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Park and ride, effects on public transport ridership

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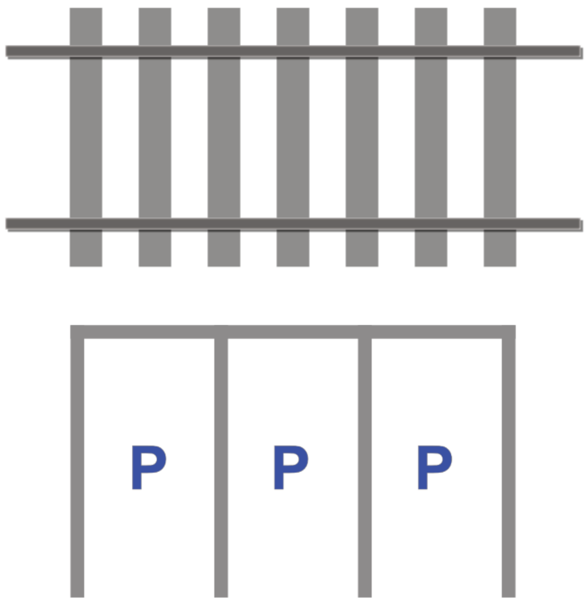

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Abstract

English

As urban growth accelerates and the need to address environmental issues regarding transportation is larger than ever and many policymakers have chosen to adapt park and ride as one of their methods to reduce car traffic. However, the effect from adapting the policy is not very well understood and since the policy can directly conflict with other policies related to land use it is important to know which effects can be expected. By knowing which effects to expect, policy makers can make more sustainable choices in their policy adaption.

This study has been carried out using data from two different counties to find out if the effects from park and ride differ depending on the type of environment it serves. Further, an additional analysis has been done using temporal data to measure the effect of adapting or expanding a park and ride facility at a public transport station or stop.

It was found that in a rural setting, the relation between park and ride and the number of passengers at a public transport station is strong. Stations with more parking spaces had higher ridership. This was not the case for stations located in a suburban environment, some effect was indicated but the relationship was not as strong. The analysis of the two counties data showed unreasonably high passenger increases from P&R, indicating that some other factor also influences the result in this analysis.

From the analysis of the temporal dataset the result showed that stations which adapted park and ride did have a higher average passenger increase than the general trend within the transport system. This indicates that park and ride do in fact increase public transport ridership.

Swedish

Den accelererande urbaniseringen har gjort behovet av att hantera miljöpåverkan ifrån transportsystemet större än någonsin och många beslutsfattare har valt att förorda pendlarparkering (park and ride) som en metod för att minska biltrafik. Effekterna av att använda denna planeringsmetod är dock inte fullt kända och eftersom pendlarparkeringar kan hamna i konflikt med andra planeringsmetoder som berör markanvändning så är det viktigt att veta vilka effekter som kan förväntas av att införa pendlarparkeringar. Genom att veta vilka effekter som kan förväntas så blir möjligheterna bättre för beslutsfattare att ta välgrundade beslut och införa hållbara direktiv kopplade till stads och trafikplaneringen.

Den här studien har utförts med data från två olika regioner för att ta reda på om effekterna av pendlarparkeringar skiljer sig beroende på vilken typ av miljö den är implementerad i. Dessutom har ytterligare en analys gjorts baserad på historiska data över resande, detta för att kunna mäta den direkta effekten av att införa eller expandera pendlarparkering på en hållplats inom kollektivtrafiken.

Resultatet visade att i glesbebyggda områden så var sambandet mellan antalet platser på pendlarparkeringar och antalet passagerare starkt. Statiner med fler pendlarparkeringsplatser hade fler resande än de med färre. Sambandet var inte lika starkt för stationer i förortsmiljö, ett visst samband kunde uppmätas men det var inte lika starkt. Analysen av de två regionerna visade dock på orealistiskt höga förhållanden mellan antalet pendlarparkeringsplatser och antalet passagerare vilket indikerar att någon annan faktor också påverkar resultatet.

Från analysen av historiska data över antal resande så visade resultatet att införandet av pendlarparkeringar ökar resandet med kollektivtrafiken i genomsnitt mer på de stationer där de införs jämfört med den generella trenden i kollektivtrafiksystemet. Detta indikerar att pendlarparkeringar har en positiv effekt på antalet resande med kollektivtrafiken.

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List of words

Definition and explanation of words used throughout this report.

P&R; short for “Park and Ride”, the policy is explained more detailed in chapter 1.

GIS; Geographical information system, type of software used for analysing geographical data

Arcmap; a GIS software

IBM SPSS: a software used to conduct statistical tests and analyses

Station / Stop; Refers to any point where public transport can be regularly boarded or alighted

Tap in; The validation of a public transport ticket at a metro gate, bus, or tram-stop

Car occupancy; The number of people on average occupying a car during a journey

Parking spot / spot; refers to one marked area intended for one vehicle

Municipality; the smallest administrative unit in Sweden, administrates local roads and infrastructure among other

County; large administrative unit which consists of multiple municipalities, administrates healthcare and public transport

1. Introduction

1.1 The policy Park and ride

Park and ride (P&R) is a type of transport concept which enables combined car and public transport trips by providing day-time parking at public transport stops (Trafikverket and SKL, 2012; Coffel *et al.*, 2013). The introduction of the concept can be done with many different purposes. The main purpose is usually to attract new riders and to gain shares from travellers who would otherwise utilise their private vehicles for the whole journey. This is suggested to work best if there is a high relative cost for car user to drive all the way to their destination. The cost could be both monetary, such as parking fees and congestion charges or in time such as delay due to bad roads, congestion, or difficulty to find a parking spot at the destination. P&R is also a way to extend the catchment area for a public transport stop as travellers from further away can access the stop within a reasonable travel time. For this reason, park and ride can also be suitable to implement in areas where there are long distances between public transport stops, alternatively to allow for longer distances between stops when a network is expanded.

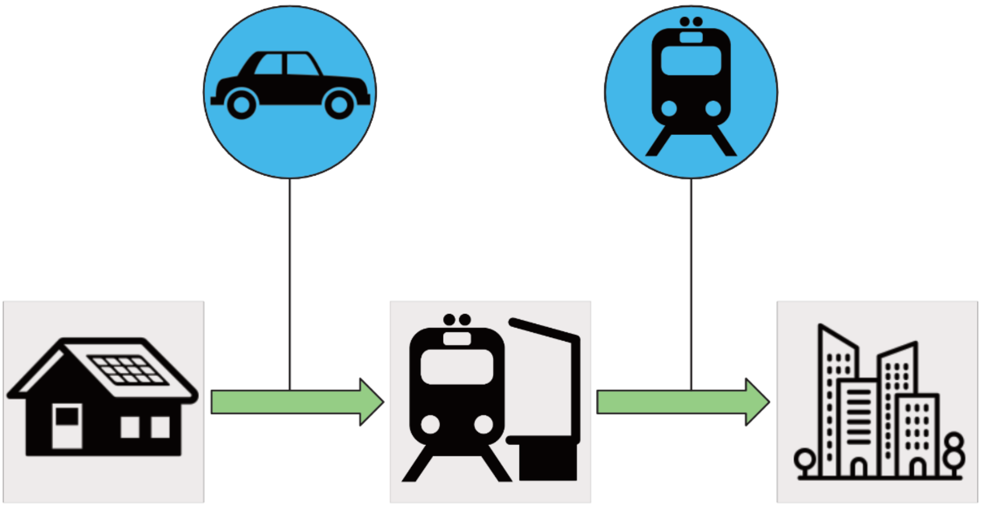

Figure 1. Illustration showing the basic priciples for park and ride.

In Sweden the concept is mostly known as *Infartsparkering, pendlarparkering or pendlingsparkering* which translates to entry-parking, commuter-parking and commuting-parking (Region Uppsala, 2019). The concept is now used in many counties throughout Sweden but saw a major uprise in Stockholm during 2006 when the congestion charge was first introduced (Stockholm parkering, 2017). P&R received an official road sign in 2005 as a preparation for the testing period with congestion charges in Stockholm as a change in traffic demand was expected (Stockholmsförsöket, 2005; Motormagasinet, 2005). At the same time many P&R facilities were opened to provide options for car commuters in Stockholm as the congestion charge was imposed.

The concept now exists in many counties and some, primarily the most populous counties, have created strategies on how to work with park and ride (Västra Götalandsregionen, 2008; Lucassi and Nyström, 2011; Region Uppsala, 2019). It has also been implemented in less populous counties such as Jämtland, Västerbotten and Jönköping (Åre Kommun, 2018;

Skellefteå kommun, 2021; Svt, 2017). This has been done either by the municipalities individually or as part of wider transport strategies such as the case for Åre municipality where it has been done as part of the infrastructure project *Mittstråket* (Åre kommun, 2020).

Figure 2. Park and ride facility in Åre municipality.

P&R facilities are usually owned and administrated by public authorities and can be either free of charge, charged or included in the public transport ticket (Bjørnson and Usterud, 2020). As an example, Nacka municipality in Stockholm county has both free P&R, and P&R which requires a public transport 'access card' to be used (Nacka kommun, 2021). Further, there is even a private, charged, P&R located within the municipality.

1.2 Project goals and research question

This study aims to provide knowledge regarding what effects can be expected when introducing P&R and if effects differ depending on the context. This could improve the ability for policy makers to compare different conflicting policies and implement the most sustainable one.

In this study the influence on public transport ridership from P&R facilities will be researched. The study will analyse both direct impact of expanding P&R facilities at a station as well as trying to distinguish general differences in ridership between station depending on if and how many P&R ride spots are available.

The few studies measuring the impact on passenger volumes were done in a North American context and the result is necessarily not valid in a European context due to generally different urban environments in North America and Europe (Friedman, 2020). Where the American cities have historically had a more automobile focused development.

In this study the influence of parking on public transport ridership will be researched with the main goal being to measure the direct impact of increasing the number of parking spots available at public transport stops. Likewise, the study aims towards gaining insight about if P&R is more useful in some contexts than in other.

The main purposes of the study can be concentrated to the following questions:

- Does P&R facilities increase the public transport ridership?
- How large is the effect on ridership if P&R is expanded or introduced?
- Is there a difference between P&R implementation in different contexts?

By answering the first question it also possible to partially determine if P&R makes passengers switch mode for their connecting journey to the station.

This study does not intend to measure the effects on vehicle kilometres travelled by car but will solely focus on P&R’s ability to increase public transport ridership.

1.3 Scope

The study is limited to three different datasets. Two data sets which contains current number of P&R spots at a station, population within walking distance, as well as the number of boarding passengers. The third dataset contains temporal passenger data and data regarding when the stations had P&R introduced or expanded and by how many spots.

The data sets are:

- Stockholm county commuter trains (Pendeltåg)
- Uppsala county regional trains (Upptåget)
- Stockholm county access card data (mixed modes)

Data for Stockholm county commuter trains and Uppsala county Regional trains are in both cases from 2019. For the access card dataset, the data is from the period between 2013 and 2019.

The three different cases are described more thoroughly in section 3.

2. Background

2.1 Literature

Parking as an academic study area is considered omitted and limitedly studied despite being a crucial part of the transport system and the urban environment (Marsden, 2006; Weinberger & Jacobson, 2014). Although, evidence exists to support the usage of parking policies as a way of reducing car traffic. Parking can greatly influence decision making among motorists as costs in form of walking time and parking charges have a larger impact than in vehicle costs. Parking policies which restrict parking access does however not necessarily have a negative economic impact, as earlier believed. These restrictions are generally done as a part of a wider policy with access for other transport modes being improved at the same time. Further, commuters are affected more by parking restraints than those using car to access commercial services. To access commercial services, motorists tend to park further away from the destination to avoid high parking charges rather than to change mode which in addition means parking policies should cover large areas to avoid undesired side effects.

The impact of parking on the urban environment is extensive, both in terms of direct physical space occupied and the influence on travel behaviour (McCahill & Garrick, 2014). Parking occupies vast amounts of land, as an example; in the United States there are over 800 million parking spots which is more than three parking spots per automobile. Furthermore, it contributes to increasing the share of trips carried out with private vehicles. While P&R often aims towards reducing car traffic and the need for parking space in city centres, it still conflicts with other interests related to land use (Parkhurst, 1995; Niles and Pogodzinski, 2021). The most common conflict of interest is regarding another urban planning policy called transit-oriented development (TOD) which is a planning method where new developments are focused on areas in the vicinity of public transport stations.

A review of the P&R adaption in Europe showed uneven implementation of P&R as a policy among the cities included (Dijk and Montalvo, 2011). Out of the participating cities, higher adaption levels were reported in Germany and the UK while lower levels were reported in southern and eastern Europe. Moreover, 93% of participating cities thought the policy was useful for decreasing car traffic, and 66% considered it a policy which could achieve positive environmental impacts in the city. In addition, around half (47%) of the cities reported that they associated the policy with negative economic benefits.

Earlier studies suggests that P&R works for increasing the land use efficiency by reducing car traffic and the need for parking spaces in central parts of cities (Parkhurst, 1995). The effect is enhanced further if there are measures reducing the availability for car traffic or with reduced road capacity (Qin, Guan and Wu, 2013; Parkhurst and Meek, 2014; Zhao *et al.*, 2019). However, effects seem to vary depending on the characteristics of the area around the P&R facility, a high density of intersections and fewer lanes are some factors having a positive effect on P&R usage. Other factors potentially affecting P&R usage are demographics and land use, where mixed land use had a positive effect on P&R usage.

When it comes to reducing distance travelled by car the evidence is not as clear, one American study based on surveys found that P&R significantly decreased car traffic based on the respondents answers (Duncan and Cao, 2020). Most respondents in the study, over 80%, stated that they would not use public transport at all if P&R were unavailable. If a P&R

facility were closed, respondents would either travel to another P&R facility or utilise their private vehicle for the whole trip.

Another study showed no clear results supporting the thesis of a decrease in distance travelled by car when P&R is introduced (Parkhurst and Meek, 2014). A modest decrease could be measured in some of the studied cases while others showed an increase in traffic. This was explained by travellers choosing the car before other mode to get to their public transport stop, simultaneously increased bus traffic, and some travellers driving longer distances than before the P&R implementation. This is confirmed by other studies showing that increasing P&R availability could in fact increase car travel as some travellers switch from biking or walking to automobile for their journey to and from the public transport stop (Parkhurst, 1995; Mingardo, 2013). Another reason for increase in car traffic is that the P&R facility could be utilised by motorists not intending to continue their journey with public transport but is instead using it to access the area around the station/stop.

One British study reported that even if there was a net increase in vehicle kilometres travelled by car as an effect of the P&R, this could still have positive economic benefits (Mills and White, 2018). This was due to the negative effects of more traffic on central congested roads is larger than the effect of more traffic on less busy roads in the periphery of a city.

Further studies indicate that imposing parking charges on the P&R facility seem to decrease the problems with unwanted parking but does at the same time decrease the overall demand for P&R (Mingardo, 2013; Bjørnson and Usterud, 2020). If the cost of parking at the P&R facility is too high in relation to the cost at the destination, there is a risk that motorists instead decide to drive the full length of their journey.

One large American study comparing the effects of P&R and transit oriented development (TOD) found that P&R was much more efficient than TOD in terms of increasing public transport ridership (Niles and Pogodzinski, 2021). Both policies did increase public transport ridership, but the effect was larger from P&R. However, the study suggested further factors needed to be accounted for when comparing the two policies, such as the need for housing, offices, and commercial space. The same study measured the impact of P&R facilities categorized by size and found that larger P&R facilities increases the ridership more than small facilities. The impact was measured for three different transport systems and varied from a 0,00% increase to a 419,30% increase for the creation of one new P&R facility where the larger P&R facilities had a more substantial impact than the smaller ones.

Measured per parking spot increases were in the range of 0,09% to 0,44% per spot. The positive effect on public transport volumes was confirmed by another American study suggesting large marginal impact of adding more P&R facilities (Duncan and Cao, 2020). However, it is also suggested that this is only the case if these facilities are placed at the right locations and planned with the overall system in mind.

2.2 Park and ride in Sweden

An evaluation of the park and ride facilities in Stockholm county was made in 2008 by a consulting firm to try and identify how the park and ride facilities were used and the future demand for them (WSP, 2008). The report used surveys among P&R users and found that most users were living between 1 to 15 km from the station they parked at. The main reason for using P&R among the respondents were the need to do errands on their way to or from the station. Further the study showed that P&R facilities closer to the city centre had a lower average occupancy than those further away.

Public transport in Sweden is administrated on a county level by a county-wide transport authority but responsibility and financing is shared by both counties and municipalities (Sveriges Riksdag, 2010). However, park and ride facilities are mostly built, owned and administrated by the municipalities, as for Stockholm county it is even stated in the guidelines for park and ride that these facilities should be constructed on land owned by the municipalities (SLL, 2019).

In 2011 the Swedish transport administration and SL published a report on a project were information through smart devices were used to try and increase the usage of park and ride while at the same time decreasing car traffic (Lucassi and Nyström, 2011). The project aimed towards reducing the time spent searching for an empty parking spot and to better utilize the park and ride capacity. Users in the try out period could for example book a parking sport before arriving and some were given free public transport tickets as an encouragement for switching mode for their journey. The result from this project was very positive with high approval from the users and an increase in park and ride usage.

A study published in 2012 by the Swedish transport administration on the subject off municipalities usage of parking policies to reduce car commuting reported that the municipalities in general lacked knowledge on how to work with parking policies (Kouchy and Renhammar, 2012). At that time, year 2012, only 4 out of the studies 10 participating municipalities reported that they worked with P&R as one of their policies to control car traffic. Further, it concluded that using different parking policies to reduce car traffic was a relatively new method in Sweden. The municipalities in the study reported that they had earlier primarily worked with increasing the attractiveness of other travel modes rather than to restrict parking or car accessibility. One reason for this was that it was claimed to be a sensitive measure to restrict access for car users. More knowledge was mentioned as something which could potentially increase their willingness to impose new policies as they would be able to argue for the benefits in a more convincing way.

Two Swedish theses could be found on the subject. One studied the occupancy of P&R facilities and which factors contributed to higher occupancy at P&R facilities in Värmdö municipality in eastern Stockholm (Johansson, 2015). The study found that the frequency of departures at the stop/station connected to the P&R was the major factor influencing the occupancy of the P&R. It also recommended expansion of P&R facilities in peripheral locations throughout Värmdö municipality.

The other one studied P&R facilities in Botkyrka municipality, how they were used and how further development and policies related to P&R facilities in Botkyrka could be developed (Scialdone, 2019). Results showed around one quarter of P&R users in Botkyrka lived in other municipalities. Further, the study showed there was a large problem in Botkyrka with users not utilizing the public transport but instead using it as a regular parking lot. Notably the parking lot was used even during night-time by residents in the nearby area. Increased parking fees for those not having a valid public transport ticket was suggested as a solution to this issue.

2.3 County strategies for P&R

Many Swedish counties have recently confirmed P&R as a part of their overall transport planning and some counties have even chosen to develop strategies or guidelines especially for P&R (Västra Götalandsregionen, 2008; Region Skåne, 2017; Region Norrbotten, 2018; Region Uppsala, 2019; SLL, 2019).

Stockholm county's strategy is called *Riktlinjer för infartsparkering* (Eng: Guidelines for park and ride) and contains both recommendations and requirements regarding how new P&R facilities should be built (SLL, 2019). The strategy handles P&R for both car and bike and gives recommendations on when it should be considered. It also gives some guidelines on the physical design as well as regulation regarding financing and the division of responsibilities between county and municipality. In addition, it states that P&R (for cars) should primarily be used as a supplement for travellers in parts of the county where the public transport is unable to reach or provide sufficient frequency for all parts of the journey. The strategy further states that P&R should be used with caution as it could potentially lower the demand for connecting bus-services if travellers choose to use the car to access the primary lines and travel modes.

Uppsala county's strategy is similar to Stockholms and also handles both P&R for bikes and cars (Region Uppsala, 2019). The strategy is not as extensive in its recommendations and requirements but handles roughly the same areas such financing, physical design, and availability. One clear difference is that Uppsala's strategy includes a map and description of which parts of the public transport network are prioritised for P&R facilities.

Another part that differs is the recommendation on how to assess the need for P&R, Stockholm has three different scenarios with different recommendations on P&R for each of them (SLL, 2019). Uppsala on the other hand recommends individual assessments for each proposed P&R facility and mention customer surveys as one method of assessing the demand for P&R (Region Uppsala, 2019).

Gothenburg did a pilot project in 2008 to evaluate how P&R facilities can be designed and how they can help increase the attractiveness of public transport (Västra Götalandsregionen, 2008). The project concluded that the safety and design of parking facilities have a large impact on traveller's willingness to use them, this was the case for both bike and car parking. In opposite of Stockholm's strategy, Gothenburg recommenderd that the P&R facilities should not be seen as a supplement to public transport but a policy which enables a developed public transport. Additionally, they saw a need for P&R to receive a higher status as a policy and should be included earlier in the overall planning process for the transport system in the county.

2.4 Literature summary

From what has been reported in earlier academic studies, it is clear there exist knowledge gaps in the subject of parking policies. This was further acknowledged by the report from the Swedish transport administration confirming that there is need for more knowledge in a Swedish context as well. The strategies developed by the counties also lacked estimations on what effect can be expected from P&R facilities even though the main goal stated is to increase public transport ridership. The fact that both counties and municipalities have stated that P&R is a policy they intend to use also acknowledges the need for research in the area.

The literature indicates that parking has a substantial impact on the urban environment and how people choose to travel, yet policymakers lack understanding of how to manage parking and gain the desired effects from the policies. Given that the major focus among most policymakers in the transport area is to decrease car traffic and its environmental impact it is important to know how these policies affect the transport system. As P&R is a policy which is mainly adapted to achieve these goals it is crucial to know which impacts to expect from it.

3. Description of cases

3.1 Stockholm commuter trains

The commuter train network in Stockholm County consists of 54 stations on seven different lines (SL, 2020). The network services wide parts of the Stockholm County with two branches in the north and three in the south, a total of three which extends outside Stockholm County. The northern branches extend from central Stockholm towards Bålsta and Uppsala, both located in Uppsala County. The Northern branch towards Uppsala also has a short appendix towards the locality of Märsta. South of Stockholm there are two major branches extending from the city centre towards Nynäshamn and Södertälje with a short connecting branch from Södertälje to Gnesta in Södermanland county. These branches are all part of the national railway network which means they are managed by the Swedish transport administration and the infrastructure is shared with regional and long-distance trains (Trafikverket, 2018). However, since 2017 the commuter trains have their own dedicated tracks through central Stockholm as well as their own underground stations.

Change to regional and/or long-distance trains can be made at Uppsala central, Knivsta, Märsta, Bålsta, Sundbyberg, Flemingsberg, Stockholm City and Södertälje syd.

P&R facilities could be identified on a total of 42 stations, all of which were located outside the most central parts of Stockholm. The number of parking spots at each P&R facility varied from 21 spots at the smallest facility to 509 at the largest facility. Stations without P&R facility but which were located outside central Stockholm were included in this analysis. They were represented in the data as having a P&R facility with 0 parking spots.

At the stations with both commuter and regional train services it is not possible to determine the share of passengers using the P&R facility for each mode. This means there is a risk that stations with many parking spots appears to attract a low volume of passengers while the users are instead using the P&R to access other train services not included in the data. Therefore, these stations have been excluded from the analysis. Further, stations which are major transit points between different travel modes were excluded since a high share of passengers might in fact not start their journey there but are simply switching mode. Any stations located within a city centre were also excluded due to being the main destinations for travellers using the commuter rail system.

When the commuter train system was studied with GIS it was found that different parts of the system had varying characteristics, even when deducting the inner-city stations. Some areas had stations very close by and in some cases the walking distance radius overlapped (see section 4.1 about walking distance). Due to the different characteristics of the stations within the systems and to get further insight on the effects of P&R, the stations were divided into two different categories: suburban stations and semi-rural stations. Suburban station was considered the default station type, a located station in a continuous suburban environment.

A semi-rural station was defined as:

- The station being the only one within the locality
- The station being located at least 2 x W away from the closest station
- The locality not being connected to other development in more than one direction

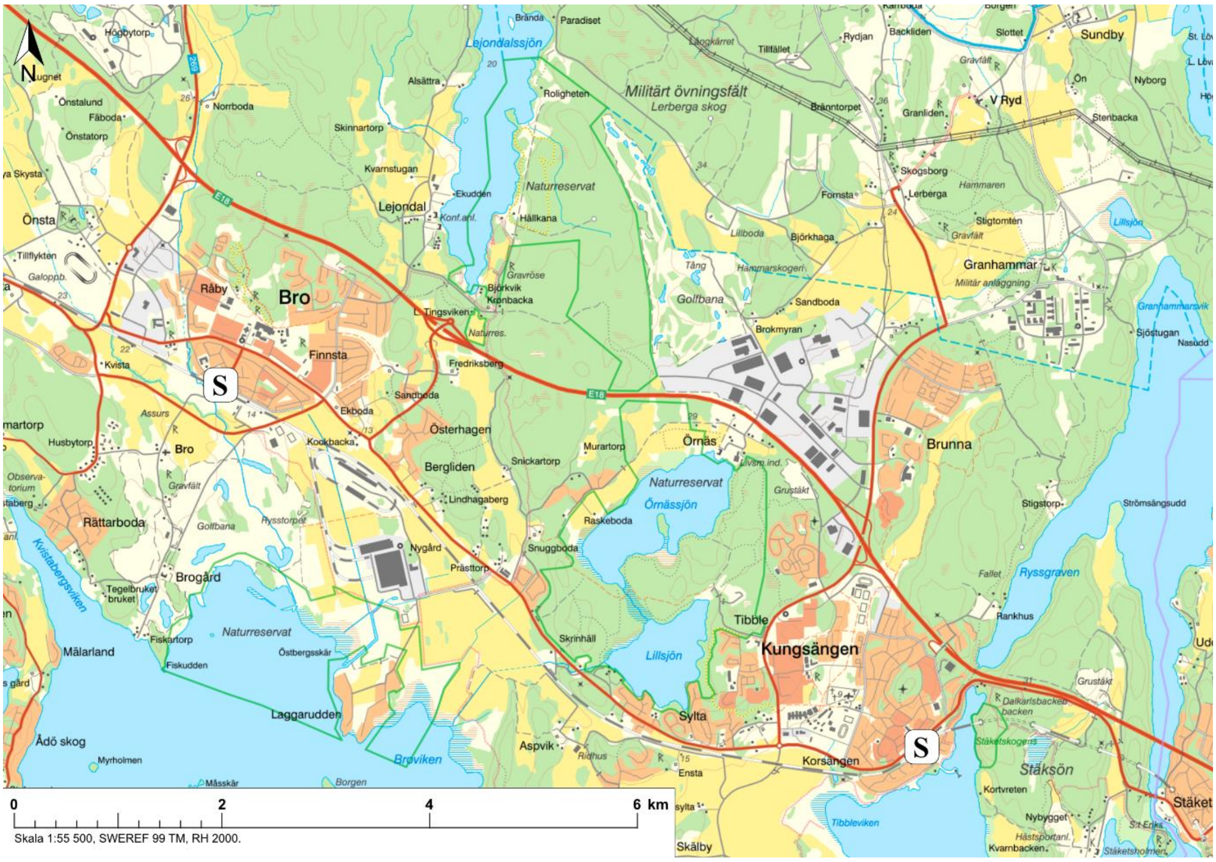

Figure 3. Map over Kungsängen and Bro, commuter train stations marked with "S".

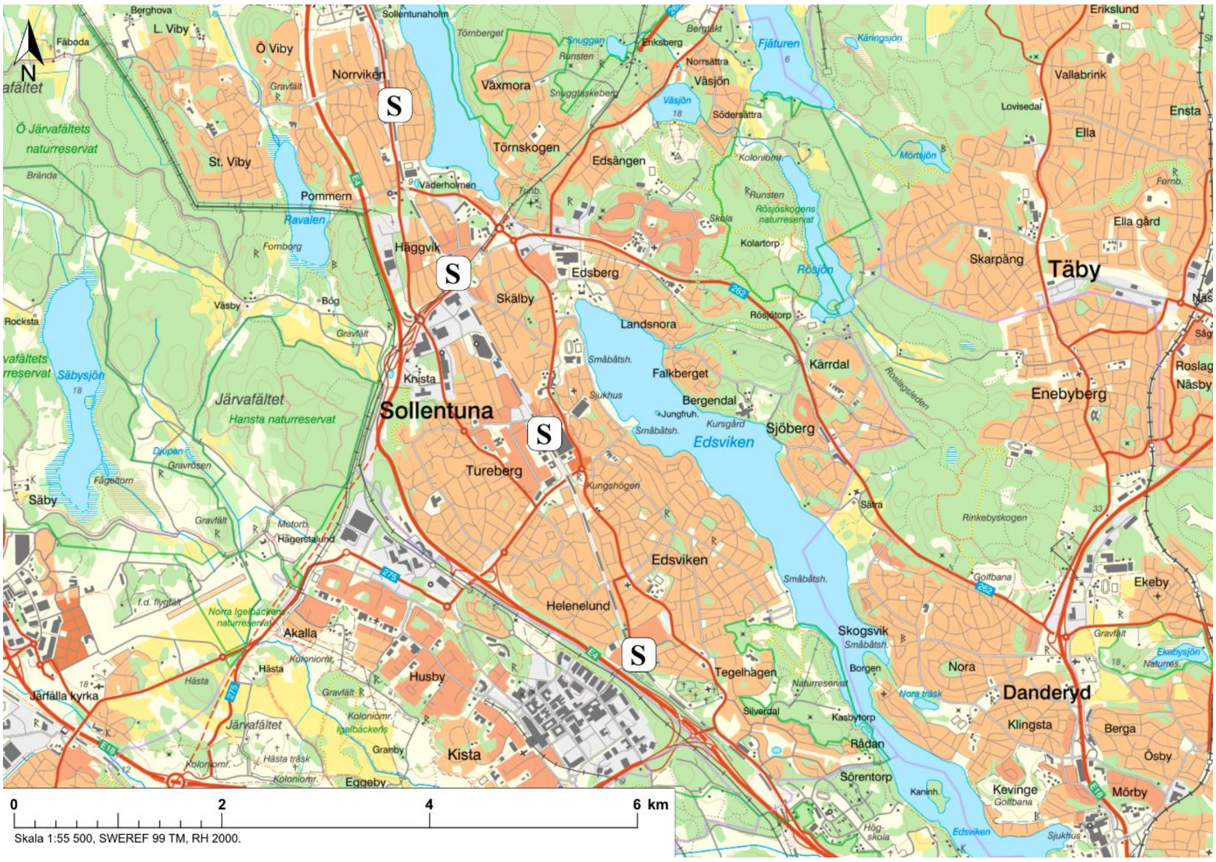

Figure 4. Map over Sollentuna, commuter train stations marked with "S".

In figure 2, an example of two stations categorised as “semi-rural” is displayed. The localities Bro and Kungsängen have no continuous development between them, and the stations are far apart. Both localities also only have one station each.

Sollentuna, displayed in figure 3, is an example of a locality where the stations are categorised as “suburban”. The development is continuous throughout the whole area and several stations are located within the locality.

Apart from the two categories a combined data set was also analysed containing all stations from both categories, referred to as “Combined” in the analysis.

3.2 Uppsala regional trains

The regional train network in Uppsala County goes by the name *Upptåget* and consists of two lines which both starts at Uppsala central station and terminates in two other neighbouring counties (UL, u.d.).

The networks two lines are:

- Uppsala – Gävle, 13 stations
- Uppsala – Sala, 4 stations

The line from Uppsala to Gävle is around 90 km long and the line from Uppsala to Sala is about 55 km long.

The network is run entirely on main-line railways managed by the Swedish transport administration which means the infrastructure is shared with other operators. Change to other regional services or long-distance trains can be done in Uppsala, Gävle and Sala.

Locations served by the network, apart from Uppsala and Gävle, consists of mostly small towns and villages as opposed to the Stockholm commuter network where most locations have the character of suburbs (Statistics Sweden, 2021).

Due to being stations in city centres as well as major exchange stations in the network, Gävle and Uppsala were excluded from the analysis. Sala was also excluded from the analysis as this station is also served by other regional train services. Since Sala has P&R spots it would not have been possible to determine which train service a P&R user choose.

The stations within Uppsala County were found to have similar characteristics to each other and no overlapping walking distance radiuses were detected. Therefore, no categorisation of the stations was made within this dataset.

However, two of the stations, Älvkarleby and Tobo, are located outside of their corresponding villages which means there are almost no population within the suggested walking distance but were left in the data set. They were therefore expected to have very high ratios.

3.3 Stockholm temporal data

Stockholm’s transport system consists of some 7254 stations divided on the modes, bus, metro, commuter train, ferry, light rail, and tram (SL, 2019). P&R facilities exist for most of the modes but is more common on commuter train stations as the assessment in chapter 4.1 indicated. To make a before and after analysis of the effect from adding more P&R spots the introduction of them had to be identified and dated. This was done through extensive web search which have mostly focused on the website of municipalities or local news-sources as it was found to be difficult to find any official assembly of information regarding introduction dates for P&R.

This dataset contains stations from different modes in Stockholm where an actual date of the introduction or expansion of P&R could be identified. It was found that not enough P&R facilities could be dated to create a categorised dataset. Instead, a mixed dataset was chosen which contains stations and stops from all modes in Stockholm. However, it is not constructed with the modes total share of passengers in mind but was instead intended to include as many stations as possible to ensure an enough large sample size for the statistical analysis.

In this report both expansion and the introduction of a new P&R facility are referred to as an *implementation* of P&R. A total of 32 P&R implementations could be identified and dated in Stockholm County. This was then narrowed down to 20 P&R facilities due to restrictions in data or station characteristics.

Stations included are from different systems in the Stockholm and consists of the following:

6 Commuter train stations
5 Metro stations
1 Light-rail stop
9 Bus stops*

**Two of the bus stops served the same P&R facility and is in the analysis therefore considered as one.*

4. Methods

The methods described in section 4.1 and 4.2 were used for the Stockholm County commuter train dataset and the Uppsala county regional train dataset. The method described in section 4.3 were used for the mixed mode temporal data set.

4.1 Static analysis of ratio relation

To compare different stations with each other and to gain some actual information on the impact of a park and ride facility close to the station the passenger data was normalised in relation to the population in vicinity of each station.

For this normalisation, the number of people living within walking distance from a station was considered as Park and ride is aimed towards people living further away than what is considered an appropriate walking distance. The walking distance considered was set in accordance to earlier studies which suggest a distance between half a mile (0,8 km) and 1 km as appropriate walking distances for express services (Kottenhoff and Lindahl, 2018; Niles and Pogodzinski, 2021). Further studies suggests longer walking distance can be accepted for more frequent and faster public transport services (Islam Sarker, 2015). Further, the number of travellers driving less than 1 km to a P&R facility is very low (WSP, 2008; Bjørnson and Usterud, 2020). Therefore 1 km was suggested for the commuter and regional train lines since these operate at a high speed and with a relatively high frequency.

The number of people living within walking distance was approximated in two steps:

First the walking distance was set as a radius according to a method from the Swedish transport administration (Trafikverket and SKL, 2012). This method simplifies walking distance analysis by dividing the desired walking distance with a factor of 1,3 which then becomes a radius set around the station giving an approximated real walking distance.

In the next step population data from Statistics Sweden were used to calculate the number of people living within the set radius. As the population statistics is given per square kilometre in predefined squares, the population within the radius was approximated by calculating the share of each “statistics square” located within the radius. This share was then multiplied with the population of the square and summarised for all squares intersected by the radius.

$$w_r = walking\ distance\ radius\ = \frac{1000}{1{,}3} \approx 770\ m$$

$$A_s = Area\ statistical\ square$$

$$A_I = Area\ intersect$$

$$w_r \bigcap A_s = A_I$$

$$P_s = Population\ statistical\ square$$

$$p_w = population\ within\ walking\ distance$$

$$\frac{A_I}{A_s} \times P_s = p_w$$

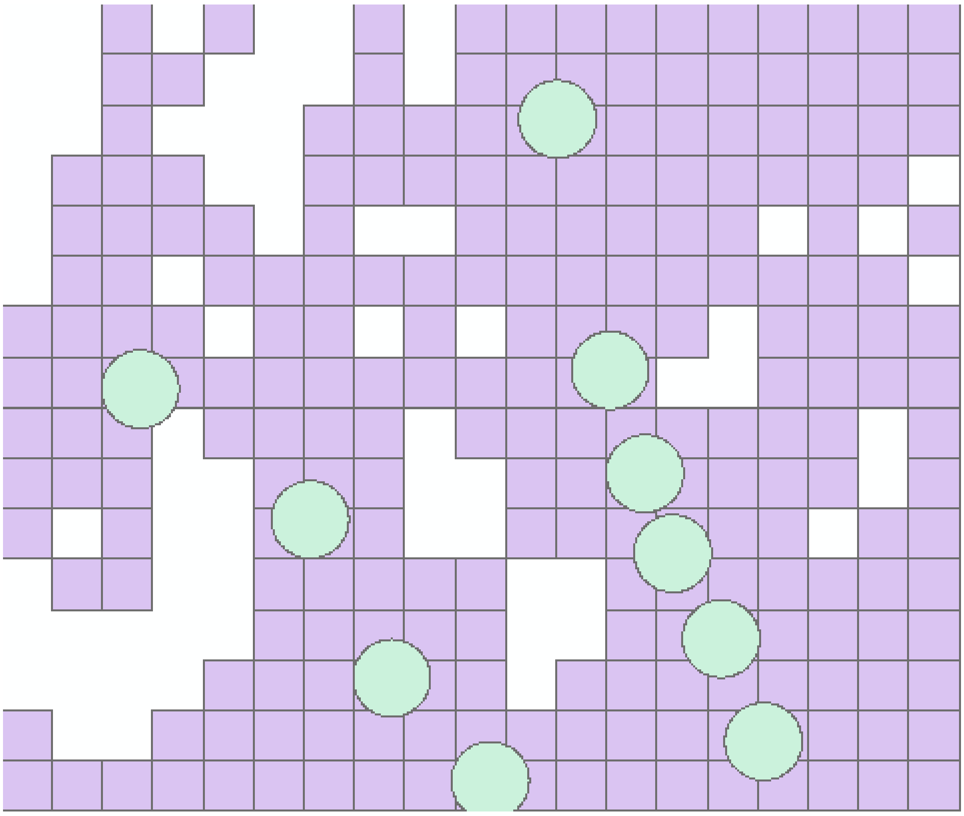

Figure 5. How the data appear in Arcmap, statistical squares in purple and radiuses in green.

The radius was then assigned to each stations geographical position using Arcmap and laid over the statistical squares for the same region, this is seen in figure 4. The white fields indicate areas without any inhabitants such as lakes, forests etc. In Arcmap the calculation of population within each radius was done automatically using the tabulated intersect tool.

By dividing the number of passengers for a station with the number of people living within the walking distance a ratio is created which indicates the relation within daily boarding passengers and people living within walking distance around the stations. A value of 1 means there is one boarding passenger per person living within walking distance. A higher value should theoretically indicate that more passengers are transiting to the station from outside of the area within walking distance.

This was calculated according to the following:

$b = boarding\ passengers$

$R = Ratio$

$$R = \frac{b}{p_w}$$

After this, a regression analysis was done using the calculated values to determine if any correlation between the number of parking spots and the ratio exists.

Regression is a statistical method which is used to analyse the relationship between two or more variables (Montgomery, et al., 2012). The regression analysis method uses the *method* *of least squares* to fit the model equation to the data, linear regression model being the most common one and is the one used in this study.

It can be written on the form:

$$y = \beta_0 + \beta_1 \times x$$

Where:

- β_0 and β_1 are constants
- x is the variable y is dependent of

The equation commonly also including a random error-component.

Further, the so called, proportion of variation or more commonly known as R2-value can be computed. This value indicates to which degree the model explains the variation in the data and ranges from 0 to 1 where a R2 of 1 means the model fully explains the variation. This can also be expressed as that a R2 of 1 indicates a 100% explanation by the model.

4.2 Static analysis of direct relation

The second method aims to measure the direct relation between passengers at a station and the number of parking spots at the station. This was done in form regression analysis which directly compared the total number of passengers with the total number of P&R spots.

The method was chosen as the total number of P&R spots was expected to have a larger direct impact at stations located further away from the city centre. Earlier studies reported that P&R facilities further from the city centre had higher utilization rate.

4.3 Temporal data analysis

The different stations which were part of the dataset had their P&R implemented or expanded at different times. This meant they could not be compared as a group directly towards another set of stations or the general trend during a certain time. Instead, each station had to be compared to the general trend for the transport system at the time it was implemented.

The method used, summarized the number of tap-ins eleven months before the P&R implementation and the month when it was implemented. This formed a value consisting of one year’s worth of tap-ins regardless of which month the P&R was introduced. The twelve months after implementation of P&R formed the corresponding one years’ worth of tap-ins for the period after.

Using these two summarized values the percental and absolute increase could be calculated. With this method the seasonal variation in travel demand was accounted for since both the data before and after the implementation was made up of values from all twelve months. The month the P&R implementation was done was assigned to the twelve months before the implementation since no large immediate effect was expected. The same process was done for the total number of tap-ins on all travel modes during the same time periods.

The calculation method is displayed below:

$m_c = month\ when\ P\&R\ was\ implemented$
$t_n = tap - ins\ for\ month\ m_c + n$

$T_n = total\ tap - ins\ for\ month\ m_c + n\ (all\ systems)$

$$d_s = \frac{\sum_{m_c+1}^{m_c+12} t_n - \sum_{m_c-11}^{m_c} t_n}{\sum_{m_c-11}^{m_c} t_n}$$

$$d_{tot} = \frac{\sum_{m_c+1}^{m_c+12} T_n - \sum_{m_c-11}^{m_c} T_n}{\sum_{m_c-11}^{m_c} T_n}$$

$d_s = difference\ for\ one\ station$

$d_{tot} = difference\ for\ all\ systems$

This generated two groups with 20 values in each. The first one referred to as P&R is the group containing the changes for all the stations which had P&R implemented. The second group referred to as System contained the whole transport systems change during the same time periods.

These two groups, P&R and System, were then tested statistically against each other to see if any significant difference could be detected. A dependent test was considered appropriate since the passenger volumes at the P&R stations are in fact included in the overall System passenger volume.

To find a suitable test, the groups variances was first tested using *Levenes test for equal variances* which is used to determine if two sample groups have different variances (Gastwirth, et al., 2009).

Further to determine appropriate test, the groups were also tested for normal distribution. This was done using a Shapiro-Wilk test which is a useful test for determining if a group of observations is part of a normal distribution (Puri & Rao, 1976). The method works similar too other statistical methods and outputs a significance (p-value) which indicates if the distribution differs from a normal distribution.

If equal variances and normal distribution appears for the groups a *t-test* can be performed to determine if the groups differ from each other (Slkind, 2007). If this is not the case a nonparametric test such as the *Wilcoxon singed-ranked test* can be performed (Kasuya, 2009). Though this test requires that the difference between the two groups is symmetrical, if the data is highly asymmetric the usage of the method is not recommended.

Symmetry can be analysed by tests, graphically or by evaluating the skewness of the data (Mandrekar, et al., 2004). Skewness is a measure which can indicate both symmetric and if a distribution is normal (Von Hippel, 2011). The measure appears as a negative a positive value indicating in which ‘direction’ the data is skewed. A negative value indicates a skewness to the left while a positive indicates the opposite, the closer a value is to zero the less skewed the distribution is.

The Wilcoxon test, like the t-test, produces a p-value indicating a certainty that the null hypothesis is true. In this case the null hypothesis being a difference between the increase for stations with P&R implementation and the total system increase. This was tested on a 95% level, which means the p-value should be below 0,05 to indicate a significant result.

This can be stated as: $H_1: \mu_1 = \mu_2$

Where μ_1 is the population mean for group 1, and μ_2 is the population mean for group 2.

For the statistical calculations, the software IBM SPSS was used.

The difference between the stations with P&R and total system data was then used to calculate an average effect caused by the P&R implementation.

$$E_p = \sum d_s - \sum d_{tot}$$

$$E_p = Effect\ from\ P\&R$$

Further the effect of adding one parking spot was estimated by calculating the *expected* number of passengers for the 12-month period after the P&R implementation if the implementation would not have happened. As each station was on average expected to follow the general increase for the whole system the estimated increase was calculated by multiplying the 12-month period before the P&R implementation with the percental change for all systems. The estimated yearly passenger increase for one parking spot was calculated by summarizing the actual passenger volumes after P&R implementation and subtracting the sum of the expected passenger volumes and dividing this with the total number of implemented parking-spots. This was later further adjuster to display the daily increase in passengers.

Calculation method is displayed below:

$$b_p = Passenger\ volume\ before\ P\&R$$

$$a_p = Passenger\ volume\ after\ P\&R$$

$$Y_p = Increase\ in\ passengers\ for\ one\ parking\ spot\ for\ one\ year$$

$$b_p = \sum_{m_c-11}^{m_c} t_n \qquad a_p = \sum\nolimits_{m_c+1}^{m_c+12} t_n$$

$$Y_p = \frac{\sum a_p - b_p \times (1 + d_{tot})}{\sum p_s}$$

This was also done individually for each station such as with the percental increase providing one average station value and one value calculated from the total increase for all stations.

5. Data

5.1 Data SL commuter trains

The data used in this analysis is collected from the official statistics presented by SL each year in form of the report *Fakta om SL och länet* (facts about SL and the county). The publication is available from year 2007 to 2020. Due the large impact of Covid-19 on travels the data from year 2020 was not used, instead the data from 2019 was used.

Data regarding the number of parking spots at each station was collected from both official sources such the municipalities websites and by manual assessment using flight images. At some locations, the parking facilities lacked marked parking spots, in these cases the capacity of the P&R was approximated by measuring the parking lots length and approximating by dividing by the measured parking spot width in the area, usually 2,5 m.

Full list of stations and data is presented in appendix 11.1.

5.2 Data Uppsala regional trains

Passenger data was provided by Uppsala County and consists of the average number of boarding passengers per day. The data is collected through sensors which around 30% of the vehicles are equipped with, the total number of daily travellers is then approximated using the measured data (Engvall, 2021). The provided data were from 2017 to 2019, however only the data from 2019 was used in the analysis.

Full list of stations and data is presented in appendix 11.2.

5.3 Data temporal dataset

Access card data is collected when passengers tap their card at the metro gates, when boarding the bus or on the platform at the light rail stations. The data is the actual number of tap-ins rather than an approximation for different time periods as opposed to the data officially published by SL in *Fakta om SL och länet.* Further the access card data is available for every month rather than just every year.

List of stations included can be found in appendix 11.3, and data for the stations can be found in appendix 11.4.

For this study, the data is used in its raw form without any transformation or processing. As this study focuses on the number of passengers boarding at the station or stop where P&R is introduced there is no need to create any analysis method to know where the passengers end their journey. It is also not necessary to know how many passengers alight at the station. Those alighting at the station will not use the P&R facility, and if they do their tap ins have already been registered when they first parked their vehicle there.

This data is available for the period of 2013 to 2021 but due to the impact of Covid-19 on travel volumes only the period 2013 to February 2020 is considered.

This data was provided by the department of transport planning at KTH.

6. Result

6.1 Stockholm commuter trains

Ratio regression

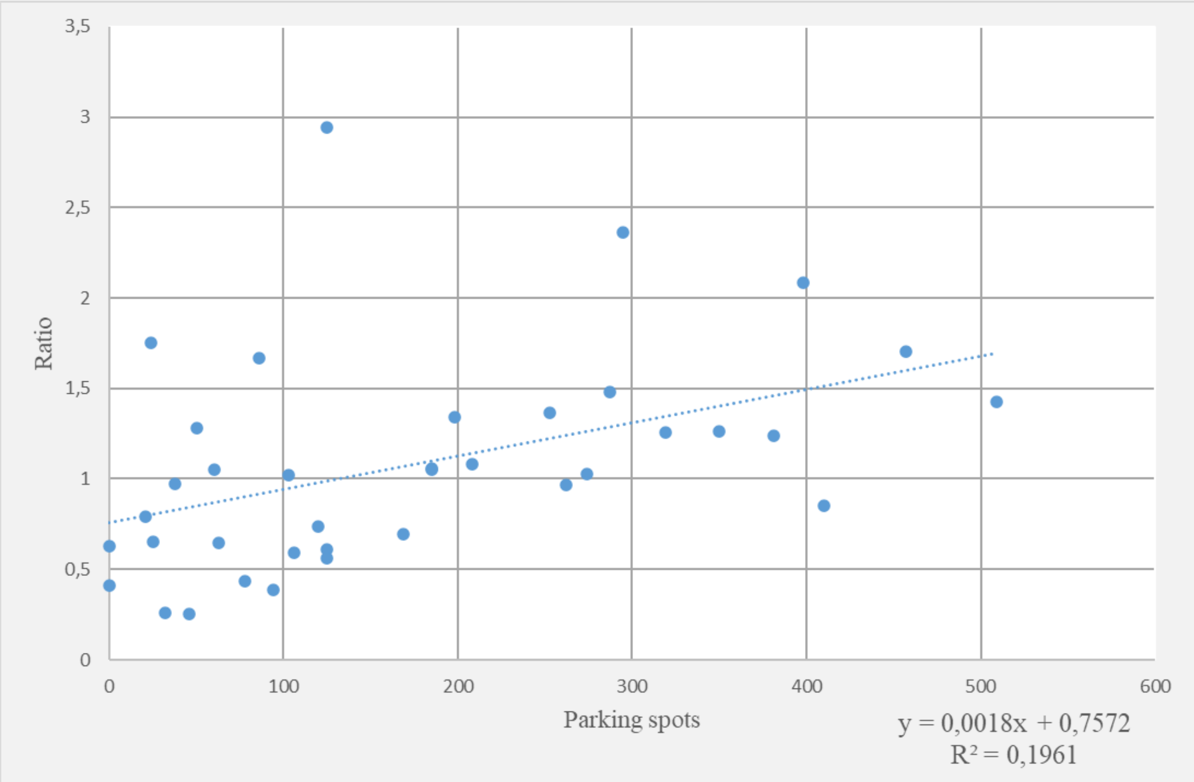

Figure 6. Scatter plot of the ratio and number of parking spots for each commuter train station.

The R2 value of 0.1961 indicates a low degree of explanation for the ration from the number of parking spots at each station. Ratios varied from 0.25 as lowest to 2.94 as highest with an average ratio of 1.08.

The linear model fitted to the data was: $R_m = 0.7572 + 0.0018X$

Where $R_m = modeled\ ratio$

This suggests a 0.0018 increase in ratio for every added parking spot.

One clear outlier, the station *Södertälje hamn*, could be identified with a relatively low number of parking spots, 125, but a very high ratio between passengers and people within walking distance 2.94.

When the outlier *Södertälje hamn* was removed the degree of explanation was improved with a new R2-value of 0.319. The average ratio was slightly lower at 1.03 with the highest ratio now belonging to Älvsjö, measuring 2.36.

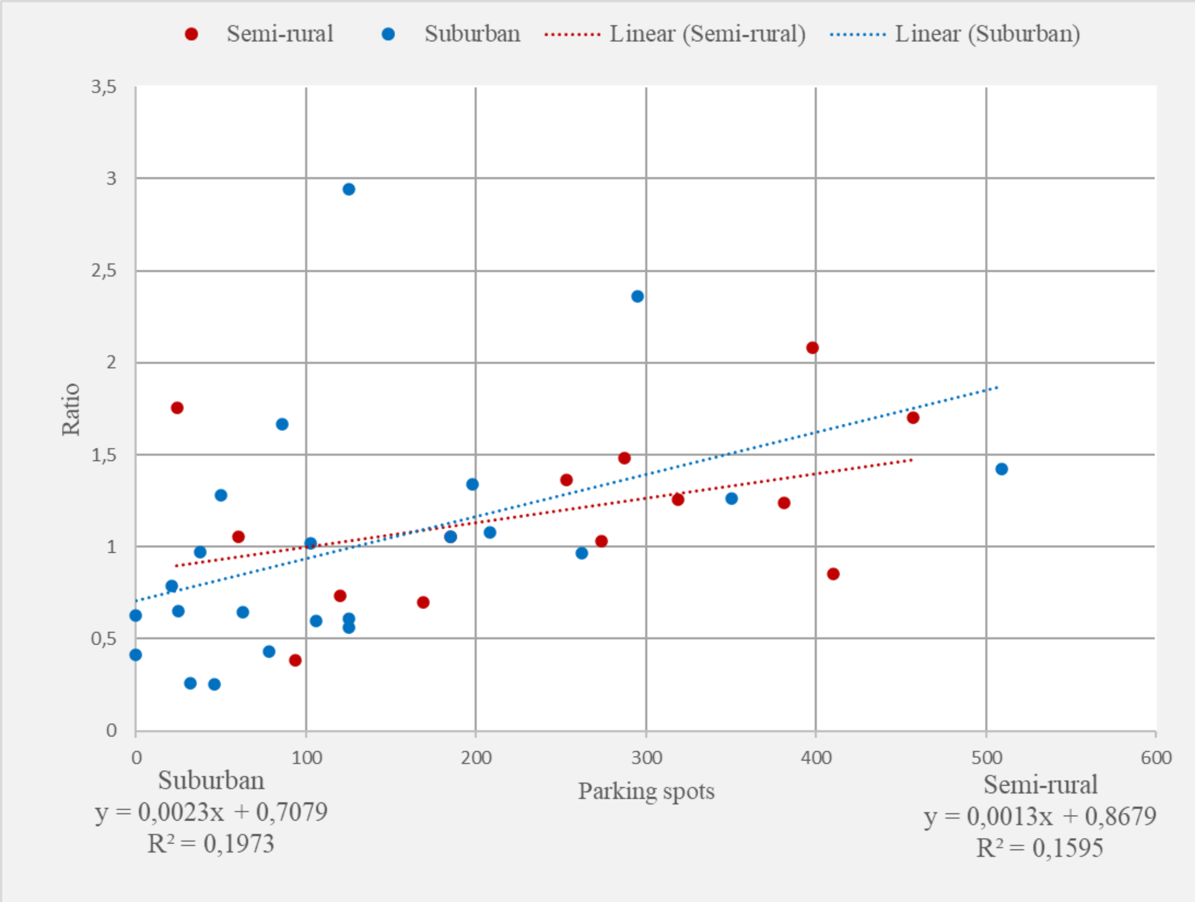

Figure 7. Scatter plot of the ratio and number of parking spots by category.

The suburban category saw a R2-value of 0,1973, marginally higher than for the combined data. The semi-rural category saw a R2-value of 0,1595 which is lower than for the combined dataset. This indicated a low degree of explanation in both cases.

Table 1. Fitted linear models for the three different categories.

Category	Linear model
Suburban	$R_m = 0.7079 + 0.0023X$
Semi-rural	$R_m = 0.8679 + 0.0013X$
Combined	$R_m = 0.7572 + 0.0018X$

The linear models differed somewhat from the model fitted to the combined data. For the suburban category the model had a steeper slope but lower intersect, whilst for the semi-rural it was the opposite case.

Direct values regression

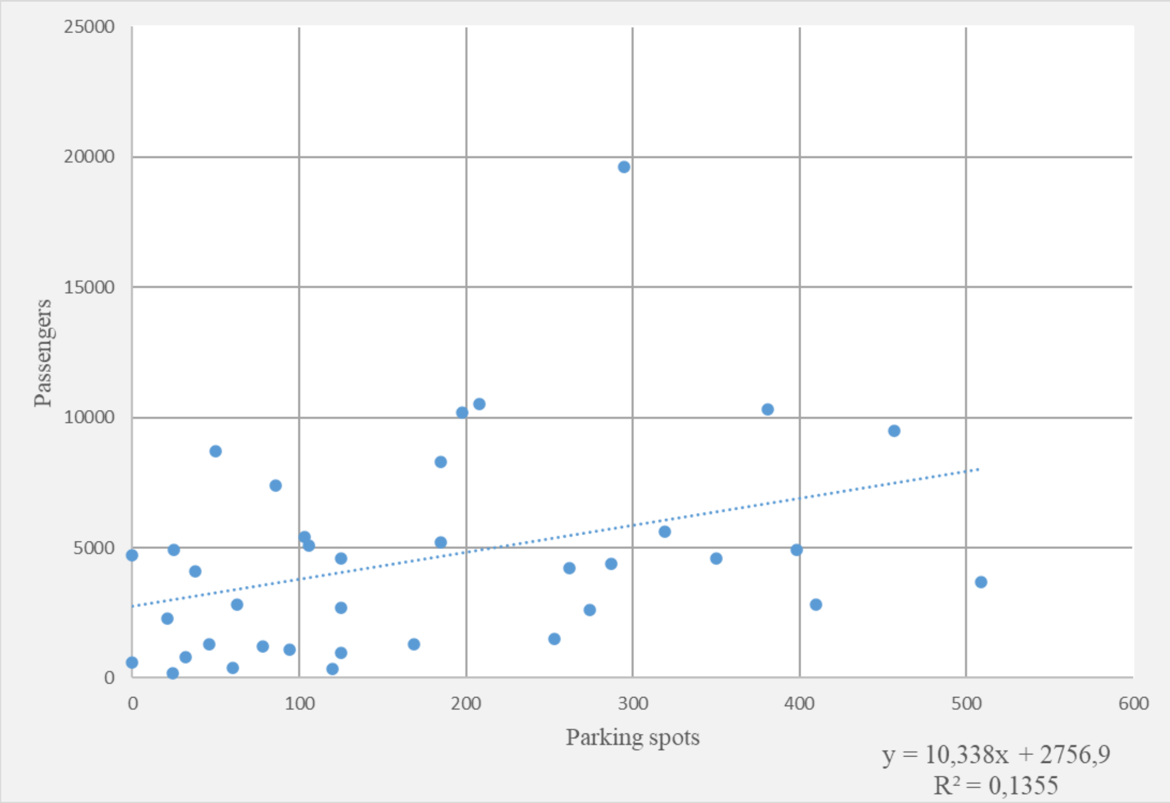

Figure 8. Scatterplot of daily passengers and parking spots for all commuter train stations.

The analysis shows a R2-value of 0,1355 which indicates a very low correlation between the number of parking spots and the number of passengers for each commuter train station.

The linear model fitted for the data was:

$$b_m = 2756{,}9 + 10{,}338X$$

$$b_m = modelled\ boarding\ passengers$$

$$X = number\ of\ parking\ spots$$

This suggests a base volume of 2756,1 passengers with an additional 10,338 passengers for every parking spot at the station.

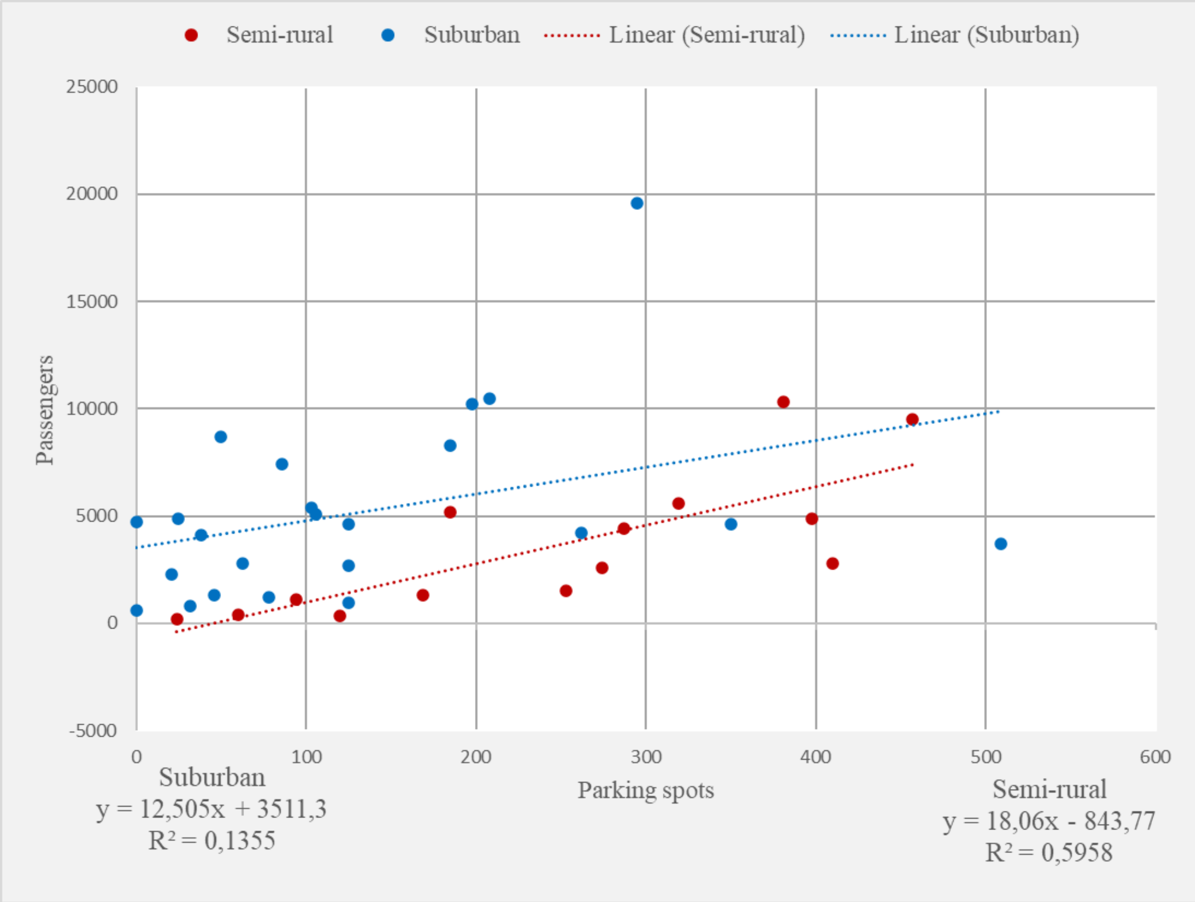

Figure 9. Scatterplot of daily passengers and parking spots for each commuter train station by category.

The R2-value for the suburban category was the same as for the total data set, 0,1355. For the semi-rural category, the R2-value was 0,5958 indicating a moderate correlation between the number of parking spots and the passenger volume.

Table 2. Linear models for the categories and combined data.

Category	Linear model
Suburban	$b_m = 3511{,}3 + 12{,}505X$
Semi-rural	$b_m = -843{,}77 + 18{,}06X$
Combined	$b_m = 2756{,}9 + 10{,}338X$

The linear model for the suburban category is similar the one for the combined data set but with a higher intercept at just above 3500 passengers. The increase per passenger (derivative) indicated a higher passenger increase per parking spot than for the combined category.

The rural model showed a negative intercept at just below -840 passengers. However, the passenger increase per parking spot was much higher than for the combined, and the suburban category at just above 18 passengers per parking spot.

Analysis

The model indicated a positive relation between ratio and number of parking spaces for all three categories with increases in ratio around 0,020 for all three. However, the low R2-values indicated low degrees of explanation for the ratio by the number of parking spots. The number of parking spots available did not to a large degree explain a stations ability to attract travellers from outside the area within walking distance. This was the case for all three categories with a slightly higher degree of explanation when removing the high-leverage outlier. The higher intersect indicated by

The regression of parking spots and passenger volumes directly, indicated more mixed results with differences between the categories. A low degree of explanation was indicated for the combined and suburban categories, even when removing one high-leverage outlier the R2-value was just above 0,3. The semi-rural saw a moderate degree of explanation with a R2-value of just below 0,6. This would suggest that in the semi-rural case the number of P&R spots affects the number of public transport users positively.

Further, comparing the linear models in table 2. it becomes clear that the measured effect per parking spot is also more substantial for the semi-rural case. An increase in 18 passengers per spot is a very high value, for comparison average car occupancies are usually in the range of 1,1 to 2 passengers per vehicle, depending on trip type (European environment agency, 2020). Higher occupancies were reported for a rural environment, but this is still implies 9 new vehicles per parking spot and day which is unrealistic. Likely there are other effects related to P&R which increases the number of passengers beyond the theoretical increase limit. Alternatively, the capacity of P&R facilities is built with regard to the number of current passenger volumes at a station.

Comparing the intersect values for the two regressions in table 1 and table 2 shows the semi-rural category has a higher intersect value than the suburban category in the ratio analysis, but in the direct comparison the case is the opposite. The other way around goes for the derivative of the functions where suburban had a higher increase in ratio per parking spot and the semi-rural a higher increase of passengers per parking spot. It appears as the semi-rural stations starts at relatively high levels of passenger to population ratio but the increase for every new parking spot is not as substantial as for the suburban case. Instead, it seems like the semi-rural stations are more dependent directly on the number of parking spots to attract passengers.

6.2 Uppsala regional trains

Ratio regression

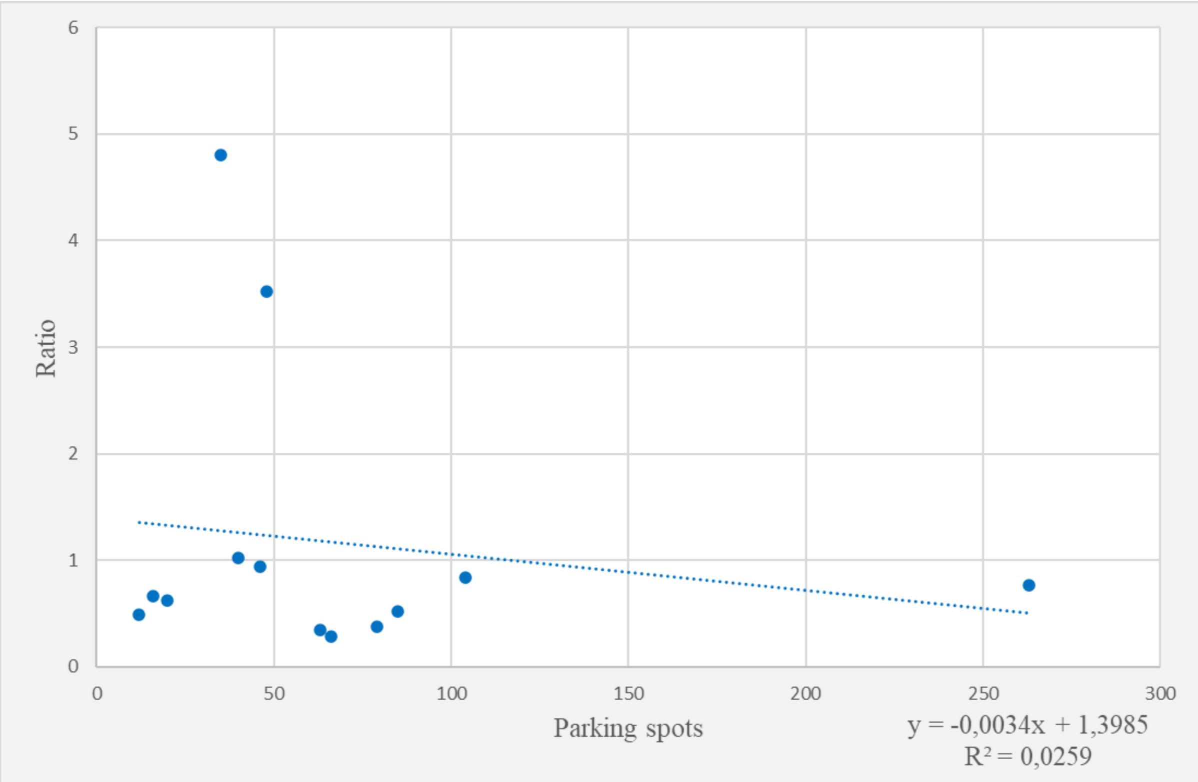

Figure 10. Scatter plot of the ratio and number of parking spots for each train station.

As seen in figure 9 there is no indication of correlation between the number of passengers and the ratio. The ratio varied from 0,13 as the lowest to 4,8 as the highest with an average value of 1,10. As expected Tobo and Älvkarleby had the highest ratios, 4,8 and 3,5 respectively. The R2-value of 0,0259 indicated a very low degree of explanation for the ratio by the number of parking spots. The R2 was not improved when the two outliers, Tobo and Älvkarleby was removed.

Direct comparison regression

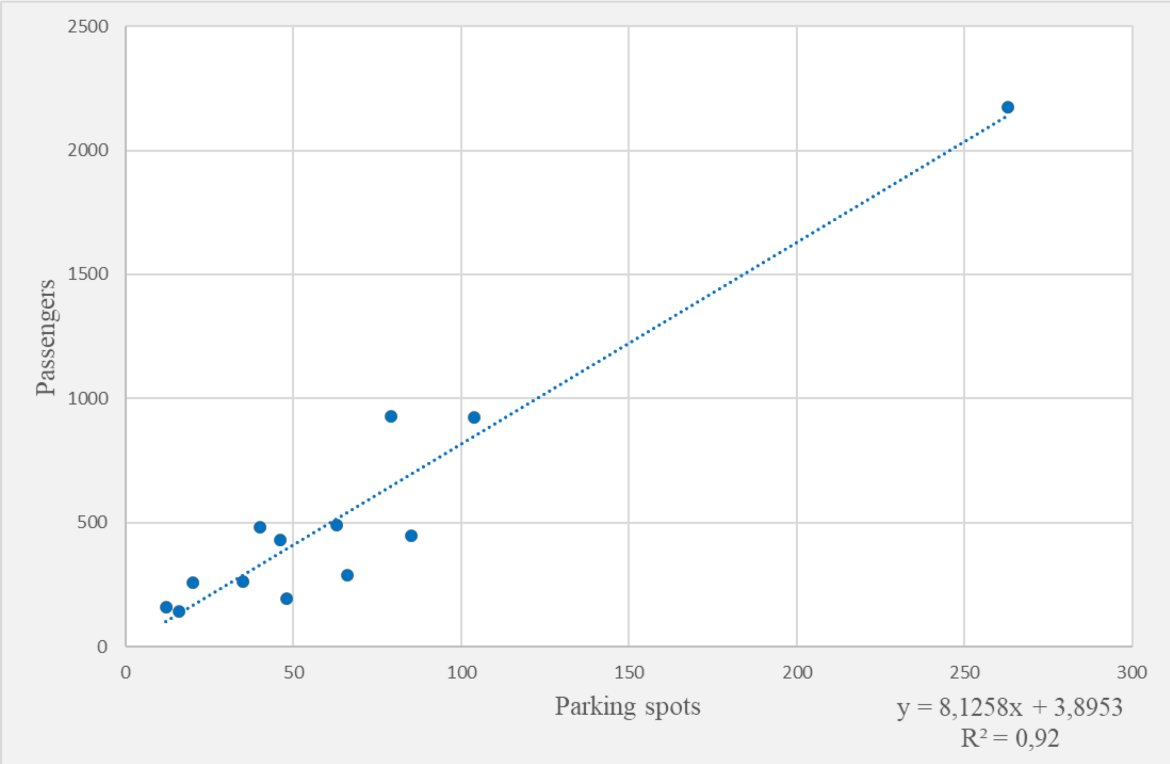

Figure 11. Scatter plot of the number of passengers and number of parking spots for each station.

The R2 value of 0.92 indicates a high degree of explanation for the number of passengers from the number of parking spots. One high leverage outlier, Tierp, can be detected. When removed from the regression the R2-value was lower at 0,6393 which still indicates a moderate degree of explanation.

The linear model fitted for the data was:

$$b_m = 3{,}90 + 8{,}13X$$

$$b_m = modelled\ boarding\ passengers$$

$$X = number\ of\ parking\ spots$$

This suggests a base volume of 3,9 passengers with an addition of 8,13 passengers for every parking spot at the station.

Analysis

The regression analysis of the passenger volumes and the ratio suggested no correlation as the degree of explanation was very low. Tobo and Älvkarleby stations clearly illustrated how the ratio can easily be exaggerated when stations are located outside the population centres. The average ratio of 1,1 does however suggest that there are passengers who transit to the stations from origins beyond walking distance. As it is not expected that everyone living within walking distance will do one trip per day, even number around 1 would still suggest some transferring passengers to the station.

When analysing the regression between daily passengers and the number of parking spot directly there was a high degree of explanation suggesting a high impact on passenger volumes from the number of parking spaces. The linear model suggested that each parking spot would generate an additional 8,13 passengers. This is a very high value which indicates that there's likely other factors related to the P&R facility which helps increase the passenger volumes. One possible factor is bike stands which is commonly included in P&R facilities, and in the case of Uppsala county this is stated as an obligatory feature in their guidelines for P&R (Region Uppsala, 2019). Bike stands are difficult to include in the analysis as the number of spots are rarely stated for each station and would likely require manual counting to be correct.

6.3 Mixed modes temporal data

The average growth between the 12-month period before P&R was implemented and the 12-month period after is displayed in the table below together with the maximum and minimum values measured for one station. Difference is the P&R stations deviation from system average.

Table 3. Average, maximum and minimum change for P&R stations, all system and difference.

	Average	Max	Min
P&R stations	3,27%	22,47%	-6,30%
System	0,04%	7,23%	-1,80%
Difference	3,23%	22,51%	-10,52%

As stated by the values in table 3 the stations which had P&R performed better on average than the system average. The average difference indicates that a station which had P&R implemented or expanded had a 3,23% (percental units) higher growth of passengers than the system average during the same time. This means stations where P&R spots were added saw a 3,23% increase in passengers on average regardless of the size of the P&R expansion. This was the value tested statistically.

The maximum and minimum differences display values for the stations with the highest respectively lowest increase in relation to the system average during the same period. Note that the systems max and min value were recorded during different time periods than for the P&R stations max and min recordings.

It was found on a 95% significance level that the distribution of values in the groups was not normally distributed. The Shapiro-Wilk test indicated a p-value of 0,032 for the P&R group and <0,001 for the system group. The variances were also unequal for the two groups according to Levenes test. Statistical results for the Shapiro-Wilk test are displayed in appendix 11.5 as well as descriptive statistics for the two groups.

The skewness of the data was positive in both cases, 1,229 for P&R and 1,765 for system which indicated a right sided tail for both groups, this is illustrated in figure 11. This further indicated that the data was not normally distributed as we would expect a skewness between about -0,8 and 0,8 on a 95% confidence level with 20 observations as in this case (Doane & Seward, 2011).

Further the difference between the two groups reported a skewness of 0,687 which indicates that the difference is moderately asymmetric with a right sided skewness. By creating a boxplot of the distribution this was further confirmed. However, this value was within the accepted level for a normal distribution at this sample size and thus this was considered sufficient to satisfy the conditions for the *Wilcoxon singed-ranked test*.

The result from the Wilcoxon test displayed a p-value of 0,032 thus indicating a difference between the two groups. A station which had P&R implemented on average saw a higher percental increase regardless of the size of the P&R expansion. Results from the Wilcoxon test is found in appendix 11.6.

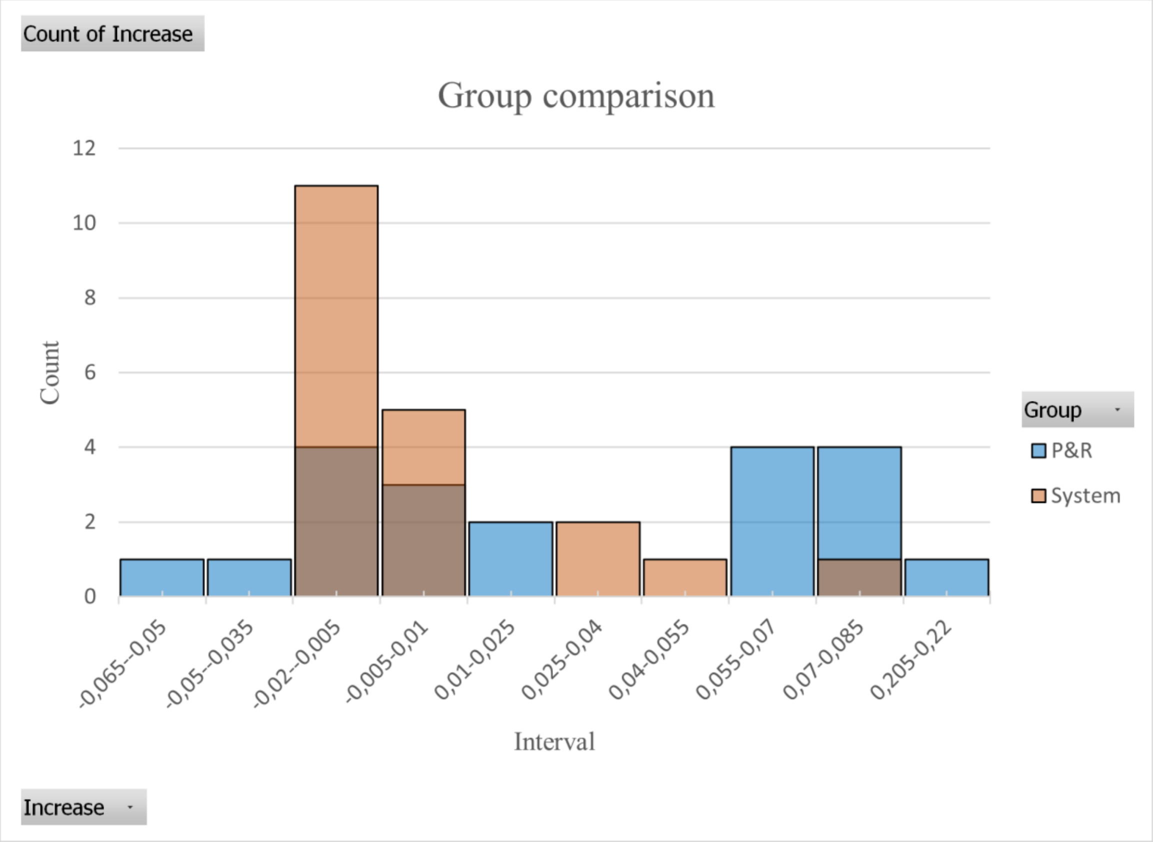

Figure 12. Histogram of relative change in travel volumes before and after park and ride was introduced for the two groups.

The relative change in passenger volumes for the two groups is shown in figure 11, the values are concentrated around 0 for both groups but with a much higher concentration for the System-group.

The percental change per added parking spot for individual stations varied from -0,13% to 0,63% with an average increase per parking spot of 0,09%.

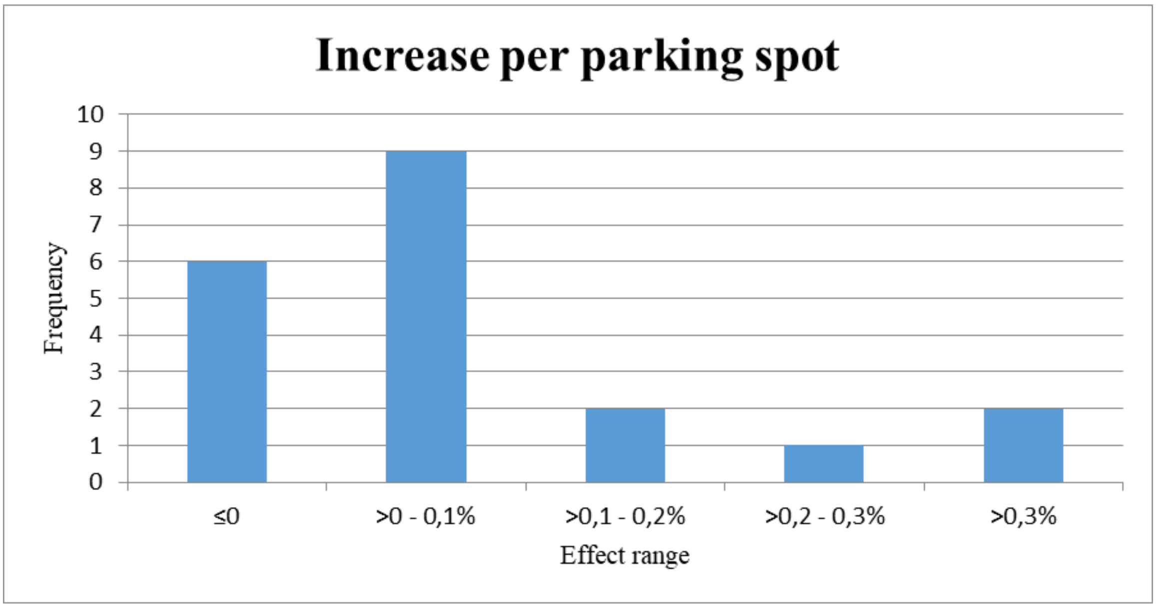

Figure 13. Histogram displaying the frequency of the effect size.

Of all stations 70% saw a positive effect for every added parking spot while 30% of the stations saw no effect or a negative effect. Most stations saw an increase of between 0 and 0,1 % per parking spot as illustrated in figure 12.

The increase in passengers was also calculated in absolute numbers as a percental increase is dependent on the earlier number of passengers.

Table 4. Calculated increases displayed as increase per day per parking spot.

P&R total	Station average	Station Max	Station Min
1,25	1,26	8,39	-1,79

Calculating from all station data (total P&R increase) the estimated increase of passengers for adding one parking spot at a station suggest that adding one parking spot increases the yearly number of passengers by 456,55. This the equivalent of a daily increase of 1,25 passengers per added parking spot. This is very close to the average station increase at 1,26. As seen by the station max and min values, the largest positive value was more substantial than the largest negative value.

Analysis
The average relative change for stations/stops which had P&R introduced was significantly higher than the general trend in transport system as indicated by the Wilcoxon-test. This strongly indicates that the introduction or expansion of P&R does in fact increase the number of passengers at the station where it was introduced. The increase should be seen as an increase in relation to the average difference in travellers. This test does however not accommodate for the numbers of parking spots introduced and it is likely that change caused by the introduction of low numbers of P&R spots could not be identified using this method. As seen in figure 11 most values are in fact close to 0, but in relation to the relative change for the system group there is still a difference.

The maximum and minimum values do seem very high when compared to the average values and this data was studied manually to try and find any reason for the large deviation from the average increase. The likely reason is that the two stations/stops which recorded the max and min values have relatively low passenger volumes which means an increase or decrease of a few hundred daily passengers could have a large impact on the percental change. When removing both from the analysis the average increase was still around 3% indicating that these measurements are unlikely to impact the result other than by a few decimal points. They might however possibly impact the result from the statistical test as the sample size would decrease.

The percental increases for each parking spot was found to be similar to the result from the earlier American study measuring passenger increase prom P&R in Santa Clara, Seattle and Los Angeles (Niles and Pogodzinski, 2021). The values reported there were increases of, 0,26, 0,44, and 0,09 percent, respectively. The result from the Stockholm County data showed an increase of 0,09% which is the same as for the Los Angeles case thus verifying that this is most likely a reasonable result.

Looking at the increase of passengers per parking spot as measured in absolute numbers 1,25 is a reasonable increase as the number lays within the interval for the most commonly measured levels of car occupancy (European environment agency, 2020; Trafikanalys, 2019). This is however lower than the average Swedish car occupancy which is 1,7 passengers/vehicle. It is though not unexpected that this value would be lower than the average considering that the calculation for the value is done by dividing the increase by all the days of the year. A value close to the Swedish average car occupancy would require each new parking spot to be used every day which is unlikely given that public transport usage is lower during weekends in Stockholm (SL, 2019). Further,

The fact that the analysis showed an increase in passengers, indicated that passengers were not changing mode for their journey to the station as suggested by some earlier studies (Parkhurst, 1995; Mingardo, 2013). Possibly passengers could choose to drive to a station further away from their home as one study suggested (Parkhurst and Meek, 2014). It is however not possible to determine this from the data analysed in this study. What is clear though is that regarding the travel mode to get to the station, P&R does not appear to cause any change for passengers at the station where it was introduced. If this was the case, we would not expect any increase in passengers caused by the P&R introduction.

7. Common discussion

The regression analyses of both Stockholm commuter network and Uppsala regional trains suggests that there exists a positive relation between the number of boarding passengers at a station and the number of P&R spots. Further, the pattern regarding the degree of explanations suggest that the relation is stronger for the regional train case where most of the stations are in a rural environment. The semi-rural category for Stockholm commuter case saw a moderate degree of explanation while the suburban category saw a low degree. This suggest the degree of explanation becomes stronger the less dense the public transport network is.

The number of P&R spots did not have a strong impact on the ability of a station to attract a high relative share of passengers from outside the walking distance catchment area as indicated by the regression of P&R spots and ratio. A low degree of explanation was indicated for both commuter train categories and the regional train. Likely the area of influence is very different for the stations thus they have different ability to attract passengers from outside the area within walking distance. This analysis has for example not accounted for other travel modes in the area. If other public transport modes are available in the area, it is possible that travellers will use this mode instead of driving to the train station thus decreasing the influence of the P&R facility.

The linear models for both Stockholm commuter trains, and Uppsala regional trains suggested increases per parking spot way above what could be expected. Likely there's some factor affecting these values which is not part of the model. The effect is clearly too large to be explained by the number of parking spots itself.

When examining the data, there appeared to be several stations in all categories which had a high number of parking spots but relatively few passengers. It is possible that in these cases the P&R facilities are not fully utilized or utilized to a low degree. If there is no demand for P&R an increase from the policy would not be expected.

To find out if this is the case the analysis would need to be supplemented with data regarding the occupancy rates of the P&R facilities. This was however not available and manual counting was not considered appropriate due to the widespread impact on travel volumes from the covid-19 pandemic during the time for this study.

Another possibility is that the number of P&R spots are related to the number of passengers rather than the opposite. Planners might choose to build P&R spots in relation to the overall passenger demand at a station rather than the demand for P&R. This would explain why there is a strong relationship between two, but an unrealistic function suggested for the relationship.

This problem was overcome with the temporal data analysis. Firstly, it is unlikely that P&R facilities would be expanded if there was no indication of demand for more parking spots. Secondly, the temporal data analysis does account for this as it would be indicated by no increase in passengers when P&R was implemented.

The temporal data analysed was extracted in a bit of an unconventional way, the most common approach would have been to compare two groups to each other during the same period. This was not possible in this case as P&R facilities are generally introduced individually rather than many at the same time. At first a dataset using a comparison group with stations and temporal data corresponding to the P&R station was tested out. This method was later discarded since it was found that the impact from the choice of stations for the comparison group was substantial. It was also clear from this first method approach that the temporal data set needed more detailed data than what could be provided through the official publication from *(Fakta om SL och länet)*. The data in those reports is rounded to the nearest hundred or fiftieth which meant there would be a considerable risk of not finding any indication of change in passengers even when one existed. Particularly the effects from small P&R facilities would have risked being undetected.

8. Conclusions

The regression analyses indicated a low positive correlation between the number of parking spot at a station and its ability to attract passengers from outside a common walking distance.

The analyses further indicated positive direct correlation between the number of parking spots and passengers. However, the fitted linear functions suggested unrealistically high increases for every parking spot. This was likely caused by low utilization rate of P&R at some stations which strongly influenced the slope of the linear function. The tendency is that more rural locations see a stronger relation between P&R and passenger volumes.

The temporal data set gave a reasonable answer and strongly indicated that P&R increases the number of passengers using public transport.

The effect is expected to be an increase of 0,09% per additional parking spot implemented at the station. Alternatively in absolute numbers, 1,25 additional passengers per added parking spot. The absolute value is suggested as a better estimation as the percental increase will be larger for small stations and lower for large stations.

As a significant increase in passenger volumes was measured when implementing P&R this suggests that passengers do not switch from other modes for their connecting journey to the station.

9. Suggestions on further research

As indicated by the literature and the review of earlier Swedish studies, there is a vast need for more research regarding parking policies. One subject seems especially useful; an estimation method or model to determine how many P&R spots are required to fill the need for the locality it serves. When searching for stations to be part of the mixed dataset the sources indicated that most P&R facilities were built or expanded when the existing ones were full. In one case a facility was expanded barely two years after it opened due to high demand. Further it was indicated that in some cases there seemed to be a very low usage. This indicates a need for a method to determine the demand and need for P&R so that planning can become more long-term.

It would be a natural step to combine a similar study with a study looking at occupancy rates at P&R facilities to find changes in occupancy rates. It is possible that people will be discouraged from using the P&R facility if they are not certain that they will be able to park there. Earlier studies suggest if spots are removed, or the P&R is full those using it will drive to another P&R or drive all the way to the destination. This could suggest an increase in parking spots could be useful even if the P&R facility does not always have an occupancy rate close to 100%. Also, it would be interesting to combine with the regression analysis in this study to try and determine what the actual influence from the P&R is at these stations.

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11. Appendices

11.1 Stockholm commuter train data

Station	Boarding	Category	Parking count	StopArea Number	pop	pop 770m	Boarding/ Pop_770m
Ulriksdal	4700	Suburban	0	5041	24013	7502	0,6264996
Krigslida	600	Suburban	0	6181	4538	1459	0,411240576
Norrviken	2300	Suburban	21	5081	10813	2916	0,788751715
Skogås	4900	Suburban	25	6141	15960	7540	0,649867374
Gröndalsviken	800	Suburban	32	6241	10784	3075	0,260162602
Nynäsgård	1300	Suburban	46	6231	8817	5147	0,252574315
Spånga	8700	Suburban	50	6041	37481	6785	1,282240236
Trångsund	2800	Suburban	63	6131	14319	4345	0,644418872
Vega	1200	Suburban	78	6145	6316	2775	0,432432432
Helenelund	7400	Suburban	86	5051	13236	4434	1,668921967
Västerhaninge	5400	Suburban	103	6171	10013	5284	1,021953066
Farsta strand	5100	Suburban	106	6121	18706	8575	0,594752187
Häggvik	2700	Suburban	125	5071	11139	4435	0,608793687
Tungelsta	950	Suburban	125	6191	3870	1692	0,561465721
Södertälje hamn	4600	Suburban	125	5221	3671	1562	2,944942382
Handen	8300	Suburban	185	6151	12747	7862	1,055711015
Huddinge	10200	Suburban	198	5161	18787	7596	1,342812006
Stuvsta	4200	Suburban	262	5151	9670	4353	0,964851826
Älvsjö	19600	Suburban	295	5141	23534	8299	2,361730329
Barkarby	4600	Suburban	350	6051	11420	3644	1,262349067
Östertälje	3700	Suburban	509	5211	8784	2597	1,424720832
Jakobsberg	10500	Suburban	208	6061	26979	9725	1,079691517
Jordbro	4100	Suburban	38	6161	11205	4218	0,972024656
Tullinge	5600	Semi-rural	319	5181	12253	4461	1,255323918
Hemfosa	200	Semi-rural	24	6201	160	114	1,754385965
Segersäng	400	Semi-rural	60	6211	765	380	1,052631579
Järna	1100	Semi-rural	94	5251	5914	2848	0,386235955
Mölnbo	350	Semi-rural	120	5261	1034	475	0,736842105
Ösmo	1300	Semi-rural	169	6221	3273	1868	0,695931478
Kalhäll	5200	Semi-rural	185	6071	11465	4934	1,053911634
Rosersberg	1500	Semi-rural	253	5111	1965	1099	1,364877161
Bro	2600	Semi-rural	274	6091	5122	2527	1,028888009
Rotebro	4400	Semi-rural	287	5091	9568	2972	1,480484522
Upplands väsby	10300	Semi-rural	381	5101	20991	8321	1,237831991
Kungsängen	4900	Semi-rural	398	6081	5601	2352	2,083333333
Rönninge	2800	Semi-rural	410	5201	6855	3281	0,853398354
Tumba	9500	Semi-rural	457	5191	16432	5578	1,703119398

11.2 Uppsala regional train data

Station	Boarding	Parking spots	Pop	Pop 770m	Boarding/pop_770m
Tobo	264	35	215	55	4,8
Älvkarleby	194	48	173	55	3,527272727
Skyttorp	483	40	782	473	1,021141649
Vattholma	429	46	1242	457	0,938730853
Örbyhus	924	104	2014	1095	0,843835616
Tierp	2173	263	6051	2849	0,762723763
Mehedeby	140	16	423	211	0,663507109
Furuvik	257	20	860	412	0,623786408
Morgongåva	447	85	1550	861	0,519163763
Marma	158	12	404	322	0,49068323
Storvreta	929	79	6086	2453	0,378719935
Skutskär	491	63	3265	1429	0,343596921
Heby	288	66	2462	1002	0,28742515

11.3 Mixed modes, list off stations

Station name	Mode	P&R expansion (nr of spots)	P&R expansion year	P&R expansion month	Source for dating	Source date
Värmdö, Näsuddsvägen	Bus	80	2016	3	Värmdö municipality	2016-10-10
Ekerö, kommunhuset	Bus	100	2016	12	Mitti Mälarö	2016-12-20
Tyresö, Trollbäckens C	Bus	12	2018	1	Vi i Tyresö	2018-02-01
Rönninge	Commuter	80	2018	7	Salem municipality	2018-07-13
Kungsängen	Commuter	90	2014	3	Vi i Upplandsbro	2014-02-25
Tyresö, Tyresö skola	Bus	20	2018	10	Mitti Mälarö	2018-10-18
Jakobsberg	Commuter	60	2018	11	Mitti Mälarö	2018-12-06
Tyresö, Lagergrensväg	Bus	14	2018	1	Vi i Tyresö	2018-02-01
Upplands väsby	Commuter	125	2018	4	Upplands Väsby municipality	2018-03-23
Sigtuna, Rosersberg	Commuter	34	2015	7	UNT	2016-03-30
Kallhäll	Commuter	178	2017	1	Mitti Mälarö	2017-01-23
Vårberg,t-bana	Metro	70	2017	10	Stockholm parkering	2017-10-18
Hagsätra T-bana	Metro	60	2017	10	Stockholm parkering	2017-10-18
Bandhagen T-bana	Metro	30	2017	10	Stockholm parkering	2017-10-18
Sockenplan T-bana	Metro	50	2017	10	Stockholm parkering	2017-10-18
Härardsvägen	Bus	70	2017	10	Stockholm parkering	2017-10-18
Hägerstensåsen T-bana	Metro	40	2017	10	Stockholm parkering	2017-10-18
Vällingby, Astrakan	Bus	75	2016	2	Stockholm parkering	2016-02-08
Nacka, Igelboda	Light rail	36	2017	1	Nacka municipality	2016-11-21
Riksmuseet, Frescati*	Bus	174	2017	10	Stockholm parkering	2017-10-18
Riksmuseet, Bergiusvägen*	Bus					

*Both stops connect to the same P&R

11.4 Mixed modes, data

Station name	P&R expansion	Passengers Prev 12 month	Passengers Next 12 month	P&R Change %	System Change%	Difference	%/spot	Pass/spot
Värmdö, Näsuddsvägen	80	2350	2202	-6,30%	4,22%	-10,52%	-0,13%	-3,0905729
Ekerö, kommunhuset	100	358495	344058	-4,03%	-0,39%	-3,64%	-0,04%	-130,55631
Tyresö, Trollbäckens C	12	561939	551988	-1,77%	-1,03%	-0,74%	-0,06%	-348,76553
Rönninge	80	739886	735874	-0,54%	0,31%	-0,85%	-0,01%	-78,596153
Kungsängen	90	874737	879307	0,52%	7,23%	-6,71%	-0,07%	-652,20995
Tyresö, Tyresö skola	20	48482	51319	5,85%	0,41%	5,44%	0,27%	131,928655
Jakobsberg	60	3288732	3481488	5,86%	0,27%	5,59%	0,09%	3062,93615
Tyresö, Lagergrensväg	14	175528	186155	6,05%	-1,03%	7,08%	0,51%	887,715504
Upplands väsby	125	2453865	2615503	6,59%	-0,04%	6,63%	0,05%	1300,55626
Sigtuna, Rosersberg	34	301319	322788	7,13%	2,91%	4,22%	0,12%	373,703749
Kallhäll	178	1108214	1201895	8,45%	-1,04%	9,49%	0,05%	591,044659
Vårberg,t-bana	70	1759475	1893606	7,62%	-1,80%	9,43%	0,13%	2369,63872
Hagsätra T-bana	60	1334884	1310637	-1,82%	-1,80%	-0,01%	0,00%	-2,7263769
Bandhagen T-bana	30	1033097	1028943	-0,40%	-1,80%	1,40%	0,05%	482,823429
Sockenplan T-bana	50	524899	537921	2,48%	-1,80%	4,29%	0,09%	449,840153
Härardsvägen	70	154293	157359	1,99%	-1,80%	3,79%	0,05%	83,5669944
Hägerstensåsen T-bana	40	1504805	1492419	-0,82%	-1,80%	0,98%	0,02%	369,07652
Vällingby, Astrakan	75	179512	192209	7,07%	2,63%	4,44%	0,06%	106,246167
Nacka, Igelboda	36	36142	43902	21,47%	-1,04%	22,51%	0,63%	225,996146
Riksmuseet, Frescati* Riksmuseet, Bergiusvägen*	174	115918	115839	-0,07%	-1,80%	1,73%	0,01%	11,5374943

*Both stops connect to the same P&R, data is combined

11.5 Mixed modes, descriptive statistics

Tests of Normality

	Kolmogorov-Smirnova			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
P&R	0,147	20,000	,200*	0,894	20,000	0,032
System	0,240	20,000	0,004	0,766	20,000	0,000

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Descriptives

			Statistic	Std. Error
PnR	Mean		3,267	1,358
	95% Confidence Interval for Mean	Lower Bound	0,425	
		Upper Bound	6,108	
	5% Trimmed Mean		2,787	
	Median		2,235	
	Variance		36,859	
	Std. Deviation		6,071	
	Minimum		-6,300	
	Maximum		21,470	
	Range		27,770	
	Interquartile Range		7,700	
	Skewness		1,229	0,512
	Kurtosis		3,105	0,992
System	Mean		0,041	0,545
	95% Confidence Interval for Mean	Lower Bound	-1,100	
		Upper Bound	1,181	
	5% Trimmed Mean		-0,257	
	Median		-1,030	
	Variance		5,942	
	Std. Deviation		2,438	
	Minimum		-1,800	
	Maximum		7,230	
	Range		9,030	
	Interquartile Range		2,185	
	Skewness		1,765	0,512
	Kurtosis		2,959	0,992

11.6 Mixed modes, statistical test result

Wilcoxon Signed Ranks Test

Ranks

		N	Mean Rank	Sum of Ranks
System - PnR	Negative Ranks	14a	11,64286	163
	Positive Ranks	6b	7,833333	47
	Ties	0c		
	Total	20		

a. System < PnR

b. System > PnR

c. System = PnR

Test Statisticsa

	System - PnR
Z	-2,165b
Asymp. Sig. (2-tailed)	0,030365113

a. Wilcoxon Signed Ranks Test

b. Based on positive ranks.