impact on the countryside as the boundary between urban and rural land becomes blurred. This is a typical concern in the UK where various groups are involved in the preservation of the countryside and where P+R fringe lots are common (Meek et al., 2008). Inner city business and citizens fear that the city might turn 'inside out' as commercial activity and new developments will be attracted towards the P+R lots on the outskirts, so-called 'edge cities' might arise (Frank, 1986). Furthermore, anti-car lobbyists and other sceptics point out that the construction of car parks cannot be regarded as a serious attempt to reduce car use as long as there is no significant reduction in the number of parking spaces in the urban centre (Meek et al., 2008; Topp, 1995). There are also concerns about social equity and justice (Parkhurst, 2003). For instance, prices of P+R services are often lower than traditional public transport fares, which gives an advantage to car users over traditional PT users.

Regarding the types of P+R facilities we observe differences in design, size, location, type of PT mode and level of service. A common distinction is the division between sites with an origin or destination-function. These categories are based on the travelled distances to the P+R lot and from the site onwards. For sites with an *origin function* PT is the main mode of transport, the car is only used to access the PT service, commonly a local PT node. Sites with a *destination function* are often specially designed to 'intercept' car traffic heading towards the urban centre on a motorway. Here the main mode is the car, PT services are only used to cover the last miles. Regarding PT services we find various types of public transport modes. In the present paper we will only use the basic distinction between *rail-based* and *bus-based* services. Another possible classification is a division based on geographical location of P+R sites (Figure 1). At least five different location types can be identified: satellite, rural transport-node, urban fringe, intra-urban and central (Guillaume-Gentil et al., 2004; Runkel, 1993; Spillar, 1997; White, 2002). *Satellite facilities* are located in smaller settlements at a certain distance from the central city in the region. *Rural transport nodes* are transfer facilities strategically located at an intersection of major transport infrastructure, e.g. a highway and railway. *Urban fringe facilities* are developed near important excess roads on the fringe of an urban area, mostly by local authorities. *Intra-urban sites* are located near the local or regional PT-network of a metropolitan area with at least 500,000 inhabitants, like the car parks at London Underground stations (TfL, 2010). Finally, *central P+R facilities* are located near major public transport nodes within an urban area and with a high service level, e.g. the railway stations of Lausanne and Antwerp.

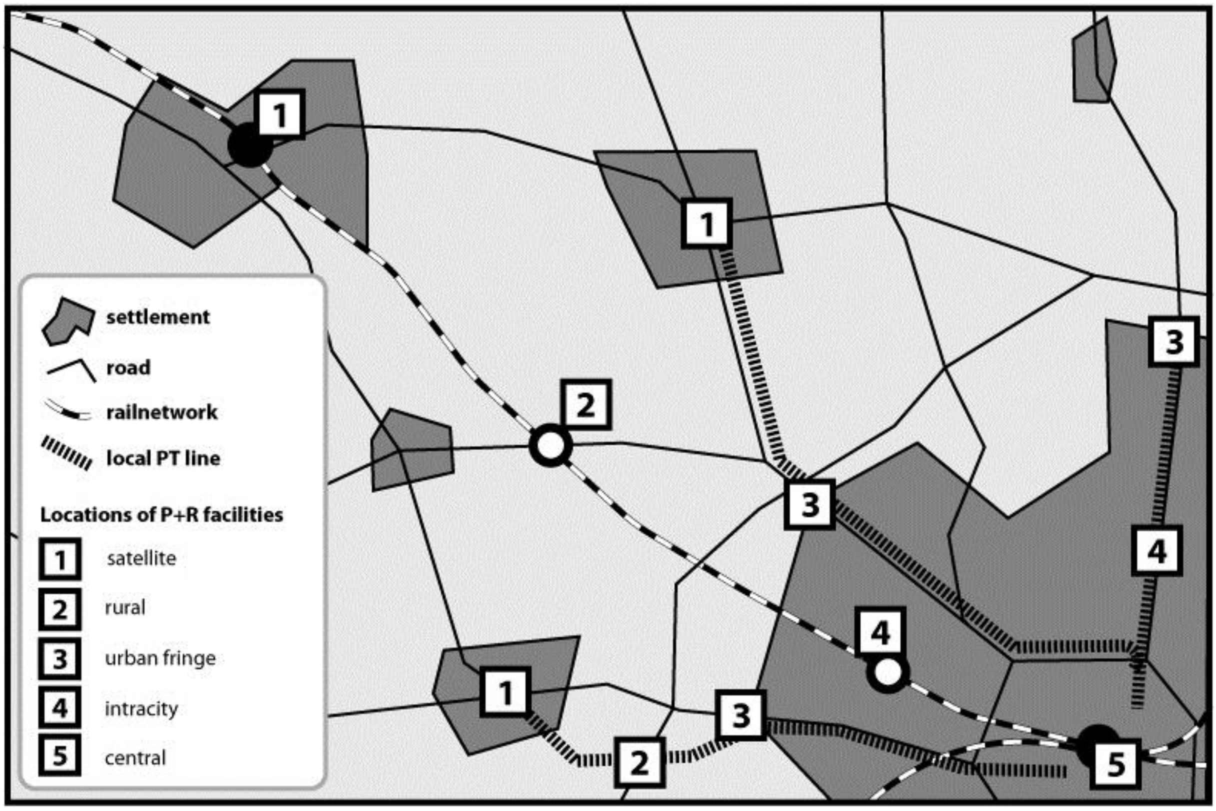

Figure 1. Five types of P+R based on their geographical location

3. Method: a meta-analysis of case studies

The approach we use to assess the effectiveness of P+R facilities is *meta-analysis*: 'a systemic framework which synthesises and compares the results of past studies' (Nijkamp, 1999, p. 3). This enables a re-examination of the earlier results and possible expansion of scientific knowledge. The concept of a meta-analysis originates from medicine and the natural sciences. It was introduced in the social sciences research in the 1970s to 'overcome common application problems such as the lack of large data sets in order to derive general results and the problem of uncertainty of information and of data values' (Nijkamp, 1999, p. 3). Former meta-analysis in the field of transport research has, for instance, been conducted by Möser and Bamberg (2008) and Cairns et al. (2008). Both papers examine the potential to achieve traffic reduction through soft measures.

3.1 Data

We collected our data from a wide range of sources. Papers, books, design guidelines and reports with data on P+R were collected using multiple search engines and keywords in four different languages (English, Dutch, French and German). In order to get the most reliable information on the effectiveness of P+R schemes we decided to use only empirical data on modal split implications from existing P+R schemes, hypothetical modelling exercises were excluded. In total we found more than 1,000 surveyed P+R sites, though most of the results turned out to be doubles, were incomplete or were not suited for our purposes. The results from London were indicated as outliers, since the share of target group users is very low. Moreover, this study is rather extensive with 39 sites and therefore seriously influenced the overall results. We excluded all these sites from this study (TfL, 2010). Finally, the results of 180 on site surveys made it to our analysis. These surveys come from 40 different sources and eleven countries (Table 1). They represent the behaviour and preferences of more than 26,000 P+R users.

Table 1. Overview of the studies used in the meta-analysis

Original source	Year	Country - Region		n	used	Reported in
MWGC (1971)	1970	US	Washington D.C.	1	1	BAA (1981)
Unknown (n.d.)	1970s	US	Seattle	1	1	BAA (1981)
Unknown (n.d.)	1970s	CA	Vancouver	1	1	BAA (1981)
Jain and Mokrzewski (1974)	1974	US	Hartford	1	1	BAA (1981)
Miller (1976)	1976	US	Shirley highway	1	1	BAA (1981)
Papoulias and Heggie (1976)	1976	UK	Oxford	2	2	Parkhurst (1996)
White (1977)	1977	UK	Oxford	2	2	Parkhurst (1996)
Devonald et al. (1978)	1978	UK	Oxford	4	4	Parkhurst (1996)
Rutherford and Wellander (1986)	1986	US	Seattle	26	5	Original
Becher et al (1989)	1988	DE	8 regions	38	36	Original
Cooper (1993)	1993	UK	York	1	1	Parkhurst (1996)
Newson (1993)	1993	UK	Oxford	2	2	Parkhurst (1996)
Pickett and Gray (1996)	1993	UK	4 cities	12	12	Original
Avon City council (1994)	1994	UK	Bristol	2	2	Marshall et al. (2000)
Jones (1994)	1994	UK	Chester	1	1	Parkhurst (1996)
Parkhurst and Stokes (1994)	1994	UK	Oxford / York	14	11	Original
SYPTE (1995)	1994	UK	Sheffield	1	1	Parkhurst (1996)
Bristol city council (1996)	1996	UK	Bristol	2	2	Marshall et al. (2000)
Holz-Rau et al (1996)	1996	DE	Ruhr-Area	1	1	Original
Faltlhauser (2001)	1997	DE	Munich	5	5	Original
Unknown	1997	UK	Bristol	2	2	EHTF (2000)
Foote (2000)	1998	US	Chicago	15	5	Original
WSA (1998)	1998	UK	8 cities	19	19	Original
Lindström Olsson (2003)	1999	SE	Stockholm	3	2	Original
Mobinet (n.d.)	1999	DE	Munich	7	5	Mobinet (2002)
Muconsult (2000)	2000	NL	Various	13	7	Original
Unknown (n.d.)	2000	NZ	Wellington	1	1	Vincent (2007)
Guillaume-Gentil et al. (2004)	2001-3	CH	Lausanne / Bern	9	8	Original
Mingardo (2003)	2002	NL	Groningen	3	3	Original
WRC (2002)	2002	NZ	Wellington	15	5	Vincent (2007)
Percy and Kota (2007)	2006	NZ	Auckland	2	2	Original
Steer Davies Gleave (2007)	2006	UK	Royston	1	1	Original
Hamer (2010)	2008	AU	Melbourne	7	5	Original
Mingardo (2008)	2008	NL	Rotterdam	3	3	Original
Mingardo (2009)	2008	NL	The Hague	6	4	Original
Attard (2013)	2008-9	MT	Valletta	2	2	Original
Meek (2010)	2009	UK	Cambridge	5	5	Original
Wiseman et al (2012)	2010	AU	Adelaide	1	1	Original
Arup, Accent and ITS (2012)	2011	UK	Scotland	8	7	Original
Vossen (2011)	2011	BE	Antwerp	2	1	Original
				242	**180**	

Our analyses consists of two parts. First, we analyse the effectiveness of P+R facilities with various characteristics making use of 14 regression analyses. We aim to identify relevant characteristics and estimate the expected performance of certain types of P+R facilities. Next, we use descriptive and analytic statistics from our data set and the results from the first step to calculate generalised effects of relevant types of P+R facilities on three policy objectives mentioned above: [1] *A reduction in the number of cars entering the city*, [2] *An increase in public transport use*, and [3] *A reduction in vehicle kilometres travelled*.

3.2 Variables in the regression analysis

To identify the differences in effectiveness of various P+R facilities we use linear regression analysis. Here effectiveness, our dependent variable, is *the share of target group users among all P+R users*. Target group users are travellers who use the P+R facility as intended by policy makers; without the P+R target group users would drive by car all the way to their destination. We observe two approaches in the surveys included in our data set. The first group of surveys tries to reveal the situation before the intervention by asking 'how did you travel to the city centre before using the P+R?' (revealed preference). The second group of surveys refers to the travel behaviour under hypothetical conditions by asking the question 'how would you travel to the city centre if there was no P+R?'(stated preference). Some studies use both methods in their survey on the P+R site. We report on the results separately, since these questions are inherently different from each other, the possible available options differ, and the studies using both methods show divergent results. In the remainder of the paper the two methods are labelled *'revealed preference'* (RP) and *'stated preference'* (SP) respectively (Table 2).

Seven explanatory variables are used in our analysis. As most of the explanatory factors are interrelated (multi-collinearity) and many sites have missing data we are unable to perform one multi-linear regression with all variables. Instead we execute a regression for all seven explanatory variables for both methods (RP and SP). As a result, we present 14 regressions in total. The explanatory variables are: PT mode, capacity, headway, point of intercept, week-weekend, share of commuters, and location type (Table 2). For PT mode we are able to distinguish only between rail and bus-based services. Capacity is measured by the number of parking spaces on the P+R facility. Headway is a linear alternative for frequency of service. It indicates the time in minutes between two successive services addressing the site during peak hours. The point of intercept is calculated using the average travel distance to the P+R site divided by the total trip distance. The next variable, week-weekend, makes a distinction between sites based on the day the surveys we used were carried out. The share of commuters is the percentage of people with work-related trips among the P+R users. For location type we are only able to use three location types, namely urban fringe, intra-urban and satellite, due to insufficient data for the other two location types. PT mode, capacity, headway and location type can be regarded as design factors, whereas the other three factors reflect the actual use of the P+R facility. We control for the period and the region of the survey using 5 control variables. We distinguish between three periods: [1] pre-1990, [2] 1990-1999, and [3] post-1999. For region we divide the studies used into UK, US, Continental Europe (including Malta) and Australia. As point of reference we use continental Europe after 1999.

Table 2. Variables included in the model

Dependent	N	Range	Mean (sd)	Median	Skewness	Kurtosis	Description
RP	117	74.5 (10-84.5)	48.1 (18.9)	46.0	0,11 (.22)	-1,21 (.44)	Former car users
SP	94	77.1 (2.9-80)	46.0 (20.5)	53.1	-0,49 (.25)	-0,81 (.49)	Otherwise car users

Explanatory	N	Values	Mean (sd)	Median	Description
PT Mode	169	Dummy (0-1)	-	-	Rail-based (82) or Bus-based (87) P+R facility
Capacity	90	1277 (68-1345)	481 (300)	426	Parking spaces on P+R
SQRTCapacity	90	28.4 (8.3-36.7)	21.0 (6.4)	20.6	Square root of capacity
Headway	92	27 (3-30)	10.8 (4.9)	10	Time between PT services (min.)
Location P+R	129	(1-5)	-	-	Satellite (24), Fringe (78) or Intra-urban (24)
P. of Intercept	59	0.84 (.07-.91)	0.65 (0.26)	0.77	Distance to P+R / Total distance
Weekend	88	Dummy (0-1)	-	-	Weekday (73) or weekend (15) survey
%Commuters	92	0.95 (.0-.95)	0.57 (0.27)	0.51	Share of commuters among P+R users

Control	N	Values	0	1	Description
Before1990	180	Dummy (0-1)	126	54	Surveys before 1990
1990to1999	180	Dummy (0-1)	109	71	Surveys from 1990 to 1999
UKDummy	180	Dummy (0-1)	106	74	Surveys from UK
USDummy	180	Dummy (0-1)	165	15	Surveys from US and CA
AUDummy	180	Dummy (0-1)	166	14	Surveys from AU and NZ

3.3 Assessing the effect of P+R facilities on three policy objectives

The reduction in the number of cars entering the city is obtained by multiplying the P+R use by the share of target group users. P+R use itself is calculated by using the median peak occupancy rate of the parking spaces and the median share of improper P+R users on the site. By the latter we mean the share of cars on the P+R facility from people without the intention to use the service from the P+R service onwards. In order to simplify comparison of the results all types of P+R facilities have the same size, namely 100 parking spaces. Any influence of the parking space capacity of effectiveness is disregarded in our calculations.

To assess the impact on PT use we calculate the additional kilometres in PT by target group users and new users and subtract the loss in PT kilometres by people who formerly or otherwise would use PT from door to door. To calculate the impact of the P+R site on vehicle kilometres travelled (VKT) we use a comparable approach: the increase in vehicle kilometres is obtained from the new travellers and the non-target group users on the P+R facility (those who did not use a car before for their trip but who now access the site by car), the decline in kilometres comes from the use of the facility by target group users. The effect on VKT and PT use are both expressed by the alteration in travelled kilometres per P+R user. In these two calculations we use both mean and median values. Mean values are the preferred method, though these are also sensitive for outliers. Because there are some outliers, the median values provide a suitable complement.

4. Effectiveness of P+R facilities

4.1 Effectiveness and P+R characteristics

The results from all 14 regression analyses are shown in Table 3. The explanatory variables Public Transport mode and Point of Intercept show significant results for both methods used (RP & SP). This means that the type of PT service and the location of transfer within a trip seem to have a decisive influence on the share of target group users. The difference in share of target group users between rail-based and bus-based schemes is about 27 (RP) to 38 (SP) percentage points, with rail-based schemes being the least effective having only 26% (SP) to 30% (RP) target group users on the site. The results for point of intercept can be interpreted as follows. When the average P+R user transfers from car to PT after just a quarter of the total journey length the average share of target group users is about 33% (SP) or 45% (RP). When the transfer is made after three quarters of the journey the share of target group users is approximately 52% (SP) or 65% (RP). Note that PT mode and Point of Intercept are interrelated. Most rail-based services have an origin function, while most bus-based schemes have a clear destination function.

There are two other significant relationships following the revealed preference method, namely Week-weekend and Share of Commuters. These two variables are correlated as the share of commuters drops on weekend days. Both models have a high explanatory value with sufficient observations and an adjusted R2 of 0.84 and 0.74 respectively. Moreover, the results point in the same direction. Non-commuters or weekend visitors are more likely target group users of the P+R. Even when we control for 'PT mode' in the linear regression model both explanatory variables remain significant. This does not mean that the P+R is unable to attract commuters. We see that the average share of commuters is about 51% (Table 2), which is rather high when we consider the overall share of work-related trips. Possible reasons for the higher share of target group users for non-commuters are differences in time and cost sensitivity.

According to the stated preference data there are three other significant relationships. First, parking space capacity on the P+R facility has a positive relationship with our dependent variable. Larger facilities do attract a higher share of target group travellers. Second, headway of PT services shows a significant negative relationship. This suggests that a longer wait at the facility has a negative influence on the share of people that would otherwise drive all the way to their destination. A drop in frequency from once every ten minutes to once every fifteen minutes will result in approximately 8 percentage point less target group users. However, both models for capacity and headway lose their significance when controlled for PT mode. Third, location type of the P+R is significant for both fringe and intra-urban facilities. These facilities are able to attract more target group users compared to the reference category, the satellite P+R facility. This again relates to previous findings, as most types of P+R facilities are dominated by a certain PT mode. Indeed, 22 out of 24 satellite lots are rail-based and 69 of the 73 urban fringe lots are bus-based.

We observe two meta-typologies in our data set. The first group consists of satellite facilities, rail-based sites and P+R facilities with an origin function. Most satellite facilities are rail-based and have an origin function, the distance travelled to the satellite facility is significantly shorter than from the site onwards. We label this group 'Satellite type facilities'. The second group comprises fringe lots, bus-based services and facilities with a destination function. This group will be labelled 'Fringe type facilities'. These two meta-typologies will return in part two of our analysis.

Table 3. Results from the 14 regression analysis

	Public Transport Mode#		**Square root of Capacity**		**Headway**	
Method	RP	SP	RP	SP	RP	SP
	B (S.E.)	B (S.E.)	B (S.E.)	B (S.E.)	B (S.E.)	B (S.E.)
Intercept	29.8 (3.3)**	26.3 (3.3)**	66,7 (10.0)**	11.6 (8.1)	52.4 (6.7)**	56.1 (7.5)**
Before1990	3.0 (3.4)	9.8 (9.7)	28.2 (8.7)**	-	-	-
'90-'99	8.8 (4.0)*	3.6 (4.3)	7.7 (5.7)	24.2 (5.3)**	12.2 (5.0)*	14.4 (4.9)**
UKDummy	1.7 (4.7)	-11.8 (4.9)*	-7.2 (6.4)	-12.3 (6.1)*	2.3 (6.2)	1.7 (5.8)
USDummy	-10.8 (3.9)*	-	-43.8 (8.2)**	-	-35.4 (8.2)**	-
AUDummy	-3.9 (4.5)	-18.3 (6.5)*	-41.3 (9.4)**	-	-28.1 (10.3)*	-
Expl-var	26.9 (3.5)**	38.2 (5.1)**	-0.163 (.35)	1.63 (.42)**	-0.115 (.48)	-1.66 (.43)**
Observations	117	83	47	58	54	73
Adj. R^2	0.71	0.65	0.56	0.38	0.56	0.37

	Point of Intercept		**Share of Commuters**		**Weekday – Weekend†**	
Method	RP	SP	RP	SP	RP	SP
	B (S.E.)	B (S.E.)	B (S.E.)	B (S.E.)	B (S.E.)	B (S.E.)
Intercept	34.1 (10.1)*	23.9 (7.0)**	73.1 (4.6)**	44.9 (11.2)**	69.1 (7.4)**	45.9 (3.7)**
Before1990	0.4 (8.8)	-	28.2 (6.7)**	-	-18.1 (10.4)	9.9 (15.2)
'90-'99	16.2 (4.3)**	-0.6 (5.3)	10.8 (3.8)*	12.2 (6.0)*	-23.6 (10.2)*	0.9 (10.8)
UKDummy	-15.8 (5.4)*	-1.1 (6.4)	-1.2 (4.4)	-3.8 (7.3)	17.3 (7.1)*	2.9 (10.8)
USDummy	-	-	-15.3 (6.5)*	-	-13.0 (7.4)	-
AUDummy	-31.9 (9.5)**	-	-	-31.0 (9.3)**	-37.3 (7.7)**	-37.9 (7.6)**
Expl-var	41.9 (12.4)**	37.1 (9.8)**	-46.3 (7.0)**	-6.2 (13.9)	10.1 (2.4)**	7.7 (5.8)
Observations	45	45	54	69	62	58
Adj. R^2	0.55	0.24	0.74	0.26	0.84	0.39

	P+R Location Type‡	
Method	RP	SP
	B (S.E.)	B (S.E.)
Intercept	45.8 (7.2)**	20.5 (3.5)**
Before1990	20.0 (5.9)**	11.7 (4.3)
'90-'99	12.7 (4.8)*	5.5 (4.1)
UKDummy	9.6 (7.7)	-7.3 (4.3)
USDummy	-35.5 (7.3)**	-
AUDummy	-16.9 (6.7)*	-
Fringe	-2.7 (9.6)	37.6 (4.2)**
Intra-Urban	8.6 (6.6)	34.5 (7.7)**
Observations	76	82
Adj. R^2	0.62	0.61

Notes
* Significant on a 0.05 level
** Significant on a 0.01 level
\# Rail-based facilities are reference category
† Weekday surveys are reference category
‡ Satellite facilities are reference category

4.2 Effects on three policy objectives

The estimated reduction in the number of cars entering the city is shown in Table 4. The median peak occupancy rate for various types of P+R sites ranges from 68% to 94% of the total available parking capacity. To correct for cars from non-P+R travellers on the site we use the median value of 6.3%. This is significantly lower than the mean value from our data set, namely 16.1% based on 87 surveyed P+R lots. Based on this input the number of cars from P+R users varies from 64 to 88 per 100 parking spaces. The share of target group users varies from a minimum average of 19 to a maximum of 64%. This multiplied by the number of cars from target group P+R travellers provides the estimated reduction in number of cars per 100 parking spaces.

The estimated reduction in number of cars entering the city ranges from 15 to 50 cars per 100 parking spaces (Table 4). The results demonstrate a clear pattern following the meta-types.

Satellite, rail-based and P+R facilities with an origin function provide a modest contribution to the reduction of cars. The reduction is about 15 to 29 cars per 100 parking spaces. Urban fringe lots, bus-based facilities and P+R facilities with a destination function perform significantly better. The reduction for this group ranges from 37 to 50. This makes the latter about two times as effective as the first group. However, it is still only an average reduction of 1 car per 2.5 parking spaces, while the latter group is often specially designed to reduce the number of cars entering the city.

Table 4. Estimated reduction of cars entering the city for various types of P+R facilities

	PT Mode				**Location type**						**Function**			
	Rail-based		Bus-based		Satellite		Fringe		Intra-urban		Origin		Desti-nation	
Number of parking spaces	100		100		100		100		100		100		100	
Median peak occupancy rate	81%		70%		94%		81%		68%		81%		87%	
Median share improper P+R use	6%		6%		6%		6%		6%		6%		6%	
Cars from P+R users	76		65		88		76		64		76		81	
Method	RP	SP	RP	SP	RP	SP	RP	SP	RP	SP	RP	SP	RP	SP
Drive without P+R (%)	31	19	57	64	33	18	64	56	41	55	35	19	62	55
Observations (n)	53	23	64	60	7	15	51	64	18	3	18	16	45	51
Reduction in number of cars	**24**	**15**	**37**	**42**	**29**	**16**	**48**	**43**	**26**	**35**	**27**	**15**	**50**	**44**

The results for *promoting public transport* use are mixed (Table 5). As expected, the mean values show more extreme values compared to the median values. Fringe type facilities will most likely not contribute to an increase in PT use. One might even observe a loss in PT kilometres, as all results for P+R facilities with a destination function are negative. Satellite type facilities look more promising. All calculated changes in the PT kilometres are positive and the mean values range from 3 to 16 additional PT kilometres per P+R user. This is mainly due to the considerable average distance between the satellite lots and the city centre. Intra-urban facilities also show potential for promoting PT within urban areas.

In many respects the *changes in VKT* and *PT use* are related (Table 6), though this is not a one-to-one relationship as there are also pedestrians and cyclists switching to car use. Fringe type facilities lead to an increase in VKT, according to our estimates. The results range from about 1 to 4 additional kilometres per P+R user, when using mean or median values. Satellite type facilities have a potential to lower the VKT. We observe a range of -1 to -4 kilometres per P+R user for the mean values. The intra-urban lots also have a certain potential to lower the VKT.

Table 5. Changes in PT kilometres per P+R user

		PT-mode				**Location type**						**Function**			
		Rail-based		Bus-based		Satellite		Fringe		Intra-Urban		Origin		Destination	
	Method	RP	SP	RP	SP	RP	SP	RP	SP	RP	SP	RP	SP	RP	SP
Additional PT use by target group	Mean	6.3	5.1	4.0	2.3	9.8	5.7	2.7	2.2	5.6	nd	10.4	5.7	2.4	2.1
	Median	3.9	3.1	3.0	2.3	6.6	3.4	2.8	2.1	3.9	nd	10.7	3.4	2.4	2.1
Loss of PT use as feeder mode	Mean	3.8	2.6	2.9	3.5	nd	1.8	3.2	4.3	2.0	nd	1.1	1.8	3.3	4.4
	Median	3.8	2.8	2.3	2.9	nd	2.0	3.0	3.2	1.0	nd	1.0	2.0	3.0	3.6
Extra PT use by new travellers	Mean	5.6	0.9	1.3	0.4	nd	0.9	0.6	0.4	3.5	nd	6.5	0.9	0.5	0.5
	Median	5.0	0.0	0.3	0.4	nd	0.0	0.2	0.4	4.9	nd	4.9	0.0	0.2	0.4
Change in PT use per P+R user	Mean	8.1	3.4	2.4	-0.8	-	4.9	0.1	-1.7	7.2	-	15.9	4.9	-0.3	-1.8
	Median	5.1	0.3	1.0	-0.1	-	1.4	0.0	-0.7	7.8	-	14.7	1.4	-0.4	-1.1

Note: nd = no or insufficient data

Table 6. Changes in VKT per P+R user

		PT-mode				**Location type**						**Function**			
		Rail-based		Bus-based		Satellite		Fringe		Intra-Urban		Origin		Destination	
	Method	RP	SP	RP	SP	RP	SP	RP	SP	RP	SP	RP	SP	RP	SP
Additional VKT by non-target group	Mean	3.4	4.1	3.3	3.6	4.2	4.1	3.6	4.4	2.6	2.0	2.6	3.6	3.8	4.5
	Median	3.4	4.3	3.0	3.8	4.0	3.6	3.4	4.7	2.4	1.3	2.1	3.1	3.2	4.6
Reduction of VKT by target group	Mean	7.9	4.9	4.5	4.1	9.4	5.1	2.7	2.4	5.4	7.3	9.5	5.3	2.4	2.1
	Median	4.3	2.9	2.8	2.6	8.1	4.6	2.7	2.4	4.1	6.5	9.0	5.1	2.3	2.1
Extra VKT by new travellers	Mean	0.8	0.3	1.6	1.4	nd	0.3	1.9	1.7	nd	0.5	nd	0.2	2.0	1.7
	Median	0.7	0.1	1.2	1.5	nd	0.1	1.3	1.8	nd	0.4	nd	0.1	1.3	1.8
Change in VKT per P+R user	Mean	-3.7	-0.5	0.5	1.0	-	-0.7	2.8	3.7	-	-4.9		-1.5	3.4	4.1
	Median	-0.2	1.5	1.4	2.7	-	-0.9	2.0	4.0	-	-4.8	-	-2.0	2.2	4.4

Note: nd = no or insufficient data

5. Discussion

Regarding the research findings we think the over-all level of 'target group' travellers is the most striking result. There is a clear difference between the intended use of the P+R and its actual use. The average share is about 46% (RP) and 48% (SP) of P+R users. Not even one out of every two travellers is a target group user. This is a serious concern and raises questions about the added value of P+R facilities in the transport system. It negatively influences the potential of P+R facilities to achieve policy objectives, such as promoting PT use, reducing VKT and the number of cars entering the city. Our results confirm the conclusion by Parkhurst (2000, p. 159) regarding bus-based fringe lots in the UK: 'It is concluded that the main effect of the schemes is traffic redistribution, and that their role within traffic restraint policies is unlikely to be directly one of traffic reduction'. Both the potential to reduce VKT and to promote PT use are more promising for satellite facilities, though even more parking spaces are needed, since the share of target group users is even lower. Investments in local walking and cycling conditions or PT services might be more helpful. This is an interesting issue for further research.

Another striking result in our study is the difference between rail-based and bus-based facilities. This conclusion conflicts with the well-established notion of the 'rail-bonus' (Axhausen et al., 2001). The obvious explanation is that these facilities have a fundamentally different function in the transport system. Almost all rail-based sites have an origin-function in an urban satellite, while most lots with bus services are sites with a destination-function located on the fringe of an urban area. In addition, many fringe facilities come with new, frequent bus services, while most of the satellite facilities are constructed near existing rail services. Moreover, the P+R facilities in the urban area – often served by bus - are more likely introduced along with restrictive car policies, such as congestion charging, higher parking fees or less road capacity. In these cases P+R schemes are part of a broader policy package. Examples can be found in London, Stockholm and Singapore (Eliasson et al., 2009; Seik, 1997; Transport for London, 2010). Being part of a policy packages might be of decisive importance in regard to the success of P+R schemes (Dijk and Parkhurst, 2013; Givoni et al., 2013). Unfortunately, we were unable to control for these issues in our research project; the importance of PT service improvements and restrictive measures next to P+R facility availability remains unknown. Also because most reports fail to provide basic information on the number of parking lots, parking fees, model split, local transport policy and so on.

In this paper we defined an effective P+R facility as a site with a maximum share of target groups travellers among the P+R users. There are at least three disadvantages of this approach. First, by only focussing on the share of target group users among the total of P+R users one might draw the wrong conclusions regarding 'the success of P+R' with respect to sustainable passenger transport. In our data set the share of target group users is higher in the US and the UK compared with continental Europe. A suitable explanation, in our opinion, is the overall higher level of car use in these countries. The chances of attracting a car driver are simply higher. Regional public transport systems with high levels of P+R users among all PT users are more likely to be overall low ridership systems (Dickins, 1991; Mees, 2000). Therefore, 'successful' P+R schemes in terms of 'share of target group users' might primarily signify car dominance. Second, dealing with relative instead of absolute numbers might be deceiving. The capacity of parking spaces on the P+R facilities is small compared with the total capacity in the city centre. Moreover, we assume an overrepresentation of well-used P+R facilities in our analysis. The absolute numbers we do have are likely biased. Third, we defined car users as the target group of P+R schemes. In most studies car users are car drivers, though in some cases car users concern both car drivers and car passengers. This means a bias in our results.

P+R evaluations report stated or revealed data. These two methods were analysed separately in the present paper. The results for both methods show significant differences in multiple occasions. In our view, this confirms the appropriateness of our decision. We agree with Parkhurst (1996) that the results for revealed preference are most reliable, as this concerns observed actual behaviour. This holds for one important exception, namely induced trips, which we used to assess the changes in VKT and PT use. People that did not make the journey via the P+R before, can have multiple reasons to do so, while the related question in the stated preference method is more concrete, namely 'Would you have travelled without the availability of the P+R?'. We believe stated preferences 'are a reasonably accurate guide to true underlying preferences' (Wardman, 1988, p. 89) in this particular case. Moreover, the options presented in the hypothetic situation - the P+R is not available - are real existing options.

For our analysis we used ordinary least squares regression with the share of target group users as dependent variable. This choice might have influenced our results. Therefore we also ran these models using the share of non-target group users, as target group and non-target group do not always add up to one. Moreover, we checked for consistency using quantile regression, with median values (tau=0.5). In both cases we observed little differences in regarding the main results. Our conclusion are solid.

An unavoidable result of a meta-analysis with a very heterogeneous data set is a considerable margin of error. Notwithstanding we believe this meta-analysis does contribute to our understanding of P+R facilities or schemes. Our results provide useful guidelines or rules of thumb for future design handbooks on intermodal nodes. The estimates can be used to assess the impact of new facilities and to perform cost-benefit analyses. We also provide suggestions for further research (see below). Additionally, our results press for a critical re-evaluation of P+R and its role in transport policies.

To conclude this section, we summarize and complement our suggestions for further research on P+R. First, we think it is necessary to further examine P+R characteristics that help to improve the effectiveness of P+R scheme. A high share of target group users and high occupancy levels on the facility are desirable objectives if P+R is the preferred transport policy measure. Mingardo (2013) provides a counterintuitive suggestion in this respect, namely introducing a parking fee on P+R lots. This provides an incentive to people living nearby to walk or cycle to the intermodal node. Second, in our research we were unable to control for PT service level improvements. Further research can help to determine the impact of PT service improvements and the added value of just building P+R facilities. Third, our results on the effect of headway and capacity of the P+R facility on the share of target group users are not conclusive. Especially the optimal frequency of bus or rail services can be an interesting research topic. Fourth, we concluded that not all changes in traffic flows are accounted for, as non P+R trips are missing from our data. We think it is interesting to find out if and to what extent P+R generates induced traffic. Fifth and finally, in relation to the previous issue, we think it is also advisable to assess the long-term effects of P+R schemes. On the one hand, P+R schemes might stimulate negative effects such as sprawl and car ownership. On the other hand, there might also be positive effects, as P+R use can be a first step in further PT use.

6. Conclusions

P+R has become a mature element in transport policies, though there is still doubt about its contribution to a more sustainable transport system. The aim of this research was to improve our understanding of the effectiveness of various P+R facilities and the effects on three important policy objectives. Therefore, 180 P+R facilities were analysed according to seven P+R characteristics using regression analyses. Next, we calculated the effect on the number of cars entering the city and the change in VKM and PT use.

We observe two meta-types in our data set. 'Satellite type facilities' are satellite, rail-based and origin facilities. 'Fringe type facilities' comprise sites that are located in the urban fringe, are bus-based or have a destination function. Satellite type facilities have a significantly lower share of target group users compared with Fringe type facilities. For the first group the share of P+R users that did (RP) or would otherwise (SP) drive all the way is on average 32 to 35% (RP) and 18 to 19% (SP). For the latter group these average shares are about 62% (RP) and 55% (SP). The results for the regression analyses with other P+R characteristics are mixed. In only one of the two methods we used they provide significant results. Again we observe multi-collinearity, if controlled for PT mode or Point of Intercept some models lose their significance. Although, solid results are found for weekday or weekend surveys and share of commuters. If the share of non-utilitarian travellers drops the share of target group users rises.

Satellite type facilities have a limited impact on the reduction of cars entering the city. The average reduction is about 15 (SP) or 26 (RP). This group does contribute to more PT kilometres and a reduction in VKT, though many parking spaces are needed to achieve noticeable change as only 1 in 5 (SP) or 1 in 3 (RP) is a target group traveller on the P+R. Fringe type facilities do contribute to a reduction of the number of cars entering the city, on average by 37 to 50 (RP) or 43 (SP) per 100 P+R parking spaces. Fringe type facilities do not contribute to more PT use. The kilometres travelled in PT might even drop. Moreover, an increase in VKT is to be expected.

Our results cast doubts on the success rate of P+R facilities and their possible part in the sustainable transport objectives we have examined in this paper, though P+R might contribute to other objectives, like the accessibility of PT services for disabled people or a more robust transport system. In addition, our results are especially useful in the assessment of the effects of future P+R interventions or the formulation and evaluations of transport policies with P+R schemes.

Acknowledgements

The authors would like to thank Jennifer Bonham, Dirk Wittowsky, Paul Hamer, Giuliano Mingardo, Manish Shirgaokar, Graham Parkhurst and W.S. Atkins planning consultants for their assistance. We are especially grateful to Gordon Stokes and to Simon Weaver for providing an actual data set from P+R surveys. Many thanks to John Linnegar and Katrien De Langhe for text corrections. This research project is financed by the Flemish government within the framework of Research Centre on Commodity and Passenger Flows.

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