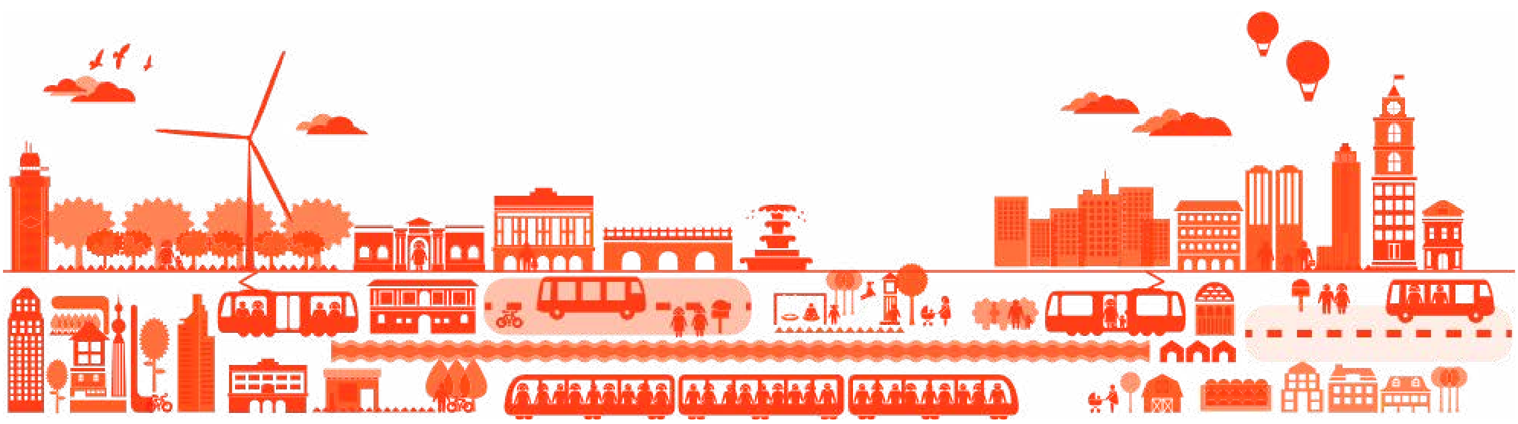
K2 WORKING PAPER 2023:5

Understanding Mobility Patterns in Ten Swedish Urban Regions

Jeff Kenworthy



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Foreword

The author wishes to sincerely acknowledge the dedicated support of my research assistant Ms Monika Brunetti in the assembly of the data for this project. I also want to gratefully acknowledge the support of Dr Helena Svensson in being a party to the research application and in both helping to locate people who might help with data collection, as well as for listening to my many and varied complaints about how hard it is to collect a lot of critical transport and related data in Swedish cities. I wish to also acknowledge her support in providing insightful feedback on the paper, which has helped to significantly improve it. Of course, there are literally countless individuals in a plethora of government agencies who were incredibly generous in the time they spent providing the requested data for this project. It is impossible to acknowledge them individually, but the author is incredibly grateful to all of them. The author also wishes to acknowledge the generous support of Dr Hamid Mostofi from the Technical University in Berlin who kindly produced the Pearson correlation results for the research with data provided by the author. The results presented in the working paper are entirely the author's responsibility.

Lund, August 2023

Jeff Kenworthy

Author

Summary

This working paper builds on the research done during two other research projects on Swedish cities which sought to build a comprehensive picture of mobility and mobility-related factors in Sweden's ten largest cities and to compare them to other international cities (Kenworthy, 2019; Kenworthy, 2020). The definitions of each city were the same as in the previous two projects (Table 1). Specifically, this current research assembled a new set of factors that might supplement and expand understanding of the public transport and non-motorised mode mobility patterns in the same ten cities. The twenty primary variables collected are shown in Table 2 and fall broadly into the following categories: demographic factors, taxi data, non-motorised mode infrastructure, public transport infrastructure and public transport financial factors. The data collection process highlighted many inadequacies in Sweden in the recording and even the understanding of important information that relates to the sustainability of transport in Swedish cities. A significant discussion has therefore been provided detailing these problems and why it would be important to try to remedy this.

From these new primary data, a very wide range of normalised variables were calculated so that the ten cities can be compared, and these are presented systematically in a series of tables in the report. The car park and ride data and investment in public transport, which were also collected for 1995 in the Millennium Cities Database for Sustainable Transport for 84 cities worldwide (Kenworthy and Laube, 2001) are compared to the Swedish cities in 2015 to gain some insight into where the latter sit in a continuum of world cities. Some statistical investigations on the significance of these new data in understanding the Swedish cities' public transport and non-motorised mobility patterns are provided, together with other policy matters that naturally arise from the information collected. Additionally, the report draws upon the wide range of mobility and mobility-related data collected in the previous two projects, to also help understand mobility patterns in a statistical sense. These statistical analyses help to give an insight into the policy implications for Swedish cities.

Key findings from the research in this working paper are as follows:

- The population age data (Table 3) show a remarkable consistency in Swedish urban demographic characteristics, at least in these ten cities. The patterns of variation in the six generational age groupings of population across these cities (GI generation born between 1901 to 1924 through to Gen Z born 1996 to 2020) is very small and does not follow any notable pattern that yields a significant relationship to public transport and non-motorised mode usage. The percentage of people in each city who are employed (ranging from 46% to 54%) also bears no relationship to public transport or non-motorised mode use.
- Taxis are fulfilling a specialized niche role in Swedish cities which has little bearing on overall mobility patterns and certainly cannot compete with the efficiency of public transport or other modes in, for example, energy use or the amount of driving needed to serve their passengers (Table 4). On the other hand,

they provide essential mobility and access to those who cannot choose other means.

- Although the non-motorised infrastructure provision data (length of cycleways, length of footpaths and length and area of pedestrianised streets) vary widely amongst the ten cities (Table 5), a careful statistical exploration of these and the data from earlier projects (see next) in relation to the percentage of daily trips by walking and cycling together and separately, does not reveal any statistically significant relationships. This is contrary to the global sample where increasing urban density is strongly associated with higher non-motorised mode use. It appears that what determines people's use of walking and cycling in Swedish cities where densities do not vary strongly, is also much more complicated than simply the amount of basic infrastructure that is provided to promote these modes and is likely linked to other more detailed factors such as the cycling "culture", the qualitative aspects and urban design of the walking and cycling environments, bicycle parking availability, or perhaps even some weather influences or other factors. Significant personal preferences towards certain modes such as bikes may also play a part. All such factors are beyond the scope of this project, and many would be difficult to quantify.
- The non-motorised mode use was also correlated with other potential explanatory factors developed in the previous two projects, but again no significant relationships could be found in the Swedish cities. It can be concluded from this that it is unlikely that non-motorised mode use can be explained by city-scale variables, be they demographic, infrastructure, urban form-related or any other mobility-related characteristics.
- Public transport infrastructure data collected here were the average age of vehicles by mode, the number of stations and stops by mode and the amount of park and ride (P&R) facilities and number of spaces for cars and bikes (Table 6). Although the average age of vehicles varied from 4.3 years to 11.4 years, there was no significant relationship with public transport use.
- P&R also did not correlate with the per capita use of public transport in the ten cities, but the data are valuable in that they show that P&R (car and bike) can only contribute relatively small percentages of overall public transport use (the average for the ten cities was 8.8% with a range of 0.1% to 17.6% (Table 7). Car P&R, the much more expensive and space consuming form of P&R varied from only 0.1% to 7.4% with an average for the ten cities of 3.9%. These data lead to examination of how much farebox revenue can be raised in each city from P&R (Table 8) and to the broader question of the economic costs and benefits of P&R provision, especially for cars.
- Another major policy question of car P&R aside from costs, is therefore whether the land occupied by P&R is the highest and best use of this land, given the relatively small amounts of farebox revenue it generates. Would the land occupied solely by car P&R (either surface or in parking garages) be better utilised if the P&R was placed underground with higher value land uses above, which also can generate extra public transport use. These are important policy questions that also have a bearing on the overall re-structuring of urban regions around public transport using dense, mixed use sub-centres. Answers to these questions depend on the circumstances in each city.

- Car P&R provision in Swedish cities is also compared to 84 world cities (1995) based on car spaces per kilometre of reserved public transport route and per 10,000 persons (Figures 1 and 2). The Swedish cities are relatively modest on the former basis but quite robust on the latter (see discussion).
- The only item of public transport infrastructure collected in the current project that correlated with public transport use in a simple bi-variate Pearson correlation was a positive relationship between the spatial density of public transport stops (Figure 4 - r- squared 0.72).
- The public transport financial data that were collected in this project were the percentage of total tickets that are pre-sold (any time length), and the percentage of pre-sold tickets of 1-month or longer. Additionally, the total amount of investment spending (new construction, maintenance, refurbishment, vehicle purchase etc) from all sources was collected for the 2013-2017 five-year period and an average for the 5- years determined. This was expressed as per capita spending and as the percentage of metropolitan GDP that is expended on public transport (Table 9). Stockholm was the highest ranked city with 1.22% and Umeå only 0.11% of metropolitan GDP being spent on investing in public transport. This placed Stockholm as the 5th highest investor in public transport in the entire global sample, while Umeå sat next to Los Angeles and Denver, which are world renowned, at least historically and probably only a little better today, for their neglect of public transport.
- The pre-sold tickets data did not reveal any significant statistical relationships with public transport use, although the 1-month or more tickets had a weak positive relationship. On the other hand, the percentage of metropolitan GDP spent on investing in public transport systems was significantly and positively correlated with public transport use in the Swedish cities, as it was in the international sample (Figures 4 and 5). It appears that the more committed cities are to improving public transport, the more this is reflected in higher use.
- The research also revealed the sources of the investment data (Table 10), which on average were highest from the national government (53.3%), 21.3% from regional government agencies, 18.3% from municipalities and 7.1% from co-financed national government projects. There was significant variation, however, amongst the cities on this factor.
- The international comparisons of the percentage of metropolitan GDP spent on public transport (Figure 3) showed that the average level of public transport investment spending for the 84 cities in 1995 was 0.43% while the Swedish cities in 2015 averaged 0.35%. However, the split within the Swedish sample is big, with the larger cities realising 0.54% of GDP and the smaller cities only 0.16%.
- The Pearson correlation statistical analysis undertaken on the data collected in previous projects (Table 11), revealed some highly significant relationships with the four measures of public transport use (including that all four measures of public transport use - percentage of daily trips by public transport, boardings per capita, passenger kilometres per capita and the percentage of total motorised passenger kilometres by public transport - are highly correlated with each other – Table 12). Combined with the results from the new data, these results suggest that

the following factors appear to be strongly associated with enhanced public transport use in Swedish cities:

- Increasing population and job density
- Greater wealth as measured by metropolitan GDP per capita
- Greater total public transport vehicle kilometres of service per person
- Greater total public transport seat kilometres of service per person
- A higher density of public transport stops
- A larger percentage of city wealth being spent on investment in public transport

For metropolitan GDP and its positive correlation with public transport use, it cannot be said that simply increasing GDP automatically increases public transport use. Rather it appears that the result is a statistical artefact suggesting that the larger, wealthier and more economically attractive cities in Sweden have evolved with and go hand-in-hand with the best, most utilised public transport systems. The other five factors, on the other hand, are policy relevant and suggest that by increasing densities, expanding public transport service (especially seat kilometres which generally means more rail), plus increasing the density of the network of stops (public transport network coverage) and investing more in public transport, should yield higher public transport use (especially one would assume, if all these are done simultaneously). The global sample similarly shows increasing public transport use with increasing density and the amount of public transport service.

The analysis also suggested that two factors negatively impact public transport use:

- Increasing length of road per person
- Increasing passenger cars per 1000 persons

While not being what could be called a "driving factor" of public transport use, but rather a spin-off, is the statistically significant higher amount of farebox revenue generated for every vehicle kilometre of service provided as public transport use per capita increases - in other words a better financial yield on the services run.

The Pearson correlations highlighted significantly correlated variables which were then subjected to a multiple regression analysis (Table 13). The results suggest that a high percentage of the variance (83% to 92%) in all four measure of public transport use can be explained by a combination of four variables:

1. Activity density,
2. Total annual public transport seat kilometres per person,
3. Total public stops per hectare and
4. The percentage of city wealth (GDP) being spent on investment in public transport.

Whilst these regressions do not imply a cause-and-effect relationship, they are significant in a policy sense as they imply, through association, that increasing all four of the above factors is likely to improve public transport use.

Another aim of the research in this current study was to examine the energy and greenhouse gas savings potential of public transport systems and non-motorised transport, as well as through changes in private transport in Swedish cities. This is not included in this working paper because it has already been published in the international refereed journal *Sustainability* (Kenworthy and Svensson, 2022).

Sammanfattning

I detta projekt sammanställdes och analyserades en uppsättning faktorer som kan komplettera och förbättra förståelsen för resandet med kollektivtrafik och icke-motoriserade transporter i tio svenska kommuner. Data samlades in via kontakter med tjänstepersoner i regioner och kommuner och från officiella register. Datainsamlingen visade på brister i statistik om hållbara transporter i Sverige och till viss del brist på förståelse för varför den här informationen är viktig. En lärdom från projektet var att det finns behov av att i mycket större utsträckning samla in och följa upp grundläggande data om kollektivtrafik och infrastruktur för icke-motoriserade transporter. Detta inte minst för att få en korrekt och transparent bild av nyttan av de pengar som investeras i dessa transportsätt.

Resultaten från studien visade, på ett statistiskt signifikant sätt, att en högre kollektivtrafikanvändning i dessa svenska kommuner är förknippat med:

- Större befolkning och ökad täthet av arbetsplatser
- Högre välstånd mätt som regionens BNP per capita
- Ett större totalt utbud av kollektivtrafikkilometrar per person
- Ett större totalt utbud av kollektivtrafiksäten per person
- Tätare hållplatser/stationer för kollektivtrafik
- Större andel av budgeten som går till investeringar i kollektivtrafik

Antal parkeringsplatser för bil och cykel hjälpte inte till att förklara andelen kollektivtrafikresor, så en mer grundlig studie av betydelsen av parkeringsplatser vid kollektivtrafiknoder utifrån svenska förhållanden kan behövas. Studien visade också att gång- och cykelanvändning i dessa kommuner inte kunde förklaras av mängden infrastruktur för icke-motoriserad trafik eller med data som demografi, stadens form eller mobilitetsrelaterade faktorer.

1. Introduction

Trying to understand patterns of mobility that exist in individual cities can provide useful policy support in defining the way ahead for a more sustainable transport system. Ideally it enables the identification of specific underlying strengths and weaknesses in a city's mobility landscape and what might be done to improve matters.

The current project sought to build on earlier research for K2 looking at the major mobility patterns of Sweden's ten largest urban areas and key factors that may explain those patterns. The current project has added a wide range of further potential factors that might help explain those patterns.

The structure of the report is as follows. The report first provides a brief methodology section explaining what data were collected and how it was collected, followed by an explanation of the numerous problems with data collection in Swedish cities. Second, it provides detailed tables showing the results of the data gathering on these additional items, using standardised variables that enable comparisons to be made across cities. The report then explains the results of the quantitative data collection grouped into five sets of factors, highlighting the significant observations and any relevance they have to the patterns of public transport and non-motorised mobility in the ten cities. The five factors being considered are: demographic factors, taxi service and use, non-motorised mode infrastructure (cycleways, footpaths and pedestrian areas), public transport infrastructure (vehicle age, stations and stops and park and ride for cars and bikes) and public transport financial factors (pre-sold tickets and investment in public transport over 5 years). Some statistical explorations are provided on all these new factors in relation to public transport and non-motorised mode use along with a similar analysis on relevant data collected in the two previous K2 projects (Kenworthy, 2019; 2020). Policy implications are brought out in the discussion of these results.

2. Methodology of data collection

This study collected data on the ten Swedish urban regions defined in Table 1. Where data had to be collected on a wider area than that specified, the data were normalized according to the population or area of the larger city definition. The primary data items collected for these cities is outlined in Table 2.

The data in Table 2 were collected, where possible, from on-line statistical resources available through Statistics Sweden (SCB) and other databases such as through Svensk Kollektivtrafik (Frida database) the Trafikverket, regional public transport agencies and online data from individual municipalities comprising each of the ten cities. The SCB was overall the most comprehensive. However, independent data collection from online sources, without referral, clarification and assistance from people in the respective agencies for assistance, was limited.

In practice, to collect the data in Table 2 required countless emails and phone calls to hundreds of people spread across a multitude of mostly government or quasi-government agencies in Sweden and occasionally the private sector. This is because a high proportion of the data being sought are for the most part not kept uniformly across Sweden and are certainly not reported in any uniform fashion or at all, mostly the latter. The only way to collect most of the data is to "dig" and dig deep. This is unlike the situation in the United States, for example, or indeed in the UK, where data generally are more standardised (e.g. the USA's standard and exemplary annual reporting requirements for all public transport agencies under the Federal Transit Administration's National Transit Database). In the UK, mobility-related data collection at many geographic levels is facilitated both by the extensive UK online databases under gov.uk and by the strong enforcement of Freedom of Information (FOI) requests when data online are not readily available. Agencies simply must respond, even though they often say, "we do not hold these data". Mostly though, they will make helpful referrals to a more appropriate respondent.

Therefore, data collection success in Sweden relies primarily on both the goodwill and the ability of the very many people being asked to provide the needed data. This in turn also requires the establishment of a shared and agreed understanding of how to define the data item being sought, which is often, and unexpectedly, quite complicated. Since providing such data is not considered part of the day-to-day work of the agencies being contacted there is sometimes a reluctance to answer such requests, which leads to time-consuming follow-ups and attempts to find alternative sources for the data. On the positive side, it can be said that for the most part cooperation was found, one way or another, but for much of the data collected, the time required to collect it far exceeded expectations and required persistent and very detailed effort on the part of the researcher over a long period. In the next section, some of the issues involved in collecting specific data items are outlined in more detail.

Table 1. Definitions of Swedish urban regions in this study.

Urban Region	Counties and Municipalities Comprising the Urban Region
Stockholm	Stockholms län (County)
Göteborg	The official definition of *Metropolitan Göteborg* is used consisting of the following municipalities. Names and reference numbers are from Statistics Sweden. (1384) Kungsbacka (1401) Härryda (1402) Partille (1407) Öckerö (1415) Stenungsund (1419) Tjörn (1440) Ale (1441) Lerum (1462) Lilla Edet (1480) Göteborg (1481) Mölndal (1482) Kungälv (1489) Alingsås
Malmö	The official definition of *Metropolitan Malmö* is used consisting of the following municipalities. (1230) Staffanstorp (1231) Burlöv (1233) Vellinge (1261) Kävlinge (1262) Lomma (1263) Svedala (1264) Skurup (1267) Höör (1280) Malmö (1281) Lund (1285) Eslöv (1287) Trelleborg
Helsingborg	(1283) Helsingborg
Linköping	(0580) Linköping
Uppsala	(0380) Uppsala
Västerås	(1980) Västerås
Örebro	(1880) Örebro
Jönköping	(0680) Jönköping
Umeå	(2480) Umeå

Table 2: Primary data collected for the project for the year 2015 or close to it.

Demographic factors
Percentage (%) of population who are employed
Percentage of population in key generational age groups
Average age of the population
Taxi factors
Number of taxis
Annual vehicle kilometres driven by taxi
Annual passenger trips by taxis
Annual passenger kilometres travelled by taxis
Non-motorised mode factors
Length of cycleways
Length of footpaths
Length of fully pedestriansed streets
Area of fully pedestrianised streets
Public transport infrastructure factors
Average age of vehicle fleet (vehicle quality) by mode (buses, LRT, metro, suburban rail, ferries)
Number of public transport stations and stops by mode (buses, LRT, metro, suburban rail, ferries)
Number of park and ride facilities (cars)
Number of park and ride spaces (cars)
Number of park and ride facilities (bikes)
Number of park and ride spaces (bikes – i.e. bike capacity)
Public transport financial factors
Percentage of all public transport tickets that were pre-sold (any time length)
Percentage of all public transport tickets that were pre-sold (1 month or more)
Annual investment in public transport – 2013, 2014, 2015, 2016, 2017 (all government + private)

3. Specific problems with data collection

One of the outcomes of this research is to highlight where data availability in Swedish cities could be improved, which could then facilitate further research.

3.1. Non-motorised mode data

In the current local and global attention to reducing dependence on the car and enhancing the use of more sustainable modes of transport to avert climate change, there are some pieces of data that one might expect to be readily available as a regular reporting requirement for every municipality. This could be simply as a source of knowledge for further research and policy formulation, but also to track development and progress over time as a sustainability indicator. For the current project, such items include the length of cycleways (both off-road and on-road, both sides of the street) and the length of footpaths (both sides of the street). Equally, pedestrian zones in all cities constitute major efforts in enhancing the environment for pedestrians (and sometimes cyclists) and therefore the potential for walking (and cycling), as well as improving the livability and indeed the economics of city centres and sub-centres around urban regions.

For this study, the lengths of cycleways and footpaths were collected, as well as the length of fully pedestrianised streets, and for the latter their area. In no case was this a simple matter. None of the items are published and trying to locate these data for each of these ten cities required a multitude of emails to municipalities until gradually all the matters of definition were resolved and the data were finally collected. In the case of pedestrian zones, sometimes calculations by the researcher had to be done using maps to measure pedestrian street lengths and widths. Generally speaking, cycleway data are much better recorded than footpath length in Sweden. Footpath data are almost universally not recorded in any especially reliable and systematic way in Sweden. The footpath lengths here thus represent the best data supplied and/or best estimates using a combination of information supplied by the cities and supportable and reasonable judgements by the researcher.

3.2. Public transport infrastructure data

The public transport data in this project consisted of the average age of public transport vehicles by mode, the number of stations and stops by mode and the number of park and ride facilities for cars and bikes separately, along with their respective number of parking spaces. None of these data were easy to obtain and required multiple emails to various people in each city/municipality until eventually the information was assembled like a jigsaw puzzle.

In the case of the age of vehicles, which is a relatively simple item, it would be helpful in Sweden if all public transport agencies published, as a matter of course, both the type and number of vehicles they use and the year in which each vehicle type/model was commissioned. Clearly these data are held somewhere, because rolling stock must be purchased and recorded by someone with purchase details. The Frida database does have, for example, data on the age of buses, though Frida is the property of Svensk kollektivtrafik and therefore not strictly an official site.

The number and type of vehicles are also the only way a public transport system can provide its services so the information must be present in some form. From this information, the average age of each vehicle at any year could be calculated without asking for assistance. However, this is not the case in Sweden and details of the rail rolling stock used for the suburban/regional rail services in particular areas are especially difficult to pin down due to various companies operating trains across multiple geographies, as well as complexities relating to leasing arrangements.

Obtaining all the age of vehicles data by mode required persistent effort with multiple respondents for the information, which is clearly there though somehow buried deep in each agency, to be finally extracted and provided. Again, standardisation and transparency of all the details of public transport rolling stock would be helpful for a multitude of reasons. This is a case where legislation at a national level, as in the USA under the National Transit Development program, could enforce the reporting of critical items of public transport infrastructure (like numbers of vehicles), operational data and economic matters, and have it all on a centralized database on an annual basis, able to be interrogated by mode, municipality, county and operator/ownership.

Public transport stations and stops is another factor, which for all intents and purposes is basic to the operation of all public transport services. Without this information it is impossible, for example, to develop timetables for the various modal networks and all such infrastructure also needs to be maintained, so there is also a financial implication which impacts on budgets. Consequently, it should theoretically be easy to extract information about the number of stations and stops, but it is not. Again, information is there but for the most part such data are not transparently provided as part of the overall profile of a public transport system in Sweden (in Stockholm it is) and it is still not clear to this researcher who has such data in each urban area, nor for what it is primarily used within each agency. Does one contact people who do the timetabling (e.g. the operators), or are such data held in the financial area because of cost matters related to servicing it etc? Consequently, obtaining the information requires painstaking effort contacting a range of people in multiple agencies, until finally the request lands with the person who can provide the information and is willing to do so. And for areas like Metropolitan Malmö and Metropolitan Göteborg, which consist of multiple municipalities, data must be assembled by municipality.

Matters of definition are also important and in this study, all stops are counted only once so that the forward and reverse direction of a bus stop with the same name is only counted once – the same for railway stations and tram stops. This required some manipulation of data to ensure that each urban area was providing data on the same basis and there was no double-counting.

In the end, it would be helpful if all public transport agencies had, as part of their basic public transport profile, a simple table that lists the number of stops and stations by mode and municipality for each year (numbers of stations and stops can change for rail modes depending on new lines being built, but especially so for buses where services are more easily added or removed). Is such data important enough for public transport authorities to keep a record of it and publish it as a matter of course? This research takes the view that it is, simply because the data do exist and are fundamental to any public transport system, so why not formalise the recording and presentation of it?

The last public transport infrastructure items are the park and ride facilities and spaces available in each urban area. The difficulties obtaining simple station and stop data, pale into insignificance compared to the issues surrounding park and ride infrastructure. Park and ride facilities are important infrastructure in some areas where gaining access to a public transport stop is not easy or practical by foot or bus or for individuals who can't get a lift to public transport (kiss and ride). It is essential therefore to know where these facilities are located and what their capacity is for allowing parking for cars and bikes.

Having said this, none of the ten cities had comprehensive or transparent data on this factor and responsibility for it seems to be spread across multiple agencies meaning that no one, it seems, anywhere in Sweden, sees it as their responsibility to keep an overall oversight on park and ride. Ultimately therefore, this was one of the most difficult items to assemble requiring painstaking work writing to multiple agencies and especially to a plethora of individual municipalities, as well as examining many websites which sometimes had data. In one case a regional public transport authority actually assigned the task to an intern who in turn had to use aerial photography to locate the facilities and to manually count the car spaces or estimate capacity where parking bays were not marked clearly.

There are also some definitional issues such as where parking is not formally designated as park and ride, but public transport users simply use available land near railway stations to park their cars – these "informal" spaces and facilities were counted in this research. In terms of bike park and ride, there are situations where bike users make their own bike park and ride by simply leaving bikes wherever they can. This is impossible to estimate without dedicated counting surveys so in this research only the reported physical capacity of formal bike parking racks was used. It may be that the actual amount of bike park and ride sometimes exceeds the numbers that were able to be collected in this research.

In summary, good, coordinated information about the location and capacity of park and ride seems fundamental for any public transport system to know and to publish in a transparent way, but this is very far from the case in virtually all situations in Sweden. Consequently, it takes a very long time and a lot of persistence to assemble it via many individual responses from municipalities and other agencies. The effort in this study, as far as this researcher can determine, may be the most comprehensive effort to date to try to compare park and ride across Swedish urban areas. It would seem that each regional public transport authority or some other transport agency, should take the responsibility for gathering and providing such data transparently on an annual basis, regardless of where the administrative responsibility lies for park and ride's provision and maintenance (municipality or otherwise). For effective and transparent data, agencies need to work together and preferably stop the merry-go-round of deflecting responsibilities.

3.3. Public transport financial data

This part of the data collection sought information about the number of pre-sold tickets as a factor that may indicate varying levels of commitment to public transport in different cities (thus potentially impacting on use) and the amount of investment in public transport systems (averaged over a 5-year period from 2013-2017) as an indicator of how much financial commitment there is for public transport being expanded, maintained or completely renewed etc.

The pre-sold ticket data were collected in two components – the overall percentage of tickets that are pre-sold and the percentage of pre-sold tickets that are useable for one month or more. This again was not a simple item and caused some problems regarding what constitutes a pre-sold ticket (e.g. stored value tickets that can be used at any time) and then dividing them up into those that are one month or longer versus the rest. Each agency ended up eventually providing their data, but it was not a simple, nor fast task.

The investment spending on public transport was the hardest item of all to collect in the study. Investment spending was defined as:

- Investment in buildings, metro stations, bus stations, bus shelters including small maintenance spending for repairing bus stops such as glass replacement etc.
- Investment in rails (construction of new rail lines or extension of existing lines etc);
- Investment in signalling;
- Investment in electrical equipment;
- Investment to create reserved rights-of-way for public transport on roads;
- Costs incurred to buy or expropriate real estate or land and to deviate road networks for the construction of a new public transport line;
- Urban design improvements linked to the use of public transport;
- Construction of tunnels and bridges related to public transport;
- Purchase cost of new rolling stock and cost of major rolling stock refurbishment.

The problem with collecting these data not only related to the wide range of items included above, but also because the data being sought covered national spending, regional spending and municipal spending on public transport investment for the five years between 2013 and 2017. It also captured separate co-financed projects with municipalities, regions and the private sector, as well as some other “quasi-public, quasi-private” agencies who undertake investment (e.g. Transitio and Norrtåg), and whose spending must be accounted for. Based on the mostly difficult experience collecting these data, it can only be concluded that literally no single agency or even multiple agencies or organisations in Sweden collect these data in any systematic way – many agencies just have records of certain expenditure made by them on items that are covered under the above headings that relate purely to their own operations and responsibilities and not necessarily organised in an accounting sense to allow easy extraction of investment in public transport – spending categories are often mixed up. And certainly, no single organisation requires that all this be reported and brought together on an annual basis. In other words, no one in Sweden appears to have any idea how much is being invested in totality in extending, improving, maintaining or refurbishing public transport systems in specified geographic areas. This information must be carefully assembled from multiple sources. This has broad implications for Sweden's commitment to public transport and for the City Environment Agreements such as the possibility of following up on them and evaluating their success.

As implied above, there are also issues to do with trying to match the investment spending as defined above with how the accounting systems work in various organisations. For example, the expenditure on a major road project, which also includes a public transport component such as a bus lane, is not necessarily split up to show what the public transport component amounted to. Therefore, estimates sometimes had to be made by respondents to estimate such amounts.

There were also issues associated with what expenditure actually constitutes "investment", with some municipalities claiming they do not invest in public transport at all and that this is a regional and national responsibility. Digging a little deeper it was found that they do maintain and repair bus stops, for example, so investments are being made in the maintenance of public transport quality. Once this was established it required them to try to dig out of their accounting systems how much they spend on this item. The degree of difficulty here depended on how they categorise expenditure in their accounting system and to some degree the willingness and technical ability/competence of individuals to make these calculations.

The municipal spending on public transport investment was, in short, something of a nightmare. Many municipalities did answer on the initial request or via a reminder with good, hard data. However, four rounds of email requests spread out over 12 to 18 months were made for many municipalities who simply did not answer, with the final reminder request specifying that if no answer was received, then it will be assumed that no spending occurred. Numerous municipalities remained in this category, so some assumptions were made, not necessarily zeroing their expenditure, but looking to municipalities of similar population sizes who did answer with a definite zero expenditure and zeroing these. Other municipalities of higher population who did not answer were estimated based on the response from municipalities of similar size who did answer with some expenditure and an average amount was applied. These assumptions do not introduce significant errors in the overall expenditures because it was found after all that municipal spending relative to spending in other categories is mostly small (see Table 10). In the end, the data in this report on municipal spending on public transport investment can be considered the best available and far more comprehensive than anything that appears to have been attempted before.

Surprisingly, it was also quite hard in some cases to get the regional public transport authorities to assemble what they spend on public transport investment. The best and most systematic records of investment spending came from the Trafikverket for national expenditure via a very detailed spreadsheet. Data on expenditure by agencies such as Norrtåg and Transitio was also included in the research, as was separate expenditure for co-financed projects with contributions from a combination of municipalities, län and private companies.

Overall, the data assembled on public transport investment spending for these ten Swedish urban areas is the best and most conscientiously collected data that could be assembled given the inherent problems in trying to tease out a complex web of spending by multiple agencies with very diverse standards, priorities and record keeping categories for all the money they spend. Further comments on these issues are provided when presenting the investment spending later in this report. This problem was highlighted sometimes when comparing data that was collected in the City Environment Agreements at an earlier time, for the same thing that was requested in this research, and they did not match.

The overall impression from this research is that no agency in Sweden sees the value in knowing in total how much money is being invested in extending and improving public transport systems in Sweden. The data remain very fragmented and buried. Given the need to save energy, reduce local air and noise emissions and minimise greenhouse emissions, to name a few critical imperatives where more public transport can assist, this seems odd and far from ideal. For example, how can policymakers compare investment expenditures on roads to that on public transport without a thorough and transparent accounting of both? Since financial commitment to different modes is critical in changing mobility patterns and behaviour so that more sustainable modes can be improved and compete better with cars, it is important to see in a comprehensive way where current transport infrastructure investment priorities lie. This seems impossible at present.

As far as this researcher can determine, the data presented in this report is the most comprehensive and dedicated attempt so far to compare levels of public transport investment spending in different Swedish urban areas from all sources, notwithstanding the issues outlined above.

4. Results

4.1. Demographic Factors

The demographic factors collected here are summarised in Table 3 as standardised data indicating the average age of the population and the percentage of the population in specific age brackets indicating demographers' generational characterisations of the population:

- Born 1901 – 1924: The GI generation
- Born 1925 – 1945: The silent generation
- Born 1946 – 1964: The baby boomers generation
- Born 1965 – 1976: The Gen X generation
- Born 1977 – 1995: The millennials generation
- Born 1996 – 2020: The Gen Z generation

Additionally, it shows the percentage of the population who are employed.

In general, the data show a remarkable consistency in Swedish demographic characteristics, at least in these ten areas. The data show the following salient results:

The average age of the population hardly varies from 38.4 years in Umeå in 2015 to 40.7 years in Västerås, a difference of only 2.3 years. Between the two groups of cities as characterised here (large and small) there is virtually no difference in average age (39.3 years vs 39.4 years respectively). The very small variation in average age appears random and thus there would be no relationship with either public transport or non-motorised mobility patterns to assist in explaining variations in the latter two factors. When the age profiles are broken down further according to generations there is again remarkably little variation:

- The GI generation (the most elderly people aged from 91 to 114 years old in 2015) in each area is consistently only 1% of the population.
- The silent generation (aged from 70 to 90 years old in 2015) varies from a low in Stockholm of 10% up to a high of 13% in three other areas (Helsingborg, Västerås and Jönköping).
- Baby boomers (aged from 51 to 69 in 2015) range from 20% in three areas (Malmö, Linköping and Umeå) up to only 22% in Helsingborg and Västerås.
- The Gen X population (aged 39 to 50 in 2015) is similarly hardly varying at all, from a low of 15% in five areas (Linköping, Uppsala, Örebro, Jönköping and Umeå) up to 17% in two areas (Stockholm and Göteborg). One could say at best from this that Gen Xers tend to be more prominent in Sweden's three largest metro areas (Malmö had 16%), while the least proportion of Gen Xers are found in Sweden's smaller cities. This is probably understandable because being aged between 39 and 50 in 2015, is mid-working life and Sweden's larger cities probably offer the best work opportunities.

- Millennials (aged 20 to 38 in 2015 or youngish working age) vary the most in their concentration across the ten areas from a low of 25% in Västerås to a high of 32% in Umeå, but the average for the large and small cities is almost identical (28% and 29% respectively).
- The final grouping of Gen Z population (aged 0 to 19 years in 2015) is, like most of the other generations, very similar in prominence across the ten areas, varying from a low of 22% in three areas (Linköping, Uppsala and Umeå) up to a high of only 24% in Stockholm (with 23% in Malmö, Göteborg and Helsingborg).

Overall, the patterns of variation in the age groupings of population across the ten Swedish urban areas is very small and appears not to follow any notable pattern that would have any chance of bearing a significant relationship to public transport and non-motorised mode usage.

The final item in Table 3, the percentage of the population who is employed varies much more than the age factor, though again there seems to be no systematic differences that would be contributing factors to understanding mobility patterns. Malmö records the lowest percentage of working people (46%) while Stockholm records the highest (54%), but the average of the large and small city groupings is identical (both 51%). The next lowest proportion is Uppsala (48%). It is possible that the relative significance of student populations in both these cities contributes to their lower percentage of people in the workforce, although in Malmö it may also be due to a high proportion of immigrants.

Table 3: A selection of demographic factors that may influence mobility patterns in Swedish cities, 2015.

Variable	Units	Stockholm 2015	Malmö 2015	Goteborg 2015	Linköping 2015	Helsingborg 2015	SWE Large
Average age of population (in years)	years	38.7	39.0	39.1	39.1	40.5	39.3
Gen Z (born 1996 - 2020) percent of population	%	24 %	23 %	23 %	22 %	23 %	23 %
Millennials (born 1977 - 1995) percent of population	%	27 %	28 %	27 %	30 %	26 %	28 %
Gen X (born 1965 - 1976) percent of population	%	17 %	16 %	17 %	15 %	16 %	16 %
Baby Boomers (born 1946 - 1964) percent of population	%	21 %	20 %	21 %	20 %	22 %	21 %
Silent Generation (born 1925 - 1945) percent of population	%	10 %	12 %	11 %	12 %	13 %	11 %
GI Generation (born 1901 - 1924) percent of population	%	1 %	1 %	1 %	1 %	1 %	1 %
Percentage of population who are employed (%)	%	54 %	46 %	51 %	53 %	50 %	51 %
		Uppsala 2015	**Västerås 2015**	**Örebro 2015**	**Jönköping 2015**	**Umeå 2015**	**SWE Small**
Average age of population (in years)	years	38.6	40.7	39.3	39.9	38.4	39.4
Gen Z (born 1996 - 2020) percent of population	%	22 %	23 %	23 %	23 %	22 %	22 %
Millennials (born 1977 - 1995) percent of population	%	31 %	25 %	28 %	27 %	32 %	29 %
Gen X (born 1965 - 1976) percent of population	%	15 %	16 %	15 %	15 %	15 %	15 %
Baby Boomers (born 1946 - 1964) percent of population	%	21 %	22 %	21 %	21 %	20 %	21 %
Silent Generation (born 1925 - 1945) percent of population	%	11 %	13 %	12 %	13 %	11 %	12 %
GI Generation (born 1901 - 1924) percent of population	%	1 %	1 %	1 %	1 %	1 %	1 %
Percentage of population who are employed (%)	%	48 %	49 %	51 %	53 %	53 %	51 %

4.2. Taxi Factors

Table 4 provides the standardized taxi variables that help to characterize the significance of taxis in the ten Swedish urban areas. The first variable, taxis per 1000 persons measures the comparative availability of taxis, which varies between 1.18 taxis per 1000 persons in Jönköping up to 2.87 in Stockholm, an almost 2.5-fold higher level, the average for the whole sample being 1.68. Overall, there is no obvious pattern of variation between the cities. However, it is perhaps surprising that the largest city in Sweden with the most diverse and extensive public transport system, also has the highest availability of taxis, which seems somewhat counter intuitive. One possible reason could be the high number of tourists, business-people and large events that occur in the city and therefore may generate higher taxi demand.

Taxi operating characteristics are examined through the total vehicle kilometres they drive (i.e. both with passengers and seeking passengers), the number of passenger trips they capture, and the passenger kilometres travelled by taxi patrons. The total annual vehicle kilometres driven by taxis per person is naturally very small due to their relatively low taxi numbers, varying between a high of 203 vehicle km in Stockholm down to only 74 in Linköping. Looking at how much driving a taxi vehicle does per year, we see that it varies quite a lot from a high of 73,407 km in Malmö and Helsingborg to only 61,000 km in Linköping. However, when one combines the total vehicle kilometres driven by taxis and compares it to the passenger trips obtained, the numbers are surprisingly high, varying between 27.7 km per trip in Malmö and Helsingborg and 22.8 km per trip in Örebro. These kilometres include the empty driving between passenger trips and the kilometres driven with passengers.

The annual taxi trips taken per person in the ten urban areas vary between a high of only 7.6 in Stockholm and 3.1 in Jönköping (average 4.5) and the annual passenger kms per person travelled by taxi passengers ranges from 47 km in Jönköping to 115 km in Stockholm (average 67). On the other hand, by comparison, public transport systems in the same ten Swedish cities in 2015 averaged 117 annual boardings per person (26 times higher) and 1,291 passenger km per person (19 times higher).

Considering these figures, it is easy to conclude that taxis are fulfilling a specialized niche role which has little bearing on overall mobility patterns and certainly cannot compete with the efficiency of public transport or other modes in, for example, energy use or the amount of driving needed to serve their passengers. On the other hand, they provide essential mobility and access to those who cannot choose other means, so they do often perform an important social equity service. Additionally, they are likely providing convenient and fast mobility for tourists and business-people.

Table 4: Taxi factors that may influence mobility patterns in Swedish cities, 2015.

Variable		Stockholm 2015	Malmö 2015	Goteborg 2015	Linköping 2015	Helsingborg 2015	SWE Large
Number of taxis per 1000 persons	taxis per 1000 persons	2.87	1.63	1.66	1.21	1.41	1.75
Taxi annual vehicle kilometres per person	vehicle km per person	203	120	112	74	103	122
Taxi kilometres driven to capture one passenger trip	km driven per passenger trip	26.8	27.7	25.5	23.0	27.7	26.1
Taxi trips per person per year	trips per person	7.6	4.3	4.4	3.2	3.7	4.6
Taxi annual passenger kilometres per person	passenger km per person	114.6	65.3	66.3	48.4	56.3	70.2
Average passenger occupancy of a taxi (passenger km/vehicle km)	passengers per taxi	0.56	0.54	0.59	0.66	0.54	0.58
Average annual kilometres driven per taxi	km per taxi	70,939	73,407	67,493	61,002	73,407	69,250
		Uppsala 2015	**Västerås 2015**	**Örebro 2015**	**Jönköping 2015**	**Umeå 2015**	**SWE Small**
Number of taxis per 1000 persons	taxis per 1000 persons	1.71	1.74	1.82	1.18	1.62	1.61
Taxi annual vehicle kilometres per person	vehicle km per person	117	124	110	79	111	108
Taxi kilometres driven to capture one passenger trip	km driven per passenger trip	25.9	26.9	22.8	25.4	25.7	25.3
Taxi trips per person per year	trips per person	4.5	4.6	4.8	3.1	4.3	4.3
Taxi annual passenger kilometres per person	passenger km per person	68.3	69.7	72.7	47.1	64.9	64.5
Average passenger occupancy of a taxi (passenger km/vehicle km)	passengers per taxi	0.58	0.56	0.66	0.59	0.59	0.60
Average annual kilometres driven per taxi	km per taxi	68,546	71,239	60,355	67,375	68,157	67,134

4.3. Non-Motorised Infrastructure Factors

Non-motorised mobility, primarily walking and cycling, but also in recent years including e-bikes, e-scooters and other "lightly-motorised modes" are the most sustainable of all modes. It is important therefore to try to obtain some objective, quantitative measurements of physical factors that might underpin variations in the use of these modes across cities. The most commonly talked about infrastructure in this regard and the "easiest" for which to collect data are the extent of cycleways, footpaths and the length and area of streets that are pedestrianised. Of course, these are not the only physical factors that might impact on these modes, for example, availability of bike parking, traffic-calmed streets, width of footpaths and cycleways, general attractiveness/beauty of the urban environments, which may also encourage walking and cycling etc. However, such data would require a major research exercise, and as explained in a previous section, just obtaining footpath lengths is fraught with difficulties. Table 5 contains the results of this data collection.

4.3.1. Cycleways

The length of cycleways embraces all off-road and on-road cycleways on both sides of the street. This factor varies considerably across the sample with Umeå having only 0.23 metres of cycleways per person compared to Helsingborg with 3.85 metres per person (the average for the 10 cities is 2.34 metres with the larger cities having on average a more liberal provision of cycleways (2.76 metres c.f. 1.92 metres per person). When expressed as a spatial density, Helsingborg and Umeå are again the highest (84 metres per ha) and the lowest (3 metres per ha) respectively.

4.3.2. Footpaths

Examining the length of footpaths, we see that, logically, and despite the problems in collecting this item, footpaths significantly exceed cycleways in availability. In this case Umeå has the highest availability with 12.7 metres per person with Linköping the lowest 4.1 metres per person (average for the ten areas: 6.9 metres per person). The spatial density of footpaths is similar with Umeå being the highest (145.0 metres per ha) and Linköping the lowest (56.8 metres per ha). The average for the whole sample is 111 metres per ha.

4.3.3. Pedestrianised streets

Considering the fully pedestrianised streets, there is also a significant variation with the length of pedestrianised streets per person being highest in Helsingborg 18 metres per 1000 persons and lowest in Västerås (7 metres per 1000 persons), although Stockholm is the same (7 meters per 1000 persons). The sample average was 12 metres per 1000 persons. When the area occupied by pedestrianised streets is considered, Umeå is the highest rated at 364 sq. metres per 1000 persons and Västerås and Örebro the lowest (102 and 103 sq. metres per 1000 persons respectively), but again Stockholm is close with only 105 sq. metres. The average for all the cities was 161 sq. metres per 1000 persons.

The final way of considering the pedestrianised streets is to show the spatial density of the pedestrianised land. The square metres of pedestrianised streets per urban ha is highest in Helsingborg (5.5 sq. metres) and lowest in Örebro (1.4 sq. metres), while the sample average is 2.6 sq. metres per urban ha.

Unlike the previous demographic factors and those related to taxis, which are very unlikely to have any bearing on observed mobility patterns in the ten cities because of the lack of variation or the small magnitude/impact of the factors on overall mobility, the non-motorised infrastructure data appear to bear further exploration because of their significant variation. The implication of these patterns needs to be investigated to see if they together can help explain the observed modal splits for daily trips by walking and cycling (see section 5).

Table 5: Non-motorised mode infrastructure factors that may influence mobility patterns in Swedish cities, 2015

Variable		Stockholm 2015	Malmö 2015	Goteborg 2015	Linköping 2015	Helsingborg 2015	SWE Large
Length of cycleways per person	metres per person	1.72	2.70	1.95	3.59	3.85	2.76
Length of cycleway per urban ha	metres per urban ha	40.32	54.08	38.45	49.52	84.34	53.34
Length of footpaths per person	metres per person	4.34	6.40	4.63	4.12	6.31	5.16
Length of footpaths per urban ha	metres per urban ha	101.94	128.15	91.15	56.83	138.30	103.27
Length of fully pedestrianised streets per 1000 persons	metres per 1000 persons	7.47	10.56	9.45	14.45	18.00	11.98
Area of fully pedestrianised streets per urban ha	sq.metres per urban ha	2.45	2.86	2.61	1.99	5.52	3.09
Area of fully pedestrianised streets per 1000 persons	sq.metres per 1000 persons	104.55	142.84	132.27	144.61	251.96	155.24
		Uppsala 2015	**Västerås 2015**	**Örebro 2015**	**Jönköping 2015**	**Umeå 2015**	**SWE Small**
Length of cycleways per person	metres per person	2.02	2.97	2.10	2.27	0.23	1.92
Length of cycleway per urban ha	metres per urban ha	30.92	50.76	28.68	28.52	2.63	28.30
Length of footpaths per person	metres per person	7.42	7.13	7.45	8.87	12.73	8.72
Length of footpaths per urban ha	metres per urban ha	113.73	121.74	101.83	111.65	145.79	118.95
Length of fully pedestrianised streets per 1000 persons	metres per 1000 persons	12.13	7.32	14.77	10.81	14.08	11.82
Area of fully pedestrianised streets per urban ha	sq.metres per urban ha	1.74	1.75	1.41	1.90	4.17	2.19
Area of fully pedestrianised streets per 1000 persons	sq.metres per 1000 persons	113.66	102.48	102.76	151.33	364.31	166.91

4.4. Public Transport Infrastructure Factors

This section deals with a range of public transport infrastructure features which could have some bearing on how much public transport is utilised. The first set of data in Table 6 examines the age of the public transport fleet in the ten cities by mode and overall, with a newer overall fleet perhaps being one sign of public transport quality.

The second set of data looks at the number of stations and stops by mode, with each stop only being counted once (not both directions, nor multiple times where more than one bus or rail line utilises the same stop or station). Coverage of public transport systems and their accessibility is important. Knowing the relative availability of public transport stops and stations on a per capita and spatial basis may provide a measure of public transport's presence, accessibility and usability in a city.

The final set of data presents a comprehensive picture of park and ride (P&R) facilities and spaces for both cars and bikes in each city. Park and ride is often thought of as being an important component of improving access to public transport, especially for those living in more car-dependent locations or simply for those who have too far to walk and could benefit by accessing public transport on a bike. It is also seen as a way of keeping cars out of sensitive parts of cities. Of course, bike P&R does not take account of the possibility of taking a bike on public transport, rather than parking it, so bike access to public transport is likely understated by P&R data alone. The P&R data provided in this study give direct measures of the extent of car and bike P&R infrastructure in each city and therefore also, via some calculations, some insight into how significant this could be in generating public transport use and farebox revenue.

4.4.1. Age of public transport vehicles

Table 6 provides modal and overall age of public transport vehicles. Only two modes are consistently present in all ten cities (buses and suburban rail), while metro is only present in Stockholm and light rail only in Stockholm, Göteborg and Linköping. The average age of buses in 2015 does not exceed 6.5 years in any city with the youngest in Uppsala (3.8 years) and the oldest in Umeå and Helsingborg (6.4 years). The rail modes are consistently older because the rolling stock lasts longer and is subject to refurbishment. Göteborg has the oldest LRT vehicles (32.9 years) but the other two cities have much younger fleets of 10 years or less with an average of 17.3 years for the three cities. Suburban rail fleet age varies rather significantly from only 6.0 years in Stockholm to 18.0 years in Jönköping with an average for the sample of 11.5 years.

In summary, one can generally say that overall, the public transport vehicle age (weighted by numbers of vehicles in each mode) is relatively young in Swedish cities due to the preponderance of buses, ranging from only 4.3 years in Uppsala to 11.4 years in Göteborg and an average for the ten cities of 7.1 years.

4.4.2. Public transport stations and stops

Public transport stops and stations are also provided by mode, with the most significant explanatory factor in public transport use likely being the total of all modes and within this, bus stops clearly are the major contributor. Stops are normalized by population (stops per 10,000 persons), by total land area (stops per 1000 ha of total land) and stops per kilometre of total line length. For per capita availability of stops there is an average across the ten cities of 50.5 stops per 10,000 persons, ranging from a low of 19.1 in Malmö up to 83.4 in Umeå. In spatial density of stops, Stockholm and Helsingborg stand out, with 10.9 and 10.3 stops per 1000 ha while Umeå has a meager 0.40 stops per 1000 ha. The average for the sample is 4.2 stops per 1000 ha. While Malmö had the least stops on a per capita basis it was the third highest on a spatial basis (5.3 stops per 1000 ha), behind Stockholm and Helsingborg.

In these data one can clearly see the impact of urban density on whether stops are measured per person or per ha (e.g. Umeå has the most stops per capita because it has the lowest population density, but the lowest spatial density because of the large urban area that public transport must service). In terms of the potential influence of this stop and station availability data on public transport use, it would seem intuitively logical that the spatial density of public transport entry points is more cogent and meaningful than per capita availability.

The final item for stops and stations is the number per kilometre of line length. It is important to note here that line length counts every line from beginning to end, so those lines that share common sections are counted multiple times, whereas, as explained before stops are only counted as physical entities, so only once. That is, if there are 10 kilometres of road along which 5 bus routes operate that is 50 kilometres of line length. If along this stretch there is a bus stop every 500 metres that is only 20 bus stops, even though 5 bus lines use the same stops (so in these data it is not 100 bus stops for the 50 km of line length but still only 20).

In the ten cities, there are on average 0.62 stops per kilometre of line length and this is relatively consistent, ranging from a low of 0.44 in Umeå to a high of 0.85 in Helsingborg, but without these two extremes the remaining 8 cities are clustered between 0.52 and 0.67 stops per km of line length.

4.4.3. Public transport car and bike park and ride (P&R)

The final item in Table 6 concerns P&R. These data have been normalized on a per capita basis and per kilometre of reserved public transport route, since most P&R facilities occur at stations or stops along such dedicated infrastructure i.e. mostly railways stations or significant bus stops on bus lanes/BRT style operation. Previous work by Kenworthy and Laube (2001) normalized car P&R on this latter basis, therefore some comparisons can be made to the situation in Swedish cities.

The number of P&R facilities are of less importance than the spaces they provide. However, Table 6 shows that on average there are approximately 0.25 P&R facilities for both cars and bikes per kilometre of reserved public transport length, meaning about 1 facility every 4 km of reserved route in Swedish cities. For cars, this varies from a low of zero (i.e. too few to register to the 2nd decimal place) in Jönköping and 0.02 in Umeå, 0.03 in Västerås up to 0.78 in Göteborg. For bikes, again Jönköping has too few bike P&R facilities to register here and Umeå has 0.04, while Stockholm and Göteborg have comparatively generous provision with 0.48 per kilometre or almost 1 facility for every 2 km of reserved route. Finally, in both car and bike P&R facilities, it can be said that the larger Swedish cities have significantly more than do the smaller cities, probably spurred on by the fact that these larger cities try to keep as many cars as possible out of their central areas.

Considering the P&R spaces for cars, the average for the whole sample is 15 spaces per kilometre of reserved route, but the three largest Swedish cities, Stockholm, Göteborg and Malmö clearly have much more (44, 40 and 20 spaces per km respectively). By stark contrast, Jönköping does not register as having any, while Umeå has only two. Again, it is the larger Swedish cities which stand out in this factor with 24 spaces per kilometre while the smaller cities have only 6 spaces per kilometre or only one-quarter as many.

The bike P&R spaces in these Swedish cities are a little more abundant than the car spaces with 17 spaces per kilometre of reserved route. Again, Jönköping as of 2015 did not have enough bike P&R to register on this factor and Umeå had only a little more than 1 space per kilometre. However, Malmö, Stockholm and, Göteborg, and to a slightly lesser degree, Uppsala stand out in this factor with 46, 33, 24 and 18 spaces per kilometre respectively. Very clearly, the larger Swedish cities are much more oriented to linking bikes with public transport than are the smaller cities (26 spaces per kilometre on average, compared to 8). Again, it seems there is a lot more pressure in the larger Swedish cities to keep cars out of sensitive parts of the city and they have overall more attractive public transport systems that people with cars would want to access.

To gain an overall perspective on P&R by bike and car, Table 6 also reports the total P&R spaces per kilometre of reserved route and reveals clearly that Stockholm, Malmö and Göteborg stand apart from all the other cities in total P&R (77, 65 and 64 spaces per km respectively), with the nearest to these being Uppsala with 35. For the remaining six cities, the average was only 13 spaces per kilometre. The larger Swedish cities had in total a shade over 3.5 times more P&R spaces per kilometre of reserved route than the smaller ones.

Table 6 also provides for reference the number of P&R spaces per 10,000 persons for cars, bikes and in total. The comparative differences are similar, although the difference between the large and smaller cities largely levels out with the larger cities having 137 spaces per 10,000 persons and the smaller having 96, with the larger being only about 1.5 times higher in P&R. Umeå and Linköping are the lowest on this basis, with 61 spaces per 10,000 persons.

The final item simply assesses the relative importance of bike P&R against car P&R by providing the percentage of all P&R spaces that are accounted for by bikes. In the whole sample, the average was 52%, so basically evenly distributed, though Malmö, Örebro, and Helsingborg have a significant predominance of bike P&R (70%, 69% and 63% respectively). Four cities have less bike P&R than car P&R - Stockholm 43%, Göteborg, 37%, Jönköping 33% and Umeå 41% of the total P&R.

Table 6: Public transport infrastructure factors that may influence mobility patterns in Swedish cities, 2015

Variable		Stockholm 2015	Malmö 2015	Goteborg 2015	Linköping 2015	Helsingborg 2015	SWE Large
Average age of buses	years	5.0	5.6	4.9	5.8	5.6	5.4
Average age of light rail vehicles	years	10.0	-	32.9	9.1	-	17.3
Average age of metro vehicles	years	24.1	-	-	-	-	24.1
Average of suburban rail vehicles	years	6.0	7.0	13.5	8.2	7.0	8.3
Average age of ferries	years	45.0	-	-	-	-	45.0
Overall average age of all public transport vehicles	years	8.7	6.3	11.4	6.3	6.4	7.8
Bus stops per 10000 persons	stops per 10000 persons	29.51	18.72	51.59	55.29	25.02	36.02
Light rail stops per 10000 persons	stops per 10000 persons	0.52	0.00	0.78	1.21	0.00	0.84
Metro stations per 10000 persons	stations per 10000 persons	0.45	0.00	0.00	0.00	0.00	0.45
Suburban rail stations per 10000 persons	stations per 10000 persons	0.24	0.40	0.58	0.34	0.73	0.46
Ferry stops per 10000 persons	stops per 10000 persons	1.20	0.00	0.00	0.67	0.00	0.93
Overall public transport stops per 10000 persons	stops per 10000 persons	31.91	19.12	52.95	57.51	25.74	37.45
Overall public transport stops per total 1000 hectares of land	stops per 1000 ha	10.91	5.28	3.75	2.43	10.32	6.54
Overall public transport stops per total line length	stops per km of line	0.66	0.62	0.56	0.52	0.85	0.64
Number of car P&R facilities per kilometre of reserved public transport route	facilities per km	0.43	0.27	0.78	0.12	0.17	0.35
Number of bike P&R facilities per kilometre of reserved public transport route	facilities per km	0.48	0.21	0.48	0.12	0.15	0.29
Number of car P&R spaces per kilometre of reserved public transport route	spaces per km	43.8	19.6	40.1	7.6	10.0	24.2
Number of bike P&R spaces per kilometre of reserved public transport route	spaces per km	33.4	45.8	23.7	8.7	17.1	25.7
Total P&R spaces per kilometre of reserved public transport route	spaces per km	77.1	65.4	63.9	16.3	27.1	50.0
Number of car P&R spaces per 10000 persons	spaces per 10000 persons	102.3	43.4	113.6	28.7	43.3	66.3
Number of bike P&R spaces per 10000 persons	spaces per 10000 persons	78.0	101.5	67.2	32.8	74.0	70.7
Total number of P&R spaces per 10000 persons	spaces per 10000 persons	180.3	144.9	180.7	61.5	117.3	137.0
Proportion of total P&R spaces that are bike	%	43.3%	70.0%	37.2%	53.3%	63.1%	53.4%
		Uppsala 2015	**Västerås 2015**	**Örebro 2015**	**Jönköping 2015**	**Umeå 2015**	**SWE Small**
Average age of buses	years	3.8	6.1	5.3	5.3	6.4	5.4
Average age of light rail vehicles	years	-	-	-	-	-	-
Average age of metro vehicles	years	-	-	-	-	-	-
Average of suburban rail vehicles	years	12.1	17.2	17.2	18.0	9.0	14.7
Average age of ferries	years	-	-	-	-	-	-
Overall average age of all public transport vehicles	years	4.3	7.2	7.8	6.4	6.5	6.4
Bus stops per 10000 persons	stops per 10000 persons	64.1	44.7	65.5	57.5	82.9	62.93
Light rail stops per 10000 persons	stops per 10000 persons	0.00	0.00	0.00	0.00	0.00	-
Metro stations per 10000 persons	stations per 10000 persons	0.00	0.00	0.00	0.00	0.00	-
Suburban rail stations per 10000 persons	stations per 10000 persons	0.51	0.61	0.45	1.15	0.46	0.63
Ferry stops per 10000 persons	stops per 10000 persons	0.00	0.00	0.00	0.00	0.00	-
Overall public transport stops per 10000 persons	stops per 10000 persons	64.60	45.26	65.91	58.65	83.38	63.56
Overall public transport stops per total 1000 hectares of land	stops per 1000 ha	2.79	2.34	2.26	1.95	0.40	1.95
Overall public transport stops per total line length	stops per km of line	0.58	0.66	0.67	0.65	0.44	0.60
Number of car P&R facilities per kilometre of reserved public transport route	facilities per km	0.32	0.03	0.43	0.00	0.02	0.16
Number of bike P&R facilities per kilometre of reserved public transport route	facilities per km	0.29	0.30	0.22	0.00	0.04	0.17
Number of car P&R spaces per kilometre of reserved public transport route	spaces per km	16.7	4.3	7.0	0.0	1.9	6.0
Number of bike P&R spaces per kilometre of reserved public transport route	spaces per km	17.9	5.2	15.4	0.0	1.3	8.0
Total P&R spaces per kilometre of reserved public transport route	spaces per km	34.6	9.5	22.4	0.1	3.3	14.0
Number of car P&R spaces per 10000 persons	spaces per 10000 persons	97.7	54.5	29.3	0.6	36.3	43.7
Number of bike P&R spaces per 10000 persons	spaces per 10000 persons	104.3	66.8	64.9	0.3	25.2	52.3
Total number of P&R spaces per 10000 persons	spaces per 10000 persons	202.0	121.3	94.3	0.9	61.4	96.0
Proportion of total P&R spaces that are bike	%	51.6%	55.1%	68.9%	33.3%	41.0%	50.0%

4.4.4. Implications of P&R for public transport use in Swedish cities

The preceding data in Table 6 provide a unique opportunity to assess how P&R contributes to overall public transport use in Swedish cities. The objective of P&R for users is to extend the effective range or coverage of a public transport network, especially by allowing people in more car-dependent locations to leave their cars at a station and take public transport for the remainder and most likely the longest portion of their trip. In this sense, the public transport trips so derived could be thought of as being car-dependent, which is not ideal. From society's perspective, P&R is thought to provide some protection to central and inners areas against car traffic, to help minimize congestion, reduce parking needs and to earn extra fare revenue. Bike P&R performs a similar function in allowing people who are not within convenient walking distance of public transport to access it in a sustainable way. Bike-dependent public transport use is preferable to car-dependent public transport use since bike P&R is so much less expensive to provide and takes up much less space.

Table 7 provides estimates of the percentage of total annual public transport use that could be generated from car, bike and total P&R spaces in each city. The assumptions about generated public transport trips from P&R are based on each P&R space being occupied by the same car or bike all day and generating one forward and one return trip on public transport, 365 days a year. In practice, not all P&R spaces would be occupied every day of the year but more likely it would be a figure between 250 working days and 365 days, accounting for likely lower use of P&R on weekends. Of course, a P&R space may be used by more than one car or bike each day, in which case it would generate more trips. So, there is both an inflationary and deflationary factor built into the assumptions which in some way may cancel each other out.

Table 7: Car and bike P&R contribution to total public transport use in Swedish cities, 2015.

Variable		Stockholm 2015	Malmö 2015	Goteborg 2015	Linköping 2015	Helsingborg 2015	SWE Large
Maximum number of annual public transport trips from car P&R 365	trips	16,668,820	2,203,870	8,144,610	934,400	435,810	5,677,502
Percentage of total annual public transport trips that this represents	%	2.08%	2.85%	2.91%	3.28%	2.00%	2.62%
Maximum number of annual public transport trips from bike P&R	trips	12,704,920	5,152,340	4,817,270	1,065,800	745,330	4,897,132
Percentage of total annual public transport trips that this represents	%	1.59%	6.65%	1.72%	3.74%	3.41%	3.42%
Total theoretical annual public transport trips from car and bike P&R	trips	29,373,740	7,356,210	12,961,880	2,000,200	1,181,140	10,574,634
Percentage of total annual public transport trips that this represents	%	3.67%	9.50%	4.63%	7.01%	5.41%	6.04%
		Uppsala 2015	**Västerås 2015**	**Örebro 2015**	**Jönköping 2015**	**Umeå 2015**	**SWE Small**
Maximum number of annual public transport trips from car P&R 365	trips	2,525,800	1,051,200	623,420	14,600	697,150	982,434
Percentage of total annual public transport trips that this represents	%	6.62%	7.45%	5.47%	0.07%	5.85%	5.09%
Maximum number of annual public transport trips from bike P&R	trips	2,697,350	1,289,180	1,379,700	7,300	483,990	1,171,504
Percentage of total annual public transport trips that this represents	%	7.07%	9.14%	12.10%	0.04%	4.06%	6.48%
Total theoretical annual public transport trips from car and bike P&R	trips	5,223,150	2,340,380	2,003,120	21,900	1,181,140	2,153,938
Percentage of total annual public transport trips that this represents	%	13.68%	16.60%	17.57%	0.11%	9.91%	11.57%

Table 7 shows that car P&R potentially contributes between 0.07% of total annual public transport use in Jönköping and 7.45% in Västerås with an average across the sample of 3.86%. On the other hand, bike P&R could contribute 0.04% in Jönköping according to official data, but a high of 12.1% in Örebro. For the sample, the average contribution to total public transport use is 4.95%, which is higher than for car P&R.

In total, P&R across the sample is estimated to account for around 8.8% of overall public transport use in these cities with a range between 0.11% in Jönköping (Stockholm is the next lowest with 3.67%) and a high of 17.57% in Örebro. In the smaller Swedish cities, P&R generally contributes a higher percentage of total trips (11.57%) than in the larger cities (6.04%). The results are interesting in that the larger cities have much more P&R but clearly other means of accessing public transport dominate strongly. On the other hand, the smaller cities have lower levels of P&R but in terms of P&R's contribution to total public transport use, it is much higher. This is likely a function of the lower densities and the more dispersed nature of urban settlement in these cities, such that P&R access to public transport becomes proportionally more important than other means of getting to public transport stops and stations.

As a final statement one could say that P&R in total is only contributing relatively small proportions of total public transport use in these ten Swedish cities, on average around 9%, split roughly equally between car and bike P&R, with the latter being much easier and cheaper to provide and taking up a fraction of the space.

These data raise the policy question of whether the costs of providing and maintaining car P&R facilities (bike P&R is relatively inexpensive to provide), justify the amount of public transport use they generate. The amount of money raised in terms of farebox revenue (including any reimbursements for concession fares) from P&R generated trips can be calculated from farebox revenue data previously collected on these 10 cities in other K2 projects conducted by the author (Table 8).

Since P&R provision costs are unknown, as is any money raised from the use of car P&R spaces where it is not provided free, it is hard to evaluate the cost-effectiveness of car P&R. But the data in Table 8 at least provide some estimates of the amount of money raised through the farebox by the ridership generated from car P&R. These figures provide a kind of benchmark against which P&R might begin to be evaluated in economic terms.

The data show that car P&R potentially generated ridership worth a high of 181.7 million SEK in Stockholm in 2015 (21.8 million USD) and a low of 0.23 million SEK in Jönköping (0.027 million USD). These data could be used for each city to compare to the costs of providing the P&R (both construction and maintenance) in the individual circumstances in each city. For example, where P&R is underground with other valuable uses above, the evaluation of its economic value would be different compared to where the land only has the P&R and therefore could be potentially used for other purposes.

Another major policy question aside from costs is therefore whether the land occupied by P&R is the highest and best use of this land, given the relatively small amounts of farebox revenue it generates. Would the land occupied solely by car P&R (either surface or in parking garages) be better utilised if the P&R was placed underground with higher value land uses above, which also can generate extra public transport use? These are important policy questions that also have a bearing on the overall re-structuring of urban regions around public transport using dense, mixed use sub-centres (transit-oriented development or TOD). This whole issue is potentially quite complex and worthy of more detailed consideration, such as taking into account, for example, who owns the land on which the P&R is situated.

Table 8: Estimates of farebox revenue raised from car P&R generated by public transport trips in Swedish cities, 2015

Variable		Stockholm 2015	Malmö 2015	Goteborg 2015	Linköping 2015	Helsingborg 2015	SWE Large
Farebox revenue per boarding including fare reimbursements 2015	2015 SEK per boarding	10.90 SEK	12.19 SEK	11.12 SEK	14.32 SEK	9.39 SEK	11.59 SEK
Farebox revenue per boarding including fare reimbursements 2015	2015 USD per boarding	$1.31	$1.46	$1.33	$1.72	$1.13	$1.39
Number of car P&R trips generated	trips	16,668,820	2,203,870	8,144,610	934,400	435,810	5,677,502
Total farebox revenue raised from car P&R trips 2015	2015 SEK	181,685,308 SEK	26,871,749 SEK	90,547,458 SEK	13,383,827 SEK	4,094,004 SEK	63,316,469 SEK
Total farebox revenue raised from car P&R trips 2015	2015 USD	$21,802,237	$3,224,610	$10,865,695	$1,606,059	$491,280	$7,597,976
		Uppsala 2015	**Västerås 2015**	**Örebro 2015**	**Jönköping 2015**	**Umeå 2015**	**SWE Small**
Farebox revenue per boarding including fare reimbursements 2015	2015 SEK per boarding	14.68 SEK	11.53 SEK	19.41 SEK	15.57 SEK	22.50 SEK	16.74 SEK
Farebox revenue per boarding including fare reimbursements 2015	2015 USD per boarding	$1.76	$1.38	$2.33	$1.87	$2.70	$2.01
Number of car P&R trips generated	trips	2,525,800	1,051,200	623,420	14,600	697,150	982,434
Total farebox revenue raised from car P&R trips 2015	2015 SEK	37,069,109 SEK	12,118,135 SEK	12,099,859 SEK	227,355 SEK	15,686,138 SEK	15,440,119 SEK
Total farebox revenue raised from car P&R trips 2015	2015 USD	$4,448,293	$1,454,176	$1,451,983	$27,283	$1,882,337	$1,852,814

4.4.5. International comparisons of car P&R

The Millennium Cities Database for Sustainable Transport (Kenworthy and Laube, 2011) collected car P&R data (not bike) for 84 cities around the world in 1995. Although these data are now 20 years out of date compared to the Swedish cities in 2015, these earlier data remain the most comprehensive set of P&R data ever collected on cities worldwide. For this reason, it is worthwhile seeing where these 10 Swedish cities might fit within a large global continuum of car P&R.

Figure 1 shows the global cities from highest to lowest in car P&R spaces per kilometre of reserved public transport route together with the Swedish cities. It shows that Stockholm is the highest Swedish city but is very significantly below twenty other cities. The remainder of the Swedish cities are widely distributed throughout the continuum, but most are in the lower half. Jönköping's meager car P&R is not sufficient to register so shows up as zero, along with nineteen other world cities on this way of measuring comparative P&R. One thing that is clear is that cities at the very highest end of P&R provision such as Atlanta, Calgary, San Francisco and Washington certainly are not leaders in public transport use but are very car-dependent cities. Cities such as Tokyo, which have amongst the highest per capita use of public transport have almost no P&R. Overall, there seems to be little relationship between P&R provision and overall public transport use.

The average car P&R spaces per km of reserved public transport route for the ten Swedish cities was 15 and for the global sample it was 64, so for this way of comparing P&R, Swedish cities have much less than in other cities, though this is strongly influenced by the relatively large and comparatively unusual extent of suburban rail reserved route in Swedish cities (given their comparatively low density), which expands the denominator and diminishes the amount of P&R per kilometre.

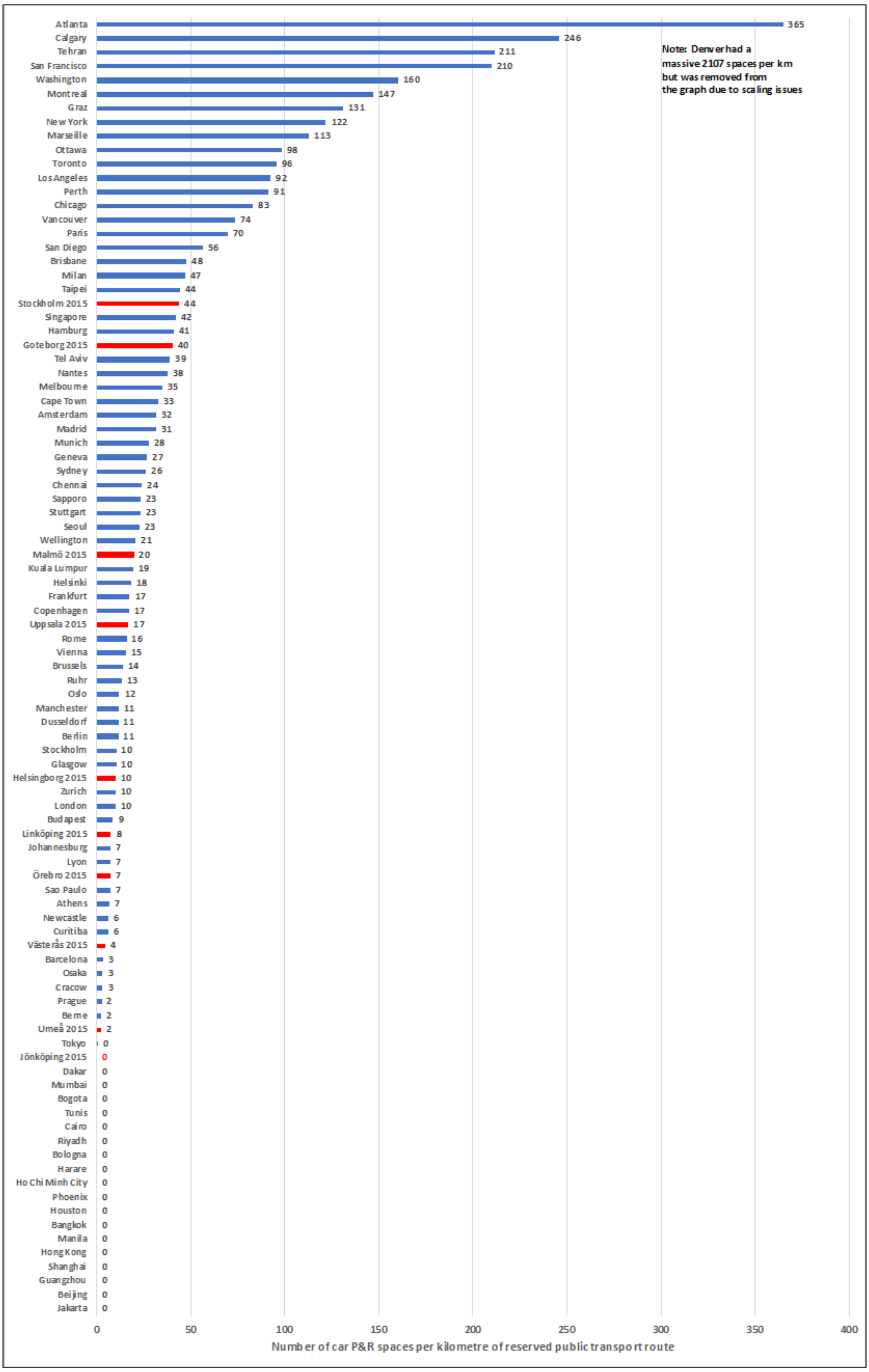

Figure 1: Car P&R spaces per kilometre of reserved public transport route in global cities (1995) and Swedish cities (2015)

The issue with this way of standardizing the data is that it therefore depends on the extent of reserved public transport route which, for example, in the case of Houston is zero so Houston appears to have no P&R whereas in fact it does have many spaces. A more consistent way of normalizing the data for comparative purposes is to use population, which is common to all cities, so the standardizing is not subject to the non-existence of the denominator. Figure 2 provides these data.

It can be seen from Figure 2 that a rather different picture emerges on the extent of car P&R without the vicissitudes of the extent of reserved public transport. It shows that Stockholm, Göteborg and Uppsala are highly ranked in terms of P&R on a per capita basis, with the remainder of the Swedish cities in the middle of the graph, apart from Jönköping which is positioned just prior to cities with zero P&R. The average car P&R spaces per 10,000 persons in the global sample from 1995 was 35, whereas the Swedish sample was 55, so some 36% higher than the global cities.

It should also be noted that Stockholm was part of the 1995 global data and in that year, it had values of 10 car P&R spaces per kilometre of reserved route and 46 spaces per 10,000 persons. However, by 2015 these figures respectively had increased fourfold to 44 spaces per kilometre of reserved route and more than doubled to 102 spaces per 10,000 persons. It appears in the intervening 20 years that Stockholm has had an increased focus on providing car P&R. It remains an open question as to whether this is a good and justifiable trend or something that could be questioned if subjected to closer analysis. Perhaps the data in this project could help this to be done.

In an overall perspective, it seems clear that P&R is certainly not a determining factor in how much or how little public transport is used in any city (see later examinations in this report). When regressions between the two measures of car P&R availability and public transport boardings per capita are performed on the 1995 global cities, there is no significant correlation whatsoever, testing all the lines of best fit (linear, power, exponential etc). Therefore, in a policy sense, whether P&R is provided or not, and in what quantity if it is provided, becomes a decision that must be made on other grounds. Where there is a priority towards transit-oriented development, then land is more likely to be used for urban development, with at best, P&R provision underground. This is the case in the Cities of Vancouver, Burnaby and New Westminster in the Vancouver region where P&R has expressly not been provided in favour of building dense, mixed land use sub-centres at Skytrain stations. Other factors also probably play a role, such as decisions to better provide for car-dependent areas where it is not possible to provide frequent and attractive public transport services or perhaps even decent bus-feeders, so people must drive to access public transport. However, this becomes somewhat of a perceived equity question, because regardless of its personal benefits to the relatively few who get to use P&R, it is not a big benefit to the overall public transport system in terms of usage. The question then becomes, is car P&R on balance a good decision or not? Schiller and Kenworthy (2011) analyse this whole issue in some detail.

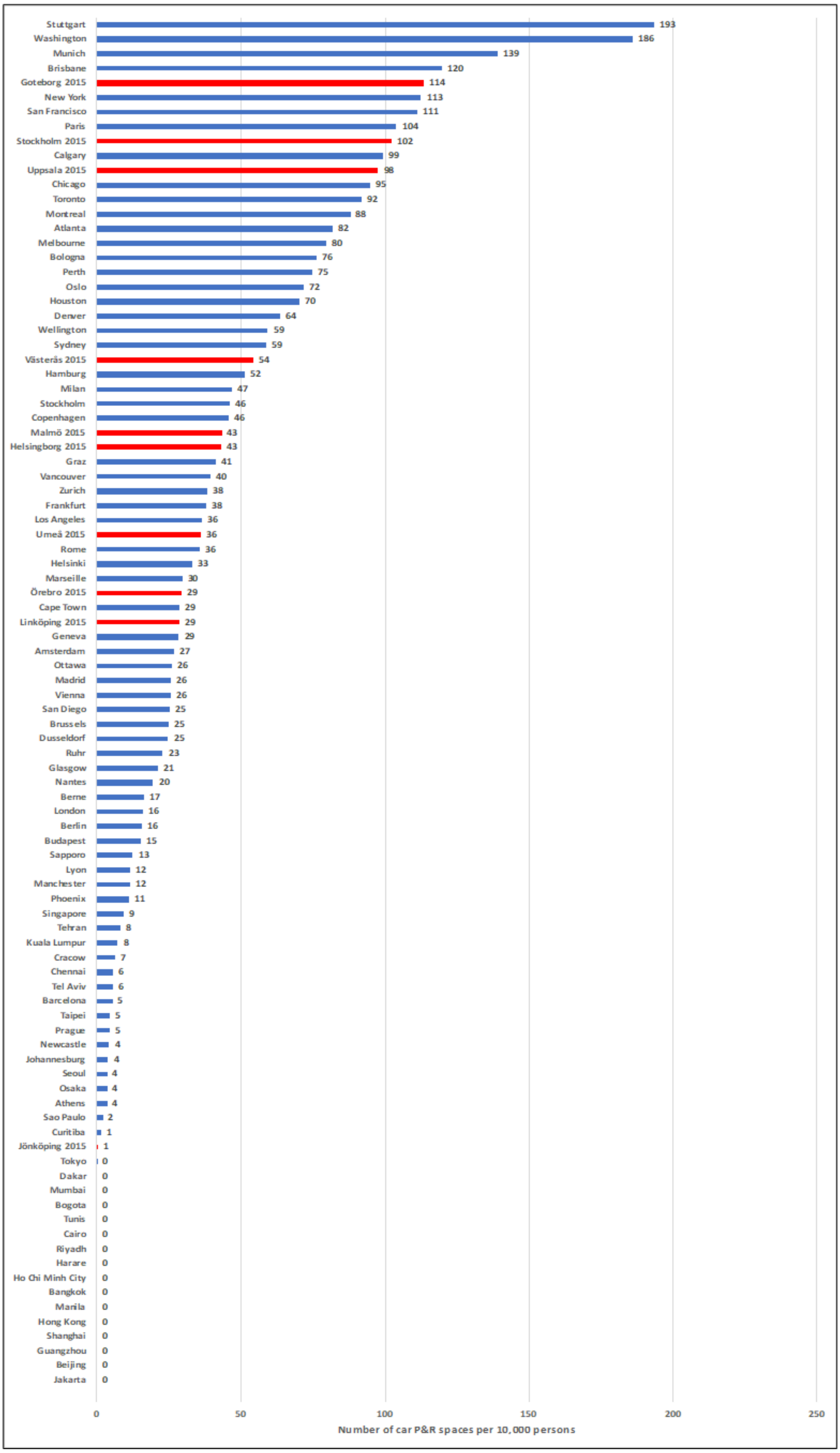

Figure 2: Car P&R spaces per 10,000 persons in global cities (1995) and Swedish cities (2015)

4.5. Public Transport Financial Factors

The public transport financial factors examined in this study were the percentage of pre-sold tickets (both overall and those that are valid for one month or more) and the amount of investment spending on public transport. These latter data represent a 5-year average from 2013-2017 to account for big differences that can occur from year-to-year in public transport investment due to specific projects and other works.

4.5.1. Pre-sold public transport tickets

Pre-sold tickets data were collected as a possible contributing factor to public transport use because buying time-based public transport tickets up-front, could indicate a higher level of commitment to public transport, as opposed to the more casual user who purchases single fares as the need arises. As explained in section 3 about problems with data collection, the pre-sold tickets variable in Swedish cities has some definitional issues associated with it that required some judgments to be made by people in the different cities and the researcher about what counts as a pre-sold ticket. This was due primarily to how ticketing offers are constructed in different authorities (e.g. stored value tickets that can be used any time as random single fares, which do not necessarily indicate a high level of commitment to public transport). There is thus perhaps some softness and/or consistency issues in the data supplied. Nevertheless, they do represent a concerted effort to gain an insight into this factor, which appears not to have been examined before in Sweden in a comparative way.

The final results settled on for this factor are shown in Table 9 which reveals that pre-sold tickets of 1-month or longer appear to be strongest in the two Skåne cities (Malmö and Helsingborg – 40%) and Stockholm (20%). The other eight cities have values of only 2% (Örebro) to 7% (Göteborg) with an overall sample average of 13%. One can conclude that the level of commitment to public transport reflected in 1-month or more pre-sold tickets is definitively higher in the bigger cities with the strongest and most diverse public transport systems (Stockholm, Malmö, Göteborg and Helsingborg). In the smaller cities with less congestion and constraints on car use, public transport is not so competitive with the car and therefore people are possibly less likely to commit to it in the form of buying monthly or longer tickets.

When pre-sold tickets in total are considered, the percentages are for the most part higher (sample average 34%) with Örebro (72%) and Stockholm (62%), being the highest. The two lowest cities appear to be Linköping (7%) and Örebro (12%). The difference between the larger and smaller cities so evident in the 1-month plus tickets is largely evened out in the total pre-sold tickets (33% and 35% respectively).

4.5.2. Investment in public transport

Investment spending on public transport is defined in section 3.3 and was collected from all possible sources of such spending (national, regional and municipality governments, plus separate co-financing/private and quasi-public/private sector sources). Table 9 provides the results of this spending and Table 10 sets out for each city, the percentage of total investment accounted for by national, regional, municipal governments and co-financed projects with the national government.

Investment spending on public transport is provided on a per capita basis in three value terms, 2015 SEK, 2015 US dollars and 1995 US dollars, the latter being to equivalence it to the same currency value as in the Millennium Cities Database for Sustainable Transport (Kenworthy and Laube, 2001), which has similar data for 84 cities worldwide. The discussion here will be provided in 1995 US dollars, but the other currency equivalents can be quickly seen in the table. It shows that per capita investment spending on public transport varied enormously over the 2013-2017 period from an average high of $602 per person in Stockholm to a low of $17 in Västerås, a 35-times difference. The larger Swedish cities clearly invested much more on public transport over this period, averaging $215, while the smaller cities averaged only $47 or a nearly a five times difference.

Another way of normalizing these data is by relative wealth, expressing the investment spending as a percentage of metropolitan GDP, which can then also be compared to the situation in a wide range of cities in 1995. A similar situation arises with Stockholm unsurprisingly being the leader with 1.22% of its metropolitan GDP spent on investing in public transport, while Västerås spent only 0.06%, except that when spending is normalized by wealth the difference reduces to 20-times more in Stockholm. Likewise, the larger cities spent an average of 0.54% and the smaller cities 0.16% of their GDP, or a reduced 3.4-times difference.

Table 9. Pre-sold public transport tickets and investment in public transport in Swedish cities, 2015

Variable		Stockholm 2015	Malmö 2015	Goteborg 2015	Linköping 2015	Helsingborg 2015	SWE Large
Percentage of pre-sold or time tickets (%) MONTHLY or LONGER	%	20 %	40 %	7 %	4 %	40 %	22 %
Percentage of pre-sold or time tickets - Overall (%)	%	62 %	40 %	18 %	7 %	40 %	33 %
Per capita investment in public transport (5-year average)	SEK (2015) per person	7,405 SEK	2,049 SEK	1,214 SEK	267 SEK	2,295 SEK	2,646 SEK
Per capita investment in public transport (5-year average)	USD (2015) per person	$886	$245	$145	$32	$275	$317
Per capita investment in public transport (5-year average)	USD (1995) per person	$602	$167	$99	$22	$187	$215
Percentage of metropolitan GDP spent on public transport investment	%	1.22%	0.51%	0.24%	0.07%	0.65%	0.54%
		Uppsala 2015	**Västerås 2015**	**Örebro 2015**	**Jönköping 2015**	**Umeå 2015**	**SWE Small**
Percentage of pre-sold or time tickets (%) MONTHLY or LONGER	%	4 %	5 %	2 %	4 %	3 %	3 %
Percentage of pre-sold or time tickets - Overall (%)	%	4 %	12 %	72 %	43 %	46 %	35 %
Per capita investment in public transport (5-year average)	SEK (2015) per person	766 SEK	203 SEK	1,230 SEK	265 SEK	414 SEK	576 SEK
Per capita investment in public transport (5-year average)	USD (2015) per person	$92	$24	$147	$32	$50	$69
Per capita investment in public transport (5-year average)	USD (1995) per person	$62	$17	$100	$22	$34	$47
Percentage of metropolitan GDP spent on public transport investment	%	0.20%	0.06%	0.35%	0.07%	0.11%	0.16%

As best that could be determined in this thorough effort to collect all investment spending from all sources, the sources of funding varied a lot, as shown in Table 10. Notwithstanding the tortured nature of money flows and the difficulties in unpicking this, which would require a concerted forensic accounting exercise, the overall pattern for the ten cities seems clear. The national government was the biggest source with 53.3% of the funding, regional governments averaged 21.3% and municipal governments 18.3%, while separate co-financed projects with the national government involving län, municipalities and private companies was the least, 7.1%.

Within the sample however, the national government contribution to total public transport investment spending over this 5-year period varied from a very large 87.1% in Uppsala (Örebro was also 82.8%) to 23.2% in Västerås. Regional governments varied from a high in Stockholm of 44.2% down to a very small 6.2% in Örebro. Municipal governments, many of whom spent zero on public transport investment nevertheless accounted for 55.4% of spending in Västerås, while in Stockholm they contributed only 1.4% (Uppsala was also low with 2.9%). The co-financed projects with the national government were significant in Stockholm, contributing 19.7% but in Västerås these were only 0.1%, with Umeå and Uppsala also being very low (1.2% and 1.6% respectively).

Examining the overall patterns in the larger versus small cities, we see that generally in the larger cities there is a greater “equality” in the funding sources, while in the smaller cities patterns are more divergent with the national government clearly dominating, regional governments contributing less, municipal governments contributing more and co-financed projects being very small compared to the larger cities.

Based on conversations with people supplying data for this project, these patterns of funding sources are most likely the result of different financing arrangements and agreements in different areas. Having said this, it was also apparent in data collection that there was in many cases a lack of knowledge or uncertainty within the different authorities about whose responsibility it is to pay for different things. This meant there were a lot of emails back and forth trying to nail down the true picture and to discern fact from fiction.

Table 10: Sources of public transport investment in Swedish cities, 2015

Variable		Stockholm 2015	Malmö 2015	Goteborg 2015	Linköping 2015	Helsingborg 2015	SWE Large
National government	%	34.6%	54.7%	72.5%	32.6%	48.8%	48.6%
Regional government	%	44.2%	17.4%	19.3%	26.0%	15.5%	24.5%
Municipal government	%	1.4%	12.7%	5.4%	34.4%	22.0%	15.2%
Co-financed with national government (municipalities, län and private companies)	%	19.7%	15.3%	2.8%	6.9%	13.6%	11.7%
Total	%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		Uppsala 2015	**Västerås 2015**	**Örebro 2015**	**Jönköping 2015**	**Umeå 2015**	**SWE Small**
National government	%	87.1%	23.2%	82.8%	56.6%	39.5%	57.9%
Regional government	%	8.4%	21.3%	6.2%	22.3%	32.7%	18.2%
Municipal government	%	2.9%	55.4%	8.5%	14.0%	26.6%	21.5%
Co-financed with national government (municipalities, län and private companies)	%	1.6%	0.1%	2.5%	7.1%	1.2%	2.5%
Total	%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

4.5.3. International comparisons of investment spending on public transport

The Millennium Cities Database for Sustainable Transport (Kenworthy and Laube, 2001) collected public transport investment data for 84 cities worldwide. It is therefore possible to provide some wider perspective on whether Swedish cities are investing a lot or little in public transport systems compared to other cities. Figure 3 provides data on the percentage of metropolitan GDP spent on public transport investment in 84 global cities in 1995 (5-year average from 1993-1997) plus it integrates the ten Swedish cities in 2015. Again, even though these data are separated by 20 years, the data for other cities is unique and have never been repeated, so it is still worth placing the Swedish cities in this international perspective.

Figure 3 reveals that Stockholm in 2015 was close to the top of the sample in investment in public transport expressed as a percentage of GDP (1.22% or 5th highest in the graph). Stockholm was also included in the 1995 data and for that 5-year average, the figure was radically lower (only 0.22%), which tends to suggest the cyclical nature of investment in public transport systems and specific projects. The level of investment then almost halves to the next highest Swedish city (Helsingborg 0.65%). Malmö (0.51%) still appears in the top one-third of the cities. After that investment spending tends to fall away with four of the Swedish cities located in the lowest 20 cities in the graph.

The average level of public transport investment spending for the 84 cities in 1995 was 0.43% of metropolitan GDP and the Swedish cities in 2015 averaged 0.35%. However, the split within the Swedish sample is big, with the larger cities realising 0.54% of GDP, which was above the global average in 1995, and the smaller cities only 0.16%.

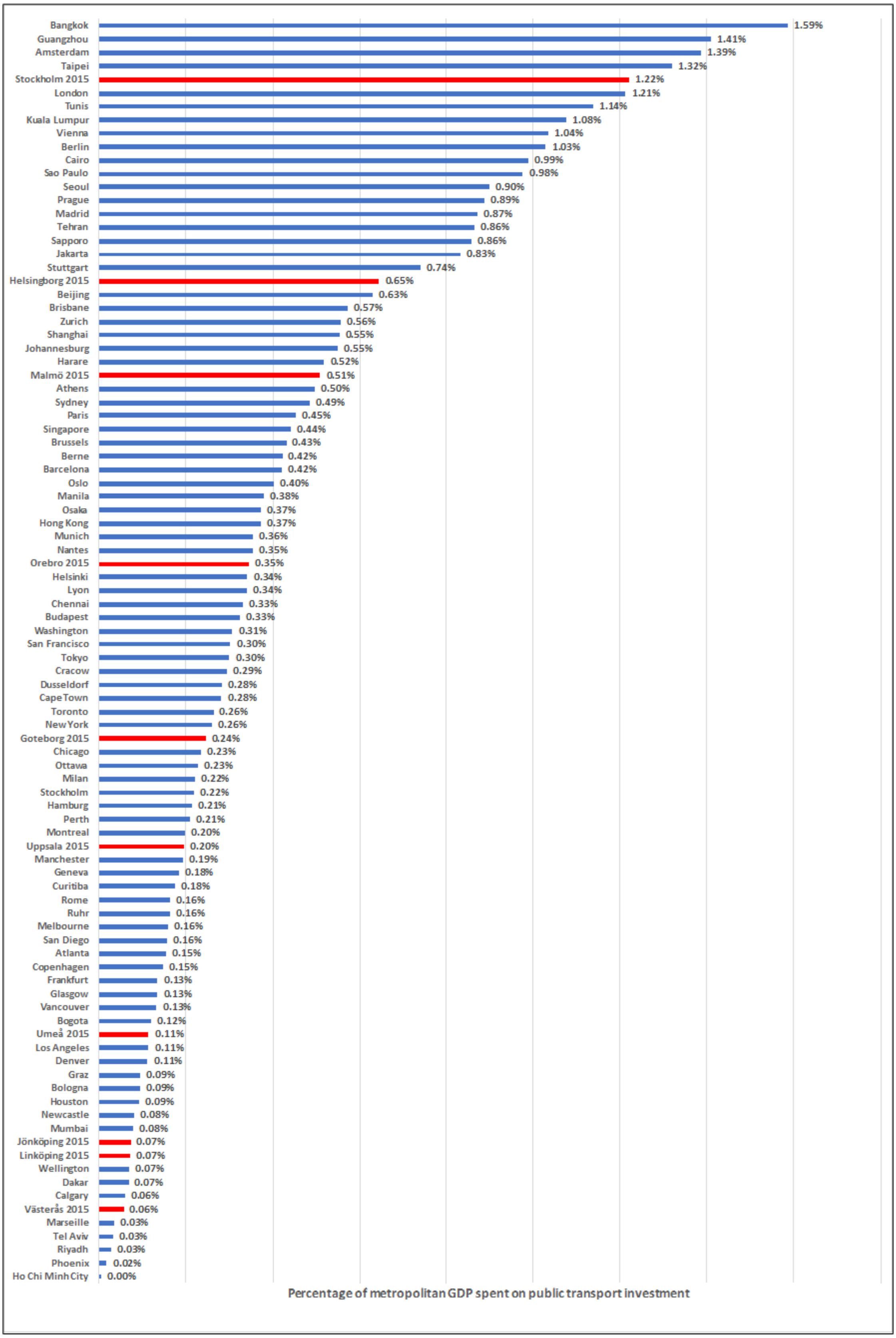

Figure 3: Percentage of metropolitan GDP spent on public transport investment in global cities (1995) and Swedish cities (2015)

5. Statistical explorations

This section provides some focused insights into the statistical relationships between the many different factors collected in this study and their possible implications for the use of non-motorised modes and public transport.

5.1. Demographic and taxi factors in understanding NMM and public transport use

The data collected in this study on demographic and taxi factors was tested statistically and neither provides any useful insights or explanatory strength that help to understand the use of non-motorised modes or public transport in Swedish cities. This is due to the lack of any significant variation in demography in these Swedish cities and the small magnitude and importance of taxi service and use.

5.2. Non-motorised mode infrastructure and non-motorised mode use

5.2.1. Total length of cycleways, footpaths and pedestrianised streets per person and per urban hectare tested against the non-motorised modes percentage of daily trips

Is the total movement infrastructure provided for walking and cycling on a per capita or spatial density basis associated with the non-motorised modal split (walking and cycling) for daily trips in the ten Swedish cities? To explore this the cycleways, footpaths and pedestrianised street lengths per person and per urban ha were added together and correlated against the percentage of total daily trips by walking and cycling. Checking for all lines of best fit (linear, exponential, logarithmic and power functions) there is no correlation whatsoever.

5.2.2. Length of cycleways and cycling modal split and length of footpaths and walking modal split

An attempt was then then made to separate the cycling and walking modal split and to correlate these respectively with the lengths of cycleways and lengths of footpaths per person and per urban ha. For cycleways and cycle use, again there was no correlation whatsoever and for footpaths, there was a very weak correlation, but it was negative suggesting implausibly that as footpath infrastructure increases, the percentage of daily trips on foot diminishes.

5.2.3. Implications of the non-motorised mode analysis results

It can only be concluded from this that what determines people's use of walking and cycling in Sweden is much more complicated than the amount of infrastructure that is provided. In the case of walking, the points made about the lack of good and comprehensive footpath data in some cities and the need to assemble this as best as possible, may have had some influence on the result obtained, especially the weak negative relationship.

Urban density is clearly important in walking and cycling since higher urban densities shorten trip distances and as density increases mixed land use increases too, which further assists walking and cycling. Urban density for the ten Swedish cities was also correlated with total NMM modal split, cycling modal split and walking modal split and only weak associations were found. The weak correlations between total modal split and density and cycling modal split and density were also negative, which again seems counterintuitive. However, the weak correlation between density and walking modal split was positive.

Explaining these results is difficult but the small differences in urban density in the ten Swedish cities (11.5 persons per ha in Umeå and 23.5 per ha in Stockholm) may be a factor here. Indeed, increasing urban density across the global sample of 84 cities where urban densities had a very high range (from around 7 persons per ha up to 350 persons per ha), was associated with increasing non-motorised mode use (power function with a r-squared of 0.35). As well, just taking the high-income cities of the sample, of which Swedish cities are members, the relationship is even stronger (power function with a r-squared of 0.47).

More likely in the much smaller Swedish sample of ten cities, are factors concerning the "culture" of walking and cycling in different places and qualitative factors concerning the broader walking and cycling environments in each place and perhaps even some weather influences. There may also be simple emotional factors, like simply preferring a bike over other modes regardless of other factors. The availability and strength of public transport systems may also play a part, which is partly borne out by a weak correlation showing that as public transport boardings per capita increase, the percentage of daily trips by walking and cycling decreases. On the other hand, the global cities sample showed that high public transport use was associated with higher non-motorised use. Finally, it may be that when a city is small, even though it is low density, distances are intrinsically shorter by virtue of size, and this may lend an advantage to walking and cycling.

Overall, it can probably be concluded that finding variables which are measurable on a whole city basis to help explain patterns of non-motorised mode use in Swedish urban environments is problematic.

5.3. Public transport infrastructure and public transport use

5.3.1. Public transport stops and public transport use

In the ten Swedish cities, as the spatial density of total public transport stops increases, so does public transport use in terms of boardings per capita, with a relatively high r-squared value of 0.72. This seems intuitively logical that as the density of stops increases, people's access to the public transport system improves (Figure 4).

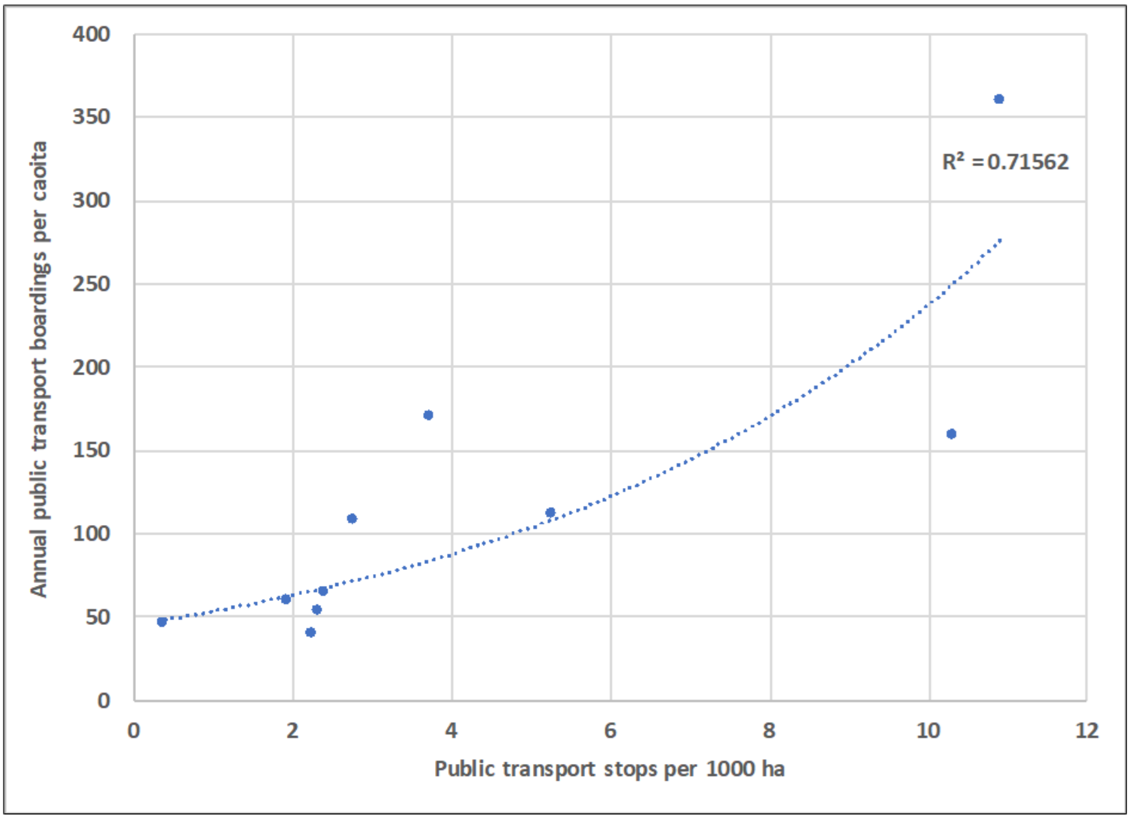

Figure 4: The relationship between the spatial density of public transport stops and public transport boardings per capita in ten Swedish cities, 2015

5.3.2. Average age of public transport vehicles and public transport use

The overall average age of public transport vehicles was correlated with public transport boardings per capita but was found to have no statistically significant relationship. The weak relationship which did appear was positive, meaning that public transport use increased with increasing age of the vehicles. The only possible explanation for this appears to be that rail vehicles are generally older than buses and more rail-oriented cities in Sweden have higher public transport use.

5.3.3. Park and ride spaces for bikes and cars and public transport use

As with the larger global sample reported earlier, no relationship whatsoever was found between P&R spaces and public transport use in Swedish cities such that P&R appears not to have any influence at all on the overall use of public transport. P&R only caters for a niche market of public transport users who gain personal benefits, but the costs of catering for this, particularly for car park and ride users versus the level of benefits that accrue to society, remains an open question.

5.3.4. Pre-sold tickets and public transport use

The percentage of all tickets that are pre-sold in the ten Swedish cities bears no relationship with the total use of public transport as measured by boardings per capita. Examining the pre-sold tickets of one-month or longer there is a weak positive relationship. However, Stockholm's performance on this factor is significantly lower than some other cities and yet Stockholm has the highest public transport use of all Swedish cities by a large margin, and this makes the relationship of very low importance.

5.3.5. Investment in public transport and public transport use

If one takes the 84 cities in 1995 and correlates the use of public transport with the level of investment spending, the line of best fit is a statistically significant power function with an r-squared value of 0.34 suggesting that as investment in public transport increases so does public transport use (Figure 5). Using the ten Swedish cities, Figure 6 shows that there is a very strong correlation between investment spending on public transport and public transport use, as measured by boardings per capita. In this case, it is a linear function with a r-squared of 0.80. Of course, no bi-variate or any other correlation indicates causation, but it is possible to say that both globally and within Sweden, there is a strong positive association between more money being invested in public transport and increasing public transport use.

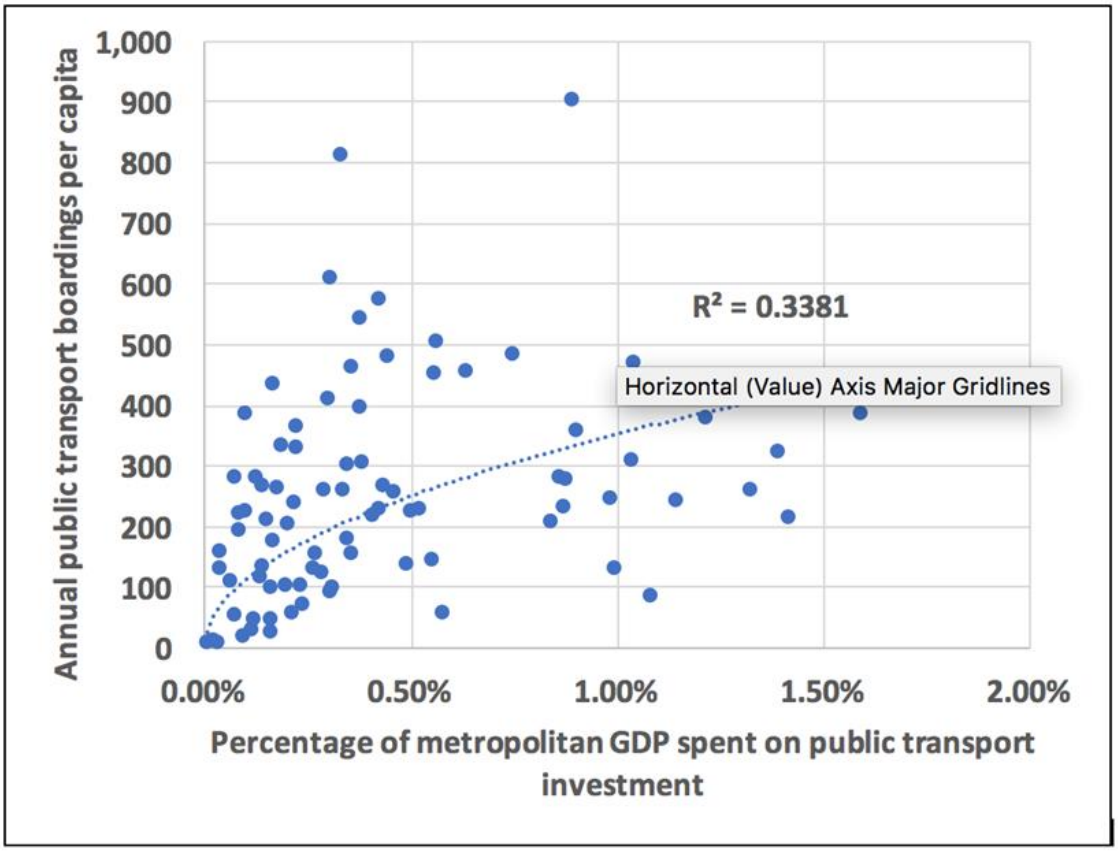

Figure 5: The relationship between the percentage of metropolitan GDP invested in public transport and public transport boardings per capita in global cities, 1995.

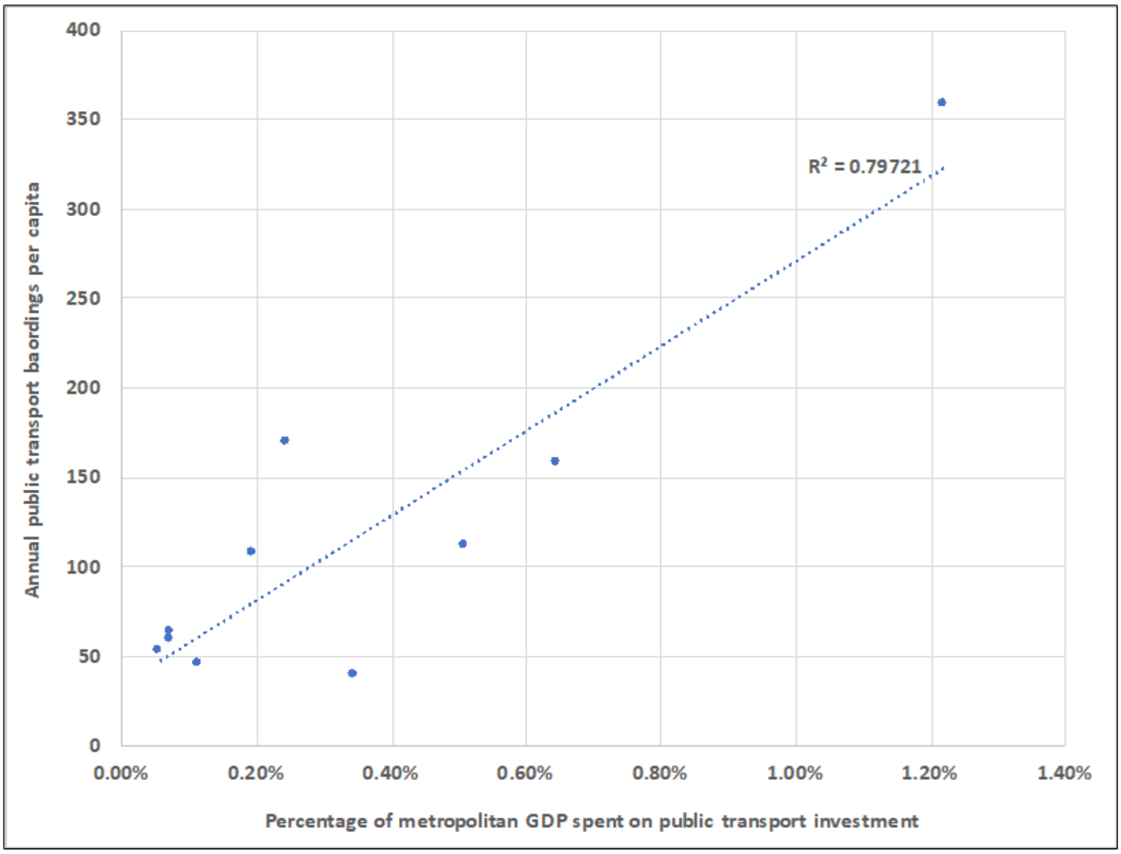

Figure 6: The relationship between the percentage of metropolitan GDP invested in public transport and public transport boardings per capita in ten Swedish cities, 2015.

5.4. Statistical analyses using data collected in previous projects

While the current project was undertaken, a more detailed statistical analysis was performed on a large sample of previously collected data on Swedish cities, which attempted to examine through simple bi-variate Pearson correlations, which variables seem to be significantly associated with various measures of public transport use and non-motorised mode use (the dependent variables). This analysis also looked at the relationships between every pair of both dependent and independent potential explanatory variables to gain an insight into the broader interactions in the data. Table 11 provides a list of the variables considered.

Table 11: List of variables from previous comparative research on the Swedish cities to explore statistical relationships.

VARIABLES	UNITS
DEPENDENT VARIABLES	
Percentage of total daily trips by motorised public modes	%
Total public transport boardings per capita	boardings/person
Total public transport passenger kilometres per capita	p.km/person
Proportion of total motorised passenger kilometres on public transport	%
Percentage of total daily trips by non motorised modes	%
INDEPENDENT EXPLANATORY VARIABLES	
Urban density	persons/ha
Activity density	persons+jobs/ha
Proportion of jobs in CBD	%
Metropolitan gross domestic product per capita	USD 1995
Length of road per person	m/ person
Length of freeway per person	m/ person
Parking spaces per 1000 CBD jobs	spaces/1000 jobs
Passenger cars per 1000 persons	units/1000 persons
Motor cycles per 1000 persons	units/1000 persons
Total length of public transport lines per 1000 persons	m/1000 persons
Total length of reserved public transport routes per 1000 persons	m/1000 persons
Total public transport vehicles per 1000 persons	units/1000 persons
Total public transport vehicle kilometres of service per capita	v.km/person
Total public transport seat kilometres of service per capita	seat km/person
Overall average speed of public transport	km/h
Average speed of the road network (24/7)	km/h
Average public transport farebox revenue per boarding	USD/boarding
Average public transport farebox revenue per passenger kilometre	USD/pass. km
Average public transport farebox revenue per vehicle kilometre	USD/v.km
Percentage of metropolitan GDP spent on PT operating costs	%
Ratio of public versus private transport speeds	ratio
Ratio of segregated public transport infrastructure versus expressways	ratio

5.4.1. Public transport correlations

Firstly, the four dependent public transport variables are, as expected, and without exception, all highly correlated with each other at the 0.01 level, as shown in Table 12.

Table 12: Pearson bi-variate correlations between the four public transport usage variables.

Variables and Statistical Test		Percentage of total daily trip by motorised public modes	Total public transport boardings per capita	Total public transport passenger kilometres per capita	Proportion of total motorised passenger kilometres on public transport
Percentage of total daily trip by motorised public modes	Pearson Correlation	1	.971**	.882**	.833**
	Sig. (2-tailed)		0.000	0.001	0.003
	N	10	10	10	10
Total public transport boardings per capita	Pearson Correlation	.971**	1	.899**	.842**
	Sig. (2-tailed)	0.000		0.000	0.002
	N	10	10	10	10
Total public transport passenger kilometres per capita	Pearson Correlation	.882**	.899**	1	.991**
	Sig. (2-tailed)	0.001	0.000		0.000
	N	10	10	10	10
Proportion of total motorised passenger kilometres on public transport	Pearson Correlation	.833**	.842**	.991**	1
	Sig. (2-tailed)	0.003	0.002	0.000	
	N	10	10	10	10

What variables are then significantly correlated, either at the 0.01 or 0.05 level, with any of the public transport usage variables in Swedish cities? The variables that conform to this are:

- Urban density (positive with all PT use variables)
- Activity density (positive with all PT use variables)
- Metropolitan GDP per capita (positive with all PT use variables)
- Length of road per person (negative with all PT use variables)
- Passenger cars per 1000 persons (negative with public transport passenger kilometres per person and the percentage of total motorised passenger kilometres by public transport)
- Total length of reserved public transport route per 1000 persons (negative with % of daily trips by public transport)
- Total public transport vehicle kilometres of service per capita (positive with three PT use variables, except % of daily trips by public transport)
- Total public transport seat kilometres of service per capita (positive with all PT use variables and with higher significance than just vehicle kilometres of service)
- Average public transport farebox revenue per vehicle kilometre (positive with all PT use variables)

None of the other explanatory variables have any statistically significant relationship with public transport use in the Swedish sample.

What are the implications of these overall results when combined with the results from the data in the current project? Clearly, correlations do not imply causation, but from the results obtained by testing a huge array of factors that can be measured at a metropolitan scale we can conclude the following:

The main six factors that are statistically significantly associated with higher public transport use in Swedish cities are:

- Increasing population and job density
- Greater wealth as measured by metropolitan GDP per capita
- Greater total public transport vehicle kilometres of service per person
- Greater total public transport seat kilometres of service per person
- A higher density of public transport stops
- A larger percentage of city wealth being spent on investment in public transport

Interestingly, the cities in Sweden that are wealthier also have higher public transport use, which goes against the notion that the wealthier a city becomes the less likely people are to use public transport. This is not hard to understand since wealth is not always a major factor in determining mobility. Mobility patterns are also very strongly linked to the overall way in which an urban region works. If there is high density, congestion and lack of parking, as in Manhattan and many other parts of cities, or even whole cities, then no matter how much money people have, there are better and faster mobility choices available than a car such as subways or good bike infrastructure and people use them because they are the most convenient and time competitive.

The other five factors are intuitively logical that higher densities and more public transport service boost public transport use (especially higher seat kilometres which especially implies more rail). A higher density of public transport stops enhances access to public transport and investment of greater amounts of wealth towards extending, maintaining and renewing public transport systems is also favourable to enhanced use.

While not being what could be called a "driving factor" of public transport use, but rather a spin-off, is the higher amount of revenue from fares for every vehicle kilometre of service provided as public transport use increases - in other words a better financial yield on the services run.

Working against higher public transport use appears to be higher car ownership and higher levels of overall road provision (although higher road provision is strongly negatively correlated with urban and activity density such that as density declines, more roads are needed to service properties, therefore this factor is linked to the significance of the two density variables).

The only "strange" correlation here is the negative relationship between the percentage of daily trips by public transport and the length of reserved public transport route per 1000 persons. Intuitively more public transport reserved route should promote public transport use, but again there appears to be a density factor involved – lower density cities in Sweden have more reserved public transport route due to long railway lines with fewer people to use them. This is confirmed in the statistical results with a strong negative relationship between urban density and total length of reserved public transport route per 1000 persons. The result is thus an artefact.

5.4.2. Non-motorised mode correlations

The results for non-motorised mode use are the same as for the detailed new data in the current study – there are simply no significant statistical correlations between the percentage of daily trips by walking and cycling in Swedish cities and any variable which has so far been examined that can be measured on a city scale (see previous discussion).

5.4.3. Other useful insights from the significant statistical correlations on Swedish cities

• The two density variables are:

- positively correlated with wealth.
- negatively correlated with the farebox revenue per boarding implying that denser Swedish cities seem to charge lower fares. This may be simply because the demand for public transport is lower in lower density cities, that they have to charge higher fares to better cover their costs. But of course, this would tend to set in motion a negative spiral as more people are turned away due to higher costs.
- positively correlated with higher farebox revenue per vehicle kilometre of service.

- The centralization of jobs measured as the percentage of jobs located in the CBD is not correlated with any variable.
- Metropolitan GDP per capita is negatively correlated with parking supply in the CBD…as wealth increases central city parking seems to decline.
- The length of freeway per person is positively correlated with the length of public transport lines per person and the length of reserved public transport route per person. In a policy sense, this seems to be counterproductive. Ideally one would expect that as public transport lines and reserved public transport route increase, freeway provision would diminish. In simple terms, Swedish public policy seems to have "a bet each way" on both private and public transport, whereas it could dedicate itself more strongly to the latter.
- Parking spaces per 1000 CBD jobs is negatively associated with public transport vehicle and seat kilometres per person, suggesting that as the supply of central city parking increases, it is associated with lower levels of public transport service which is a "negative spiral". This is partly understandable because radially focused public transport systems are the most common and if car access is prioritized in city centres, it undermines public transport.
- Car ownership is negatively associated with public transport seat kilometres of service per person and positively associated with the length of road per person.
- The size of the public transport fleet (vehicles per person) has no correlations with any variable.

- The average speed of road traffic is negatively associated with the percentage of metropolitan GDP spent on public transport operating costs. This appears to be due to inter-correlations in the data. For example, the smaller cities with less congestion have faster road traffic and have public transport systems with less service and therefore they spend less on operating their systems, relative to their wealth.
- Perhaps surprisingly, the ratio of public transport system speed to road traffic speed is not significantly correlated with anything except positively with the overall speed of the public transport system.

5.4.4. Multiple regression analysis

Based on these results, an attempt was made to undertake some simple multiple regressions using all four dependent variables describing public transport use (total annual public transport boardings per capita, total annual public transport passenger kilometres per capita, the percentage of total motorized passenger kilometres by public transport and the percentage of daily trips by public transport). The multiple regressions were done with the four most significant independent variables from the research, based on the bi-variate Pearson correlations i.e., activity density, total annual public transport seat kilometres per person, total public transport stops per hectare and the percentage of city wealth (GDP) being spent on investment in public transport.

Table 13 suggests that for all four measures of public transport use, the multiple regression results are significant at better than the 1% level. In terms of explanatory power, the adjusted r-squared (a more reliable measure of explanatory power than r-squared), ranges between 0.83 or 83% of the observed variance explained by the four independent variable for boardings per person and 0.92 or 92% for the percentage of total daily trips (all trip purposes) by public transport. Annual passenger kilometres per person by public transport and the percentage of total motorised passenger kilometres by public transport both show 86% of their variance explained by the four variables in a multiple regression.

Whilst such regressions do not reflect a cause-and-effect relationship, the associations are strongly indicative of an important influence on public transport use by the four variables in Swedish cities (i.e. (1) activity density, (2) total annual public transport seat kilometres per person, (3) total public stops per hectare and (4) the percentage of city wealth (GDP) being spent on investment in public transport).

Table 13. Results of multiple regressions attempting to explain public transport use in Swedish cities in 2015

Result for Public Transport Boardings per Person					
Regression Statistics					
Multiple R	0.951458				
R Square	0.905272				
Adjusted R Square	0.82949				
Standard Error	39.96992				
Observations	10				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	76337.52	19084.38	11.94569	0.009012298
Residual	5	7987.974	1597.595		
Total	9	84325.49			
Result for Public Transport Passenger Kilometres per Person					
Regression Statistics					
Multiple R	0.960797				
R Square	0.923131				
Adjusted R Square	0.861635				
Standard Error	231.3594				
Observations	10				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	3214064	803515.9	15.01137	0.005419076
Residual	5	267635.9	53527.17		
Total	9	3481700			
Result for Percentage of Total Daily Trips by Public Transport					
Regression Statistics					
Multiple R	0.976747				
R Square	0.954035				
Adjusted R Square	0.917264				
Standard Error	0.022265				
Observations	10				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	0.051444	0.012861	25.94485	0.001533305
Residual	5	0.002479	0.000496		
Total	9	0.053923			
Result for Percentage of Total Motorised Passengers Kilometres by Public Transport					
Regression Statistics					
Multiple R	0.96036				
R Square	0.922292				
Adjusted R Square	0.860126				
Standard Error	0.025235				
Observations	10				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	0.037791	0.009448	14.83585	0.005564577
Residual	5	0.003184	0.000637		
Total	9	0.040975			

Figure 7. shows a residuals plot for public transport boardings per person of the expected cumulative probability from the regression result versus the actual observed cumulative probability and reveals a very tight fit. Boardings per person was the weakest multiple regression result from the four different measures of public transport use, so the other four measures of public transport use have similar results.

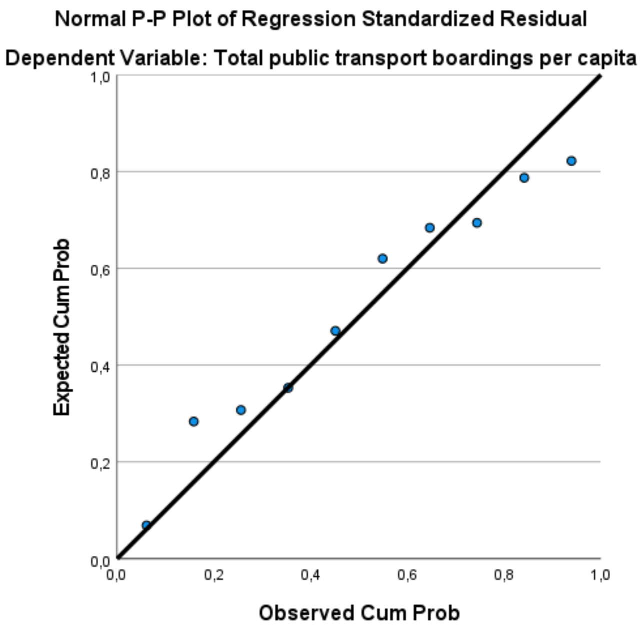

Figure 7. Residuals plot for multiple regression of public transport boardings per person

5.5. Summary

For the data collected in the current project only the spatial density of public transport stops, and the percentage of metropolitan GDP invested in public transport have a significant and reasonably strong correlation with public transport use. For non-motorised mode use, none of the variables assembled here can be used to explain the observed patterns in Swedish cities.

Notwithstanding the lack of many strong statistical results, the data have nevertheless yielded some very interesting broader insights relating to international comparisons of the Swedish cities on investment in public transport and P&R, as well as raising significant policy questions which have been detailed in previous sections (e.g. is more P&R, especially car P&R, a good approach or not, given its relatively small contribution to overall public transport use). Likewise, for the demographic factors and taxi data that were explored. The relative consistency in the demographic data across the Swedish cities and the quite weak or niche role of taxis in Swedish cities, while not yielding anything statistically meaningful for public transport or non-motorised mode use, this negative result helps to eliminate them from further considerations in understanding the broad patterns of mobility.

The statistical analysis using the previously collected data on Swedish cities yielded useful results in helping to understand a fuller set of factors that appear to be positively and strongly associated with public transport use. At the same time, it confirmed that non-motorised modal split seems not to be explainable in Sweden with city-level factors, at least not those collected to date.

Overall, the Pearson correlations and the multiple regression results suggest that a high percentage of the variance in all four measure of public transport use can be explained by a combination of four variables:

1. Activity density,
2. Total annual public transport seat kilometres per person,
3. Total public stops per hectare and
4. The percentage of city wealth (GDP) being spent on investment in public transport

6. Conclusions

This study has yielded a wealth of additional comparative data about the transport systems and correlative factors in ten Swedish cities. Combined with all the other data on these ten cities that were collected in two earlier K2 small research projects, it represents a substantial body of knowledge comparing these ten cities on aggregate city-wide urban transport and related characteristics.

The current project has attempted to explore which factors appear to enhance the use of public transport, walking and cycling using both the new data and that from the previous two projects, which are all from the year 2015. It has also explored some of the broader policy implications of the data collected such as the role of P&R and for two key variables on car P&R, these ten cities have been compared to a global sample of 84 cities. The conclusions to the study can be summarized in the following key points:

- The population age data (Table 3) show a remarkable consistency in Swedish demographic characteristics, at least in these ten cities. The patterns of variation in the six generational age groupings of population across these cities (GI generation born between 1901 to 1924 through to Gen Z born 1996 to 2020) is very small and does not follow any notable pattern that yields a significant relationship to public transport and non-motorised mode usage. The percentage of people in each city who are employed (ranging from 46% to 54%) also bears no relationship to public transport or non-motorised mode use.
- Taxis are fulfilling a specialized niche role in Swedish cities which has little bearing on overall mobility patterns and certainly cannot compete with the efficiency of public transport or other modes in, for example, energy use or the amount of driving needed to serve their passengers (Table 4). On the other hand, they provide essential mobility and access to those who cannot choose other means, as well as for tourists and business visitors to Swedish cities.
- Although the non-motorised infrastructure provision data (cycleways, footpaths and pedestrianised streets) vary widely amongst the ten cities (Table 5), a careful statistical exploration of these data in relation to the percentage of daily trips by walking and cycling together and separately, does not reveal any statistically significant relationship. This is contrary to the global sample where increasing urban density is strongly associated with higher non-motorised mode use. It appears that what determines people's use of walking and cycling in Swedish cities where densities do not vary strongly, is also much more complicated than simply the amount of basic infrastructure that is provided to promote these modes and is likely linked to other more detailed factors such as the cycling "culture", the qualitative aspects and urban design of the walking and cycling environments, bicycle parking availability, or perhaps even some weather or "emotional" influences or other factors.
- The non-motorised mode use was also correlated with other potential explanatory factors developed in the previous two projects, but again no significant

relationships could be found in the Swedish cities. It can be concluded from this that it is unlikely that non-motorised mode use can be explained by city-scale variables in Swedish cities, be they demographic, infrastructure, urban form-related or any other mobility-related characteristics.

- Public transport infrastructure data collected here were for the average age of vehicles by mode, the number of stations and stops by mode and the amount of P&R facilities and spaces for cars and bikes (Table 6). Although average age of vehicles varied from 4.3 years to 11.4 years, there was again no significant relationship with public transport use.
- P&R also did not correlate with the per capita use of public transport in the ten cities, but the data are valuable in that they show that P&R (car and bike) can only contribute relatively small percentages of overall public transport use (the average for the ten cities was 8.8% with a range of 0.1% to 17.6% (Table 7). Car P&R, the much more expensive and space consuming form of P&R varied from only 0.1% to 7.4% with an average for the ten cities of 3.9%. These data lead to examination of how much farebox revenue can theoretically be raised in each city from P&R (Table 8) and to the broader question of the economic costs and benefits of especially car P&R provision.
- Another major policy question of car P&R aside from costs is therefore whether the land occupied by P&R is the highest and best use of this land, given the relatively small amounts of farebox revenue it generates. Would the land occupied solely by car P&R (either surface or in parking garages) be better utilised if the P&R was placed underground with higher value land uses above, which also can generate extra public transport use. These are important policy questions that also have a bearing on the overall re-structuring of urban regions around public transport using dense, mixed use sub-centres. Answers to these questions depend on the circumstances in each city.
- Car P&R provision in Swedish cities is also compared to 84 other world cities based on car spaces per kilometre of reserved public transport route and per 10,000 persons (Figures 1 and 2). The Swedish cities are relatively modest on the former basis but quite robust on the latter (see discussion).
- The only item of public transport infrastructure collected in the current project that correlated with public transport use was a positive relationship between the spatial density of public transport stops (Figure 4 - r-squared 0.72).
- The public transport financial data that were collected in this project were the percentage of total tickets that are pre-sold (any time length), and the percentage of pre-sold tickets of 1-month or longer. Additionally, the total amount of investment spending (new construction, maintenance, refurbishment, vehicle purchase etc) from all sources was collected for the 2013-2017 five-year period and an average for the 5-years determined. This was expressed as per capita spending and as the percentage of metropolitan GDP that is expended on public transport investment (Table 9). Stockholm was the highest ranked city with 1.22% and Umeå only 0.11% of metropolitan GDP being spent on investing in public transport. This placed Stockholm as the 5th highest investor in public transport in the entire global sample (1995 global data), while Umeå sat next to Los Angeles and Denver.

- The pre-sold tickets data did not reveal any significant statistical relationships with public transport use, although the 1-month or more tickets had a weak positive relationship. On the other hand, the percentage of metropolitan GDP spent on investing in public transport systems was significantly and positively correlated with public transport use in the Swedish cities, as it was in the international sample (Figures 4 and 5).
- The research also revealed the sources of the investment data (Table 10) which on average were highest from the national government (53.3%), 21.3% from regional government agencies, 18.3% from municipalities and 7.1% from co-financed national government projects. There was significant variation, however, amongst the cities, on this factor.
- The international comparisons of the percentage of metropolitan GDP spent on public transport (Figure 3) further showed that the average level of public transport investment spending for the 84 cities in 1995 was 0.43% while the Swedish cities in 2015 averaged 0.35%. However, the split within the Swedish sample is big, with the larger cities realising 0.54% of GDP and the smaller cities only 0.16%.
- The Pearson statistical analysis undertaken on the data collected in previous two K2 projects revealed some highly significant relationships with the four measures of public transport use (including that all four measures of public transport use - percentage of daily trips by public transport, boardings per capita, passenger kilometres per capita and the percentage of total motorised passenger kilometres by public transport - are highly correlated with each other – see Tables 11 and 12). Combined with the results from the new data, these results suggest that the following factors appear to be strongly associated with enhanced public transport use in Swedish cities:
- Increasing population and job density
- Greater wealth as measured by metropolitan GDP per capita
- Greater total public transport vehicle kilometres of service per person
- Greater total public transport seat kilometres of service per person
- A higher density of public transport stops
- A larger percentage of city wealth (metropolitan GDP) being spent on investment in public transport

For metropolitan GDP, it cannot of course be said that simply increasing it improves public transport use but rather the larger, economically attractive cities in Sweden have evolved with, and go hand-in hand with the best most utilised public transport systems. The other five factors on the other hand are policy relevant and suggest that by increasing densities, expanding public transport service (especially seat kilometres which generally means more rail) plus increasing the density of the network of stops and investing more in public transport should yield higher public transport use. The global sample similarly shows increasing public transport use with increasing density and the amount of public transport service.

The analysis also suggested that two factors negatively impact public transport use:

- Increasing length of road per person
- Increasing passenger cars per 1000 persons

While not being what could be called a "driving factor" of public transport use, but rather a spin-off, is the statistically significant higher amount of farebox revenue generated for every vehicle kilometre of service provided as public transport use per capita increases - in other words a better financial yield on the services run.

The Pearson correlations highlighted significantly correlated variables which were then subjected to a multiple regression analysis (Table 13). The results suggest that a high percentage of the variance (83% to 92%) in all four measure of public transport use can be explained by a combination of four variables:

1. Activity density,
2. Total annual public transport seat kilometres per person,
3. Total public stops per hectare and
4. The percentage of city wealth (GDP) being spent on investment in public transport

Whilst these regressions do not imply a cause-and-effect relationship, they are significant in a policy sense as they imply through association, that increasing all four of the above factors is likely to improve public transport use.

Another aim of the research in this current study was to examine the energy and greenhouse gas savings potential of public transport systems and non-motorised transport, as well as through changes in private transport in Swedish cities. This is not included in this working paper because it has already been published in the international refereed journal Sustainability (Kenworthy and Svensson, 2022).

Finally, based on the experience in this study, it can be concluded that Sweden would be benefitted in introducing some more systematic scheme, perhaps a national dictate as in the USA, that requires a wide range of key public transport infrastructure, service supply, usage, energy consumption, economic and other factors to be transparently and consistently collected and reported on an annual basis. A similar approach to non-motorised mode factors such as lengths and areas of land devoted to cycleways, footpaths, and pedestrianised streets, bicycle parking availability, use of walking and cycling for daily trips etc, would also assist in better understanding how these most sustainable modes are evolving in Swedish cities and contributing to overall national, regional and local well-being.

At present in Sweden, data collection on many of these factors is thwarted by lack of information and coordination between agencies and in some cases lack of skills and training in understanding the factors and therefore some staff are not able to correctly respond to requests, even when data exist within an agency. Sometimes, data exist but, so to speak, the left hand does not always know what the right hand has or is doing within the same government agency. As a result, the success of enquiries for data can depend somewhat on who the request lands with.

Public transport, walking and cycling are key factors in so many facets of the sustainability and livability of all cities (social equity, energy conservation, climate change mitigation, the design and livability of public spaces etc). Therefore, having reliable and comprehensive data on all aspects that characterize these modes is the only way that their impacts can be researched, measured and evaluated.

Having solid data on public transport and non-motorised modes is also important in helping to evaluate the relative merits of investing money in these sustainable modes, compared to investing in private motorized transport infrastructure to improve car mobility. This is an important policy matter, especially since many countries are now trying to switch to electric vehicles, which will require huge investment of resources to provide for electric charging and so on. What are the comparative results of these investment decisions from a multi-faceted perspective in Sweden? Could better results be achieved by large investments in public transport and, for example, promoting e-bikes and the infrastructure needed to safely store and charge these more expensive bikes? Only sound and readily available data can answer such questions. At present this is problematic in Sweden for many relevant data items, as explained in this study.

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