K2 WORKING PAPER 2020:8

Sustainable Mobility in Ten Swedish Cities

A Comparative International Assessment of Urban Transport Indicators in Stockholm, Göteborg, Malmö, Linköping, Helsingborg, Uppsala, Örebro, Västerås, Jönköping, Umeå and Freiburg im Breisgau, Germany

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Table of contents

Summary

Urban transport is critical in shaping the form and function of cities, particularly the level of automobile dependence and sustainability. This K2 Working Paper presents a detailed study of the land use and urban transport characteristics of the ten largest urban regions in Sweden Stockholm, Malmö, Göteborg, Linköping, Helsingborg, Uppsala, Örebro, Västerås, Jönköping, and Umeå, the latter five of which are referred to as smaller Swedish cities in this report. It also presents data on Freiburg im Breisgau in southern Germany (population ca 225,000) as a benchmark case for sustainable transport against which to compare Swedish cities especially the smaller ones. It compares these cities to those in the USA, Australia, Canada, Europe and two large wealthy Asian cities (Singapore and Hong Kong). It finds that while density is critical in determining many features of urban mobility and particularly how much public transport, walking, and cycling are used, many Swedish cities maintain reasonable levels of all these more sustainable modes and only moderate levels of car use, while having less than half to one-third the density of other European cities. The smaller cities do, however, perform worst on public transport, but a little better on walking and cycling. Swedish settlement patterns and urban transport policies mean they also enjoy, globally, the lowest level of transport emissions and transport deaths per capita and similar levels of energy use in private passenger transport as other European cities, and a fraction of that used in lower density North American and Australian cities. Swedish urban public transport systems are generally well provided for and form an integral part of the way their cities function, considering their lower densities, though these systems are least well used in the smaller cities and urban rail use is very poor compared to the larger Swedish cities, which are themselves significantly lower in rail use than other European cities. Swedish cities' use of walking and cycling is high, though a fraction lower than in other European cities (but only about half the level in Freiburg) and together with public transport cater for about 44% of the total daily trip making, compared to auto-dependent regions with between about 15% and 25% of daily trips by these sustainable modes. This working paper explores these data and many other urban transport indicators in significant detail, distinguishing between patterns found in the larger and smaller Swedish cities as well as comparisons to Freiburg and the other groups of world cities. It provides a clear depiction of the strengths and weaknesses of Swedish cities in urban transport and a summary of the key differences and similarities between the larger and smaller Swedish cities. It also provides some key policy implications from the data, suggestions for making transport more sustainable in Swedish cities, while positing possible explanations for some of the unique patterns observed.

Keywords: Swedish cities; global cities; automobile dependence; public transport; non-motorised transport; urban fabrics; comparative urbanism

1. Introduction

The quest for more sustainable cities, and more sustainable transport particularly, has been written about extensively. Much of this literature is more conceptual and policy in nature, drawing only partly on quantitative data, but often including case examples or best practice to promote change (Schneider, 1979; Newman et al, 1997; Safdie and Kohn, 1998; Whitelegg, 2016; Beatley, 2000, 2005, 2010; Register, 2006; Kenworthy, 2006; Newman et al, 2017; Gehl, 1997, 2010; Giradet, 2014; Kim, 2018; Stimmel, 2015). Systematic quantitative approaches in the urban transport field based on empirical data comparing cities around the world are less extensive and come mainly from Kenworthy, Laube and Newman in a variety of publications over the last decades (e.g. Newman and Kenworthy, 1989 a, b; Newman and Kenworthy, 1991, Kenworthy and Laube, 1999, 2001).

The research in this working paper builds on a long tradition of city comparisons by the author, particularly on the theme of automobile dependence (e.g. Newman and Kenworthy, 1989a, b, 1999a, 2015; Kenworthy and Laube, 2001; Kenworthy 2017 a, b, 2019) and adds ten Swedish cities to this international comparative framework on cities developed by the author and colleagues over the last 40 years. It analyses urban transport and related indicators for the year 2015 for Stockholm (population 2,231,439), Göteborg (population 982,360), Malmö (population 695,430), Linköping (population 152,966), Helsingborg (population 137,909), Uppsala (population 210,126), Västerås (population 145,218), Örebro (population 144,200), Jönköping (population 133,310), Umeå (population 120,777) and Freiburg in Germany (population 222,082). It compares the characteristics of these Swedish cities to a large sample of other cities in the USA, Canada, Australia, Europe, and Asia and highlights the differences between the larger Swedish cities (Stockholm, Göteborg, Malmö, Linköping, Helsingborg) and the remaining five, termed here as the smaller Swedish cities.

Note that the population of Swedish urban regions falls rapidly away outside of Stockholm, Göteborg and Malmö from around 700,000 in Malmö down to 210,000 in Uppsala such that the distinction between "larger" and "smaller" Swedish cities is a somewhat loose construction, given that all Swedish cities, apart from these top three, would be considered small by most standards. However, the average population of the first group of cities to be studied by the author has been termed the "larger" five, with an average population of 840,000, while the latter or "smaller" five has an average population size of 151,000 or over 5.5 times less.

Adhering strictly to population size would see Uppsala in the five "larger" cities (making the average population 854,000) while Helsingborg would appear in the "smaller" cities (average population would then be 136,000) so creating little practical difference in the two groupings. The reason for Helsingborg's inclusion in the original group of "larger" cities was due to its co-location in Skåne län with Malmö, thus making the original work, involving a lot of manipulation of Skåne data, more practical and efficient than including Uppsala at that time.

The questions this paper seeks to answer are:

1. How do Swedish cities compare in land use, wealth, private, public, and non-motorised transport, as well as other transport-related factors?

2. Do Swedish cities follow the patterns of European and other cities or are they different?

3. Are there noteworthy differences and similarities between the sample of smaller cities and the larger ones?

4. Do Swedish cities compare well or poorly with Freiburg im Breisgau (Germany), which is often portrayed as an especially good example of sustainable or green urbanism?

5. Is it possible to explain some of the more atypical patterns of urban land use and mobility characteristic of Swedish cities?

6. Are there any policy lessons that can be learned from the comparisons?

To answer these questions, the paper systematically presents the results of the investigation through a series of indicators and discusses each one in turn. It analyses and discusses the results, tries to understand the more atypical results and draws some policy implications. The next section provides the methodology for the paper, followed by the results, then the analysis, discussion, and policy implications, and finally some conclusions.

2. Methodology

2.1. Overview

Each Swedish city is defined in Table 1 in the way Statistics Sweden defines them, while Table 2 sets out the 35 primary data variables collected for each city and a brief description of what each variable means. Readers can also refer to Kenworthy (2017a) for a more detailed explanation of the history and methodology of this comparative urban research. Some data were collected through web-based resources such as Statistics Sweden provides, but most data collection involved extensive and time-consuming repeat emails and phone calls with key personnel in a plethora of government planning agencies, traffic departments, road authorities, regional government agencies, municipalities, public transport agencies and operators and health and environmental organisations. Significant assistance was also given from within K2. This fact also helps to explain the uniqueness of the database that has been constructed here for Swedish cities, since the K2 funding received to undertake the work had to be supplemented with hundreds of hours of unfunded additional work by the author to have any hope of completion. This has always been the case with this research, even with early work (Kenworthy and Laube, 1999) and the larger funded *Millennium Cities Database for Sustainable Transport* (Kenworthy and Laube, 2001), which covered 100 cities worldwide in virtually every major language.

2.2. Some Critical Data Limitations in Sweden

It needs to be said that there are some Swedish data items that are not at all straightforward to get, compared with the often much more transparent situation in many other cities. For example, the length of bus lanes is particularly difficult and must be systematically and carefully assembled by municipality from local records in the case of bus lanes on municipal streets (if any) and from the national road authority for those bus lanes that are on national roads (more common). Much data on regional rail services in Sweden are hard to get, even the length of lines and reserved route within specified geographic boundaries, the average speed of services and sometimes even basic data such as usage levels can be problematic. Energy use by public transport in Sweden is an item that is hard to extract, but it is always there buried in the records of public transport agencies or regional authorities. It just takes a long time to find the right people to consult and supply it.

In Sweden, it is also often quite difficult to get statements of the number of public transport vehicles available in each urban region. City buses are usually the easiest to get, but regional bus fleets are very often problematic and the number of rail wagons used to operate regional rail services within specified geographies is very hard.

Ironically, the best and easiest data to collect is from the worst cities for public transport in the world - US cities - who have a standardised Federal legal requirement for public transport reporting through the National Transit Development (NTD) program and APTA, the American Public Transit Association publishes comprehensive on-line digests of this reporting every year for every operator in the USA. Where the standard data items are not included in the main report, there are supplementary spreadsheets that can be requested which bring together virtually every public transport data item needed in this research. Sweden could do well to consider this American system reporting requirement to ensure data standardisation and reporting.

CBD parking is rarely obtained without a huge amount of conversing with local authorities trying to patch together the information. Parking inventories are rare. Even length of roads can be difficult due to the inclusion of significant forestry and agricultural roads, which are not part of the usable urban road system for regular traffic and therefore must be excluded from road length. Even the length of freeway within specific geographies has presented numerous problems in some cities. The average speed of the road system in specific geographies is also highly problematic but was often overcome through government agencies requesting private companies who run the local computerised traffic models to calculate this factor. The process of discovering all this and finally resolving it is very time consuming.

Travel survey data is generally available from most municipalities and mostly quite recent. However, there is no standardisation whatsoever in the reports that are presented from these travel surveys. What is chosen for reporting varies widely and to obtain the data required often means special requests for additional information. This is frequently in the hands of companies commissioned to do the travel surveys and is therefore not forthcoming without further payment. There is a great need here to standardise data reporting from travel surveys and to review the methodologies used to obtain the data (e.g. change to reporting of the trips for all members of a participating household). This would assist knowing the average car occupancy, which is important in calculating passenger kilometres by car (see Item 9 in Table 2).

Overall, one can say that there is a substantial core of relatively good data available from online databases in Sweden or which are given in spreadsheets once the right person is discovered to supply it. However, much of the data that makes this database unique has come from tireless back and forth with a multitude of people in many agencies and even online data had to be clarified and sometimes only could be dug out with specialist help from Statistics Sweden because the database is not always transparent or user-friendly. Much of this could be streamlined by clearer systems for data reporting on transport matters at every level within Sweden.

2.3. Some Specific Notes About the Data

Note that for the international comparisons, the results pertain to the years of 2005–2006, but for Swedish cities and Freiburg, the year is 2015. These are the latest updates on this large sample of 41 other cities, which took approximately 7 years to complete and are thus not easily or quickly updated to a more recent year.

The validity of the comparisons is mostly not compromised by this 10-year time difference. However, it is explained that with certain variables, such as the metropolitan Gross Domestic Product (GDP), transport deaths, and transport emissions, which can change quite rapidly, the time difference is more significant so that where comparisons are drawn, some caveats on the data are explained.

It is important to note that for some variables, the metropolitan area definitions given in Table 1 were modified. For example, metropolitan GDP needs to be calculated on the full functional urban region or "labour market area" (in German, the Arbeitsmarktregion). Also, some public transport services, such as the regional rail and buses, cannot be separated out into smaller areas. In these cases, the population of the larger serviced area is used to calculate per capita figures to ensure that data are not inflated.

Table 3 sets out a guide of what constitutes urban land. Statistics Sweden provides detailed land use inventories for every municipality and county in Sweden on their statistics portal at Statistics Sweden (2019)

Those categories used for urban land area in Sweden are called "built-up land and associated land", which consist of:

- Land with one- or two-dwelling buildings;
- Land with multi-dwelling buildings;
- Land used for manufacturing industry;
- Land used for commercial activities and services;
- Land used for public services and public facilities and leisure;
- Land used for transport infrastructure;
- Land used for technical infrastructure;
- Land with agricultural buildings and other buildings.

Careful investigations were made of these land use categories and especially the last one, but in each case, they were found to be comparable to what was used in other cities. There are two categories of land use in Sweden, which could have raised doubts about their low densities relative to other cities, but when checked, they did not. These are namely land for "golf courses and ski pistes" and "land with agricultural buildings and other buildings" (both included in other cities). Even by (incorrectly) taking these two land uses out for two of the cities (Stockholm and Linköping), examples of higher and lower density Swedish cities, Stockholm would have an urban density of 25.3/ha (instead of 23.5/ha) and Linköping 15.5/ha (instead of 13.8/ha). This would not be significant here.

However, there is the possibility that the other requirement for "built-up" in Sweden of a minimum of 200 people with buildings no more than 200 metres apart, might in some cases, yield densities that are below the more normal "urban" definition in other parts of the world of a minimum of 400 persons per square kilometre or 4 persons per ha. There are over 2000 built up areas in Sweden and the average density of these is 14.23 persons per ha, so over three times the density normally required for "urban". However, around

25% of these 2000 built-up areas are below 4 persons per ha and range from 0.46 per ha to 82.82 per ha (personal communication, Emma Strömblad, Lund University). Theoretically, if any built up land area that has less than 4 persons per ha in the ten cities was excluded, then the density of Swedish cities would be a little higher than stated in this paper, but they would still be very much lower than typical European cities and closer to auto city densities at the higher end of that range (ca. 20 per ha or a little higher). Thus, it has been concluded that for these macro-level, aggregate comparisons, the urban density data are more than tenable and useful.

The methodology chosen for this working paper to present the results is to compare the ten Swedish cities in detail, with both tables and figures showing the values of each variable for these ten cities, as well as an average for these ten Swedish cities to facilitate comparisons to the other groups of cities. Averages are also provided for the five larger cities and the five smaller Swedish cities, plus the data for Freiburg as a benchmark smaller city known for its sustainable transport. Only averages for the American, Australian, Canadian, and the other European cities, plus the two Asian cities are presented. This was primarily to condense the results of the analysis into a working paper of an acceptable length. Readers can refer to Schiller and Kenworthy (2018), Newman and Kenworthy (2015) and Kenworthy (2018) for various detailed graphs and tables showing the results for variables on all the other cities.

The metropolitan regions used in this study were: **USA**: Atlanta, Chicago, Denver, Houston, Los Angeles, New York, Phoenix, San Diego, San Francisco, and Washington; **Canada:** Calgary, Montreal, Ottawa, Toronto, and Vancouver; **Australia:** Brisbane, Melbourne, Perth, and Sydney; **Europe:** Berlin, Bern, Brussels, Copenhagen, Düsseldorf, Frankfurt, Geneva, Graz, Hamburg, Helsinki, London, Madrid, Manchester, Munich, Oslo, Prague, Stockholm, Stuttgart, Vienna, and Zurich; and **Asia:** Hong Kong and Singapore.

Urban density is a recurring and unifying theme throughout the paper, with the Swedish cities being compared to the highly auto-dependent metropolitan regions in North America and Australia. Some basic statistical regression analysis using a power function as the line of best fit is used in the discussion section to highlight the somewhat unique cluster of the ten Swedish cities on the key two variables of urban density and car use and to use this regression as a predictor of car use for the Swedish cities compared to their actual results. This follows similar regression analyses in many of our other publications (Newman and Kenworthy, 1989a, 1999a, b, 2015).

The study has several limitations. For example, it only compares cities from an aggregate perspective and only for the year of 2015 in the case of the Swedish cities and 2005 or 2006 for the other cities. This impacts some variables more than others and this is explained in the text where relevant. No trends of the data are included, which would have been useful, but which were not available for the Swedish cities due to this being the first time they were included in such comparisons (except for Stockholm), as well as limitations on time and the available funding. For the other cities, 1995 or 1996 and 2005 or 2006 data were consistently available and some analyses of trends have already been made Kenworthy (2013).

The data perspectives in this paper are not the only ways that Swedish cities can be viewed in relation to each other and to other cities, and this limitation is partly addressed in the Analysis, Discussion, and Policy Implications section of the working paper. Some variables that are included have limitations too, for example, the freeway length. This should ideally be the lane length to indicate capacity. However, even in an age of Geographic Information Systems (GIS) systems, this is an extremely hard, if not impossible, variable to collect consistently across such a large global sample of cities. It was originally the preferred variable when measuring freeways, but had to be dropped.

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
Freiburg im Breisgau	Stadt Freiburg

Table 2. Detailed description of the primary data variables collected for Swedish Cities.

1.	**Total land area of the metropolitan area** The metropolitan region was defined in each case, which acted as the boundary for data collection for most items. The total land area of the metropolitan area included all land regardless of use. For short, the metropolitan area or urban region definition is referred to as the Defined Area or DA.
2.	**Urbanised area of the metropolitan area** The urbanised land area is very important and refers to the total “urbanised territory” within the DA. Table 3 defines urban land. Access to land use data is needed for this item, *not* urban zoned land, which may not be urbanised yet. Land use inventories are collected for each city with land use divided up into the available categories. As much detail as possible is sought to ensure that urban land can be properly specified.
3.	**Total population of the metropolitan area** This is the official population of the DA, determined as a rule by Census.
4.	**Number of jobs (at place of work) in the metropolitan area** This is the number of jobs physically located within the DA. It includes full and part-time jobs, and where part-time jobs can be distinguished from full-time jobs, these are halved to estimate equivalent full-time jobs.
5.	**Number of jobs (at place of work) in the Central Business District (CBD)** This first requires a working definition of the central business district or CBD. CBD definitions are supplied by the planning authorities of each city, not by the author. This is the main centre of the DA, usually the central core of the oldest part of the city, though some cities shift their CBD to new locations. Job data are the same as for Item 4.
6.	**Gross domestic product of the metropolitan area** GDP of the metropolitan region is an item that always must be collected for the full labour market area or commuter belt of the DA. If one takes the GDP of only the Municipality and calculates a GDP per capita using just its population, it will be inflated because many more people contribute to this GDP than those who live in the Municipality. So, the GDP is for the whole commuter belt and is divided by its population to calculate GDP per capita.
7.	**Number of passenger cars (excluding taxis)** The number of passenger cars is obtained generally from the vehicle registration system in each city. “Light commercial” vehicles are included as many trips made by these vehicles are for personal purposes. In the USA, this includes “light duty trucks”, which are mostly SUVs (sports utility vehicles).
8.	**Total annual vehicle kilometres of travel (VKT) in private cars** This generally comes from the “traffic model” and includes all VKT by private passenger vehicles (excluding motorcycles, which are collected separately). The VKT represents driving by residents of the DA. An alternative approach is to use good data on the annual average number of kilometres driven per year by passenger vehicles in the DA (e.g. odometer surveys), which are multiplied with the number of vehicles. Another method might be the total annual number of person trips in private passenger vehicles in the DA multiplied by a reliable overall average trip length (all trip purposes) and then divided by the average occupancy of the vehicles.
9.	**Total annual passenger kilometres (PKT) in private cars** PKT requires an average annual (24 hours-a-day/7 days-a-week) figure for the average number of people per car (including the driver). In wealthy cities today, this figure is often about 1.40 to 1.45 (weekend occupancies are much higher than weekdays), which is much higher than typical peak period figures of 1.10. This occupancy figure multiplied with VKT gives PKT. Referring to Item 8, if there is a total annual person trips by private passenger vehicles and a reliable overall average trip length in kilometres, then these two multiplied together will also give a measure of PKT. The Swedish method of doing travel surveys makes it especially difficult to get accurate car occupancy data because only the trip of the respondent is recorded, not the trips of those he/she may be carrying as the car driver from their household (e.g. taking three children to school), in which case the car occupancy for that trip would be four, but not recorded as such. Some work arounds were achieved for this involving car as driver and car as passenger, plus “serve passenger” trip purposes by car.
10.	**Average road network speed (7-day/24-hour)** This is the overall average road system speed across all road types and trip types (a 24-hour/7-days-a-week system average). One method can be the VKT from the traffic model divided by the equivalent number of vehicle hours.
11.	**Total centreline length of the road network (all roads from residential to freeway)** This variable represents the total linear length of all roads, often referred to as the centreline length. Generally, in developed cities, the roads are sealed and so would exclude, for example, unsealed roads only used for forestry or agricultural purposes.

12.	**Total length of express road network (ALL expressways, freeways, tollways)** This refers to all roads that fulfil three conditions: (1) No traffic lights; (2) No intersections; (3) No direct property access from the road, i.e. fully controlled access roads.
13.	**Number of parking places in the CBD (off-street)** This is the total number of off-street spaces (surface parking lots and parking buildings open to the public and all tenant parking in buildings dedicated to the employees). All parking spaces that are dedicated 100% to resident-only parking are excluded.
14.	**Number of parking places in the CBD (on-street)** This is the number of parking places on the streets within the defined CBD area. They can be metered or un-metered spaces, short or long term. These also exclude all resident-only on-street spaces, requiring a permit.
15.	**Length of reserved public transport route by each mode** This is the total length of routes for public transport vehicles that are legally and/or physically separated from general traffic. It includes all traditional rail modes that operate on their own dedicated right-of-way, as well as those sections of tram routes and bus-only lanes that are protected from general traffic. A reserved route is only counted once, regardless of how many actual public transport lines share the reserved route length (see Item 28 for clarification).
16.	**Average operating speed of each public transport mode** This is the commercial average operating speed of each public transport mode in the DA. It is often derived by operators by dividing the annual revenue vehicle kilometres of service by the annual revenue vehicle hours of service needed to deliver those kilometres. It specifically excludes dead-heading kilometres and time.
17.	**Annual revenue vehicle kilometres of service by each public transport mode** For each mode, this item is the total annual number of kilometres of service operated by the public transport provider. It is a widely reported operating statistic and excludes dead-heading.
18.	**Annual revenue seat kilometres of service by each public transport mode** Some operators report this, but usually they report place-kilometres. The usual method in this research is to get a table showing the number and type of each vehicle operated by all the public transport providers (see Item 27) and the number of seats that each of these different types of vehicles contain. A weighted average number of seats is used to calculate the annual seat kilometres for each operator and mode.
19.	**Annual boardings by each public transport mode** Boardings are the number of entries into public transport vehicles in one year (as opposed to a whole public transport trip from A to B, which may involve several boardings, due to changing modes or routes).
20.	**Annual passenger kilometres by each public transport mode** Annual passenger kilometres by public transport modes is often reported by public transport operators. If it is not reported, then the average distance that each boarding travels within the system is collected and then multiplied by the number of boardings to get passenger kilometres. Most operators know this today from electronic ticketing systems and other electronic surveillance means, or they conduct manual boarding and alighting surveys on the vehicles.
21.	**Private passenger transport energy use (litres of petrol, diesel, Liquid Petroleum Gas (LPG), Compressed Natural Gas (CNG), kilowatt hours (kWh) of electricity or others)** This is often known or estimated by the local, regional, state, or national environment agency due to the need to conduct inventories of CO_2 emissions. The fuel use matches the VKT in Item 8. It is only the fuel use of private passenger motor vehicles. Another potential method is a good estimate of the average litres per 100 km of fuel by in-use vehicles operating within the DA. Fuels cover petrol, diesel, LPG, CNG, and now electricity (kWh).
22.	**Public transport energy use (for each public transport mode, all fuel types)** Public transport operators always know exactly how much fuel they have consumed in each of their vehicle types because they pay for it. This item is generally quite precise and covers all the fuel types that are today used in public transport systems of cities (e.g., bio-diesel, Rape Methyl Ester (RME), etc., in addition to the others mentioned above).
23.	**Total transport-related deaths** Transport deaths cover all transport modes within the DA. These are not the deaths reported by the police, who typically only record deaths at the scene of an accident. The source is the WHO's International Classification of Diseases (ICD 10), items V01 to V99. Usually, the local or national health authority has these data. They apply a 30-day rule of death in hospital after a transport accident.
24.	**Number of two-wheeled motor vehicles (motorcycles)** The total number of motorcycles is defined as all motorised vehicles with two wheels, which are admitted to general traffic. This definition includes all classes of motorcycles and motor-assisted bicycles (mopeds) and motorcycles with sidecars. Pedelecs (e-bikes) are classed as bikes and are excluded here.
25.	**Vehicle kilometres of travel on two-wheeled motor vehicles (motorcycles)**

	This is the same as Item 8, but for motorcycles, as defined in Item 24. An average annual number of kilometres per year of a typical motorcycle multiplied by the number of registered motorcycles is a common method, given the general lack of attention to motorcycles in transport planning.
26.	**Passenger kilometres on two-wheeled vehicles (motorcycles)** This is the same as for Item 9, but only for motorcycles as defined in Item 24. Generally, the average 24/7 occupancy of a motorcycle in wealthy cities is close to 1.00, most often between 1.02 and 1.08, rarely more.
27.	**Public transport vehicle fleet by mode** This is an inventory of the public transport vehicle fleet by mode (number of buses, minibuses, tram wagons, rail wagons, ferries, etc.). For all rail modes, the number of *wagons* are collected, not the number of trains, which have variable numbers of wagons.
28.	**Length of public transport lines by mode** This is the length of all lines by mode. Where multiple routes share the same section of track or roadway they are counted multiple times. For example, five bus lines operating over the same five kilometres of road constitute 25 km of bus lines–similarly for rail modes. This is unlike a reserved route, where it is only counted once, regardless of the number of lines operating along it.
29.	**Annual total public transport farebox revenue** This is all farebox revenue for all modes together (not split by mode), but rather the farebox revenue for all modes and operators in one figure. Also collected is the farebox revenue with and without government reimbursements for concession fares (pensioners, students, people with disabilities).
30.	**Annual operating expenses of public transport** This is all genuine operating costs, not split by mode, but covering all modes and operators. Public transport operating costs include: energy; supplies of goods and services (including sub-contractors' services); personnel costs, including salaries and other charges, retirement pensions, etc.; overheads (rent, etc.); financial charges (interest payments); depreciation; maintenance of rolling stock and infrastructure; taxes and fees.
31.	**Air pollutant inventory from transport sources in the city (carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO_2), and VHC-volatile hydrocarbons)** These data are from an inventory of emissions, usually prepared by the national or local environmental agency. They include all transport sources of emissions.
32.	**Number of daily walking trips** These are the walk-only trips from origin to destination.
33.	**Number of daily mechanised, non-motorised trips** These are mostly the bike-only trips (or any other "feral transport", like skateboards).
34.	**Number of daily motorised trips on public modes** These are trips on all the public transport modes (bus, rail, ferry, etc.). They are linked trips, not trip segments, boardings or unlinked trips.
35.	**Number of daily motorised trips on private modes** These are the trips by all private motorised modes, such as cars, vans, motorcycles, and taxis (linked trips, not trip segments).

Table 3. Urban land definition (Item 2, Table 2).

Land Use Category	Type	Comment
Agricultural	n/u	
Meadows, pastures	n/u	
Gardens, local parks	u	These areas are not generally built up, but in their size, they are too small and in their human recreational uses, they are too intense to qualify as genuine non-urban land.
Regional scale parks	n/u	These are large, contiguous areas set aside within metropolitan areas for non-intensive or restricted recreational uses, water catchment functions, green belts, etc.
Forest, urban forest	n/u	Urban forests are larger than parks and are often significant wildlife and forestry areas.
Wasteland (natural)	n/u	This includes flood plains, rocky areas, and the like.
Wasteland (urban)	u	This includes derelict land, culverts, etc.
Transportation	u	Road area, railway land, airports, etc.
Recreational	u, n/u	Depending on the intensity of use, this group can belong partly in either category. Golf courses are urban, as their use is intense. Mostly, recreational land is considered urban.
Residential, industrial, offices, commercial, public utilities, hospitals, schools, cultural uses, sports grounds	u	
Water surfaces	n/u	

3. Results

The results presented here are designed to answer the research questions. Although Table 2 sets out definitions of all 35 primary variables collected for the study, not all standardised variables presented are discussed in detail in this paper. Readers should refer especially to the detailed tables.

3.1. Land Use, GDP, and Private Transport Infrastructure Characteristics

Table 4 provides a key set of variables on the above three topics.

3.1.1. Urban Density

Urban density (population divided by urbanised land area, not floor area ratio) is critical in understanding the urban transport characteristics in any city. Low densities are associated with automobile dependence, and higher densities are associated with less automobile dependence and a greater role for public transport, walking, and cycling (Newman and Kenworthy, 1989a, 1999a). Although such claims are disputed (Newman and Kenworthy, 1989b 1992), evidence continues to emerge of density's fundamental importance in promoting less car use (Lewis and Grande del Valle, 2019).

Swedish urban regions have a low density, averaging less than the larger Canadian cities in 2006 (urban population density of 16.9/ha compared to 25.8/ha) and they are a bit more than 1/3 the typical European urban density of 47.9/ha. The Stockholm region has the highest urban density (23.5/ha), while six of the smaller cities (Uppsala, Linköping, Jönköping, Västerås, Örebro and Umeå) average only 14.0 persons per ha, the same as Australian cities. The larger Swedish cities (average 19.8/ha) are at the lower end of the density range generally considered necessary for less automobile dependence, while the smaller ones are clearly within the range of densities that suggest higher automobile dependence (see later). We have shown in previous research (Newman and Kenworthy, 2006) that urban densities below about 35 persons per ha are associated with steeply increasing levels of car use, but these Swedish cities tend not to follow this norm. These results on density are referred to in later discussions of the results for other variables and in section 4 on the Analysis, Discussion, and Policy Implications. As noted before, the urbanised land area for 2015 from Statistics Sweden was carefully checked for accuracy and compatibility with the urban land area for other cities. Figure 1 summarises the results for the cities on urban density.

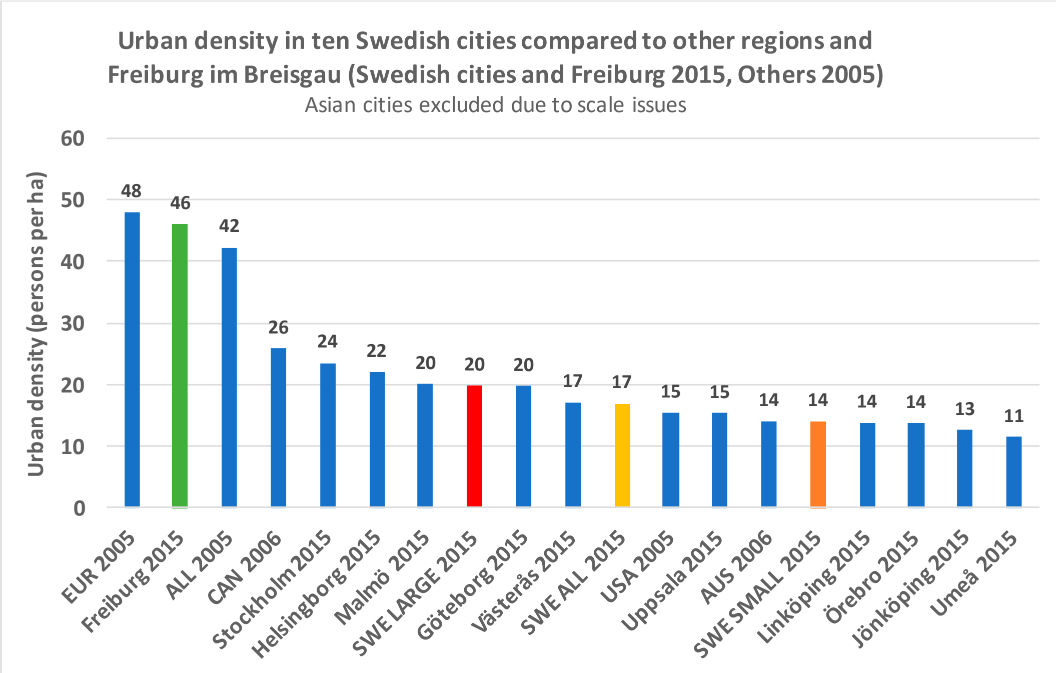

Figure 1. Urban density in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

3.1.2. Proportion of Jobs in the CBD

Thomson (1977) clearly identified how important the centralisation of work can be in shaping urban transport, especially jobs located in the CBD of cities. The proportion of metropolitan jobs located in the CBDs of Swedish cities shows them to be rather centralised (17.3%), compared to 18.3% in Europe (Figure 2). The larger Swedish cities are slightly less centralised than the smaller (16.3% cf. 18.3%), perhaps because as cities grow larger they begin to develop significant sub-centres beyond the CBD. The larger Swedish cities are identical to Freiburg with 16.3% of jobs in the CBD. Swedish cities are the second highest across the city groupings in this factor. This generally works in favour of public transport, at least for work-related travel and to some extent in small cities, probably also better access to work by non-motorised modes.

3.1.3. Metropolitan Gross Domestic Product (GDP) per Capita

Wealth was measured as metropolitan GDP per capita. The data in Table 4 were calculated for the labour market region of each city (see Table 2). Note that for the purposes of the international comparisons published over many years using my urban comparative data (Newman and Kenworthy, 1989a, 1999a; Kenworthy and Laube, 2001), some of which are contained in the present working paper, all financial data were converted to constant 1995 US dollars.

In 2015, Swedish cities were moderately wealthy, averaging $33,197 per capita, which was more than both the Australian ($32,194) and Canadian cities ($31,263) were in 2006, though these cities now likely have higher GDP per capita than the Swedish cities. However, the other European cities were generally higher in wealth ($38,683). The global sample in 2005 averaged $37,700. Stockholm, the largest and most important Swedish city, clearly stands out in wealth ($49,271) and in 2015 was higher than the US cities were in 2005, the wealthiest group in the global sample ($44,455). The smaller cities have clearly lower GDP per capita than the larger Swedish cities ($30,001 cf. $36,393). An important point to note is that Freiburg has significantly lower GDP per capita ($25,782) than all the Swedish cities.

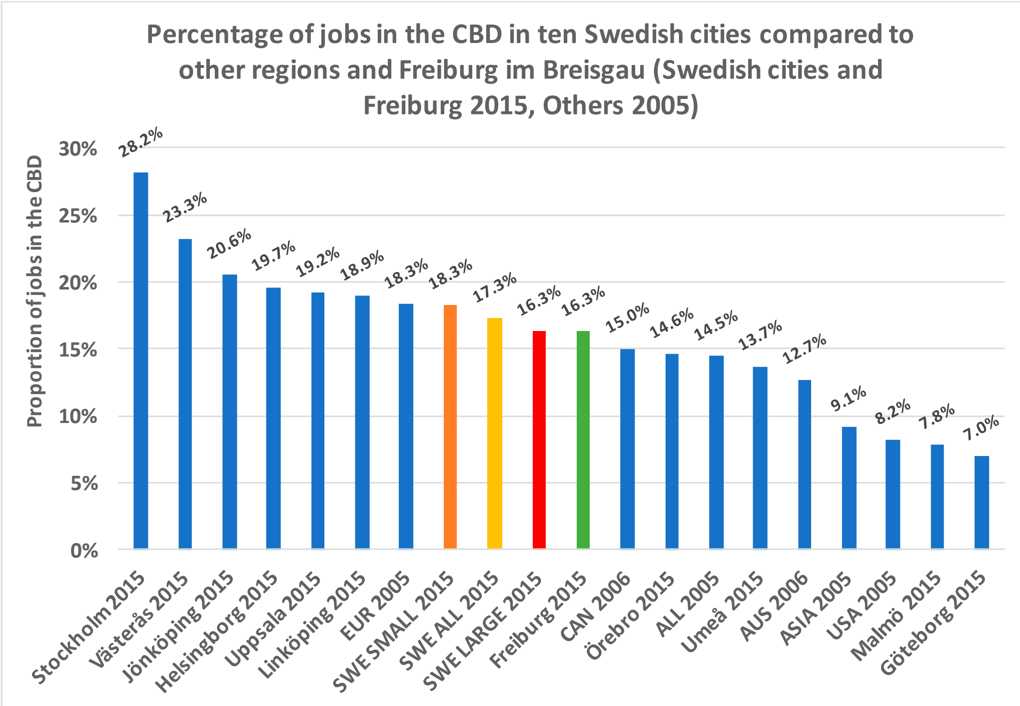

Figure 2. Proportion of jobs in the CBD in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

Of course, GDP is one of the variables that does change significantly over time. Therefore, the Australian, Canadian, and European cities' GDPs by 2015 would likely be significantly higher than that of the Swedish cities in 2015. The two Asian cities are still likely to have lower GDPs per capita than those in Sweden, but they are likely to have caught up significantly.

3.1.4. Road Length per Capita

When all roads are considered, from residential streets to freeways/highways, the Swedish cities are well-endowed, averaging 7.6 m/person. This is the same as in Australian cities (7.6 m/person), while the larger cities (6.5 m/person) are similar to US cities (6.0) and higher than in Canadian cities (5.4). All Swedish cities are significantly higher than Freiburg in road length per person (2.3). They are also more than double the European cities with only 3.1 m/person, though this is somewhat to be expected, given the lower densities of the Swedish cities (road length increases as densities decrease due to the commensurate longer roads needed to service development). Again, logically, Stockholm has the least roads (4.7 m/person), while Umeå, the least dense of the Swedish cities, has the most (10.6 m/person). Table 4 shows the spatial density of roads (m/urban ha) to also be high is Swedish cities (123 m/urban ha cf. 118 in the entire world sample in 2005-2006).

Table 4. Land use, GDP, and private transport infrastructure characteristics of Swedish and international cities.

Variable	Units	Stockholm	Malmö	Göteborg	Linköping	Helsingborg	SWE LARGE	Uppsala	Västerås	Örebro	Jönköping
Urban density	persons/ha	23.5	20.0	19.7	13.8	21.9	**19.8**	15.3	17.1	13.7	12.6
Job density	jobs/ha	12.6	9.2	10.1	7.3	11.0	**10.0**	7.4	8.4	7.0	6.7
Activity density	persons+jobs/ha	36.1	29.2	29.8	21.1	32.9	**29.8**	22.7	25.4	20.7	19.2
Proportion of jobs in CBD	%	28.2%	7.8%	7.0%	18.9%	19.7%	**16.3%**	19.2%	23.3%	14.6%	20.6%
Metropolitan gross domestic product per capita	USD 1995	$49,271	$32,709	$40,808	$30,260	$28,917	**$36,393**	$31,998	$29,594	$29,045	$29,952
Length of road per person	m/ person	4.7	6.9	5.0	9.1	6.9	**6.5**	7.0	8.6	8.1	9.6
Length of freeway per person	m/ person	0.138	0.232	0.225	0.269	0.287	**0.230**	0.180	0.224	0.366	0.496
Length of road per urban hectare	m/ha	110.8	138.9	97.8	125.8	150.3	**124.7**	106.8	146.9	110.7	121.4
Length of freeway per urban hectare	m/ha	3.3	4.6	4.4	3.7	6.3	**4.5**	2.8	3.8	5.0	6.2
Parking spaces per 1000 CBD jobs	spaces/1000 jobs	125	237	160	225	483	**246**	169	501	461	287
Passenger cars per 1000 persons	units/1000 persons	398	442	405	432	435	**423**	387	461	435	481
Motor cycles per 1000 persons	units/1000 persons	24	29	35	30	30	**30**	25	27	31	38
Average speed of the road network (24/7)	km/h	37.1	41.0	39.0	30.5	39.1	**37.3**	51.3	48.5	47.4	45.0

Table 4 cont.

Variable	Units	Umeå	Freiburg	SWE SMALL	SWE ALL	USA	AUS	CAN	EUR	ASIA	ALL
Urban density	persons/ha	11.5	46.0	**14.0**	**16.9**	15.4	14.0	25.8	47.9	217.3	42.2
Job density	jobs/ha	6.1	24.2	**7.1**	**8.6**	8.1	6.2	14.1	29.6	113.3	24.3
Activity density	persons+jobs/ha	17.5	70.2	**21.1**	**25.5**	23.6	20.3	39.9	77.5	330.6	66.5
Proportion of jobs in CBD	%	13.7%	16.3%	**18.3%**	**17.3%**	8.2%	12.7%	15.0%	18.3%	9.1%	14.5%
Metropolitan gross domestic product per capita	USD 1995	$29,415	$25,782	**$30,001**	**$33,197**	$44,455	$32,194	$31,263	$38,683	$21,201	$37,700
Length of road per person	m/ person	10.6	2.3	**8.8**	**7.6**	6.0	7.6	5.4	3.1	0.5	4.4
Length of freeway per person	m/ person	0.000	0.063	**0.253**	**0.242**	0.156	0.083	0.157	0.094	0.026	0.112
Length of road per urban hectare	m/ha	121.0	103.9	**121.4**	**123.0**	84.4	105.1	143.9	134.1	85.3	118.0
Length of freeway per urban hectare	m/ha	0.0	2.9	**3.6**	**4.0**	2.3	1.1	3.9	4.1	4.8	3.4
Parking spaces per 1000 CBD jobs	spaces/1000 jobs	240	271	**332**	**289**	487	298	319	248	121	314
Passenger cars per 1000 persons	units/1000 persons	435	393	**440**	**431**	640	647	522	463	78	512
Motor cycles per 1000 persons	units/1000 persons	36	36	**31**	**30**	16	21	15	41	19	29
Average speed of the road network (24/7)	km/h	46.7	29.9	**47.8**	**42.6**	50.4	42.8	45.4	34.3	30.6	40.2

3.1.5. Freeway Length per Capita

Freeways are a premium road infrastructure and are much more indicative of automobile dependence than roads *per se*. Freeways have been known for decades to encourage and increase car use (Watt and Ayres, 1974). Ideally, freeways should really measure lane-kilometres for a better indication of capacity, but, in practice, as already explained, it is surprisingly difficult to obtain even a linear length of freeways, let alone lane-kilometres. A pattern begins to emerge here in the Swedish cities of a relatively strong orientation to the car. This is despite a comparatively moderate wealth when measured by metropolitan GDP per capita, though it does tend to correlate with the lower densities of Swedish urbanism.

Combined with lower densities, the Swedish cities are well-endowed with freeways, averaging 0.242 m/person, (0.230 in the larger cities and 0.253 in the smaller cities) and significantly higher than any other group of cities in the global sample. Freiburg has only 0.063 m/person of freeway. US and Canadian cities had in 2005/6 some 0.156 and 0.157 m/person of freeway, respectively, while the global sample averaged 0.112 m/person or less than half that of the Swedish cities. In keeping with Stockholm's distinctive features, it also has the least freeway infrastructure (0.138 m/person), apart from Umeå, which appears not to have any freeways as defined here, while Jönköping, on a per capita basis, is the highest city in this global sample for freeways (0.496 m/person). Figure 3 depicts this significant result.

Despite low urban densities the length of freeway per urban ha in Table 4 is also high (virtually identical to the European cities and higher than all other cities except the two in Asia where densities are extreme).

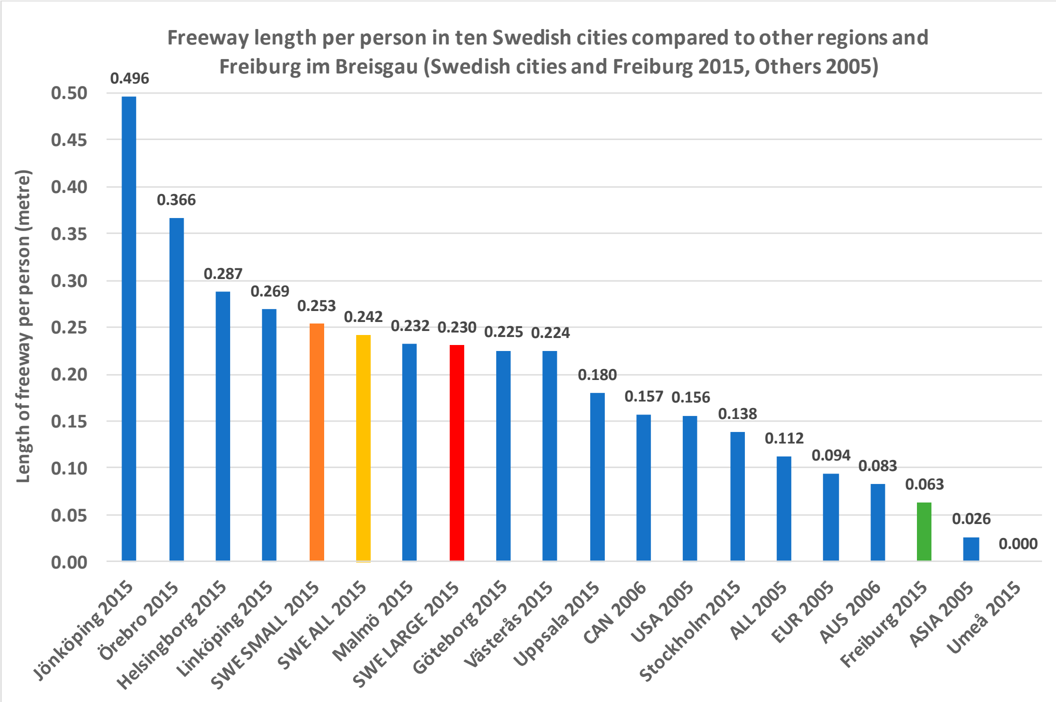

Figure 3. Freeway linear length per person in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

3.1.6. Parking Spaces per 1000 CBD Jobs

Parking availability and, to a lesser extent, cost are key determinants influencing how likely people are to use cars (Shoup, 2011, 2018). For trips to the CBD, parking is comparatively limited in Swedish cities, with only an average of 289 spaces per 1000 jobs, theoretically meaning that only about 1 in 3.5 people working in the CBD would be able to park a car. It is lower in other European CBDs (248 spaces per 1000 jobs). The larger Swedish cities perform a little better than Europe generally (246/1000 jobs) while the smaller Swedish cities have 332 spaces per 1000 jobs. Low CBD parking also favours public transport, walking, and cycling access to Swedish city centres. Additionally, parking in Swedish cities is greatly below that of all the other regions, apart from the Asian cities, but is a little higher than in Freiburg (Figure 4).

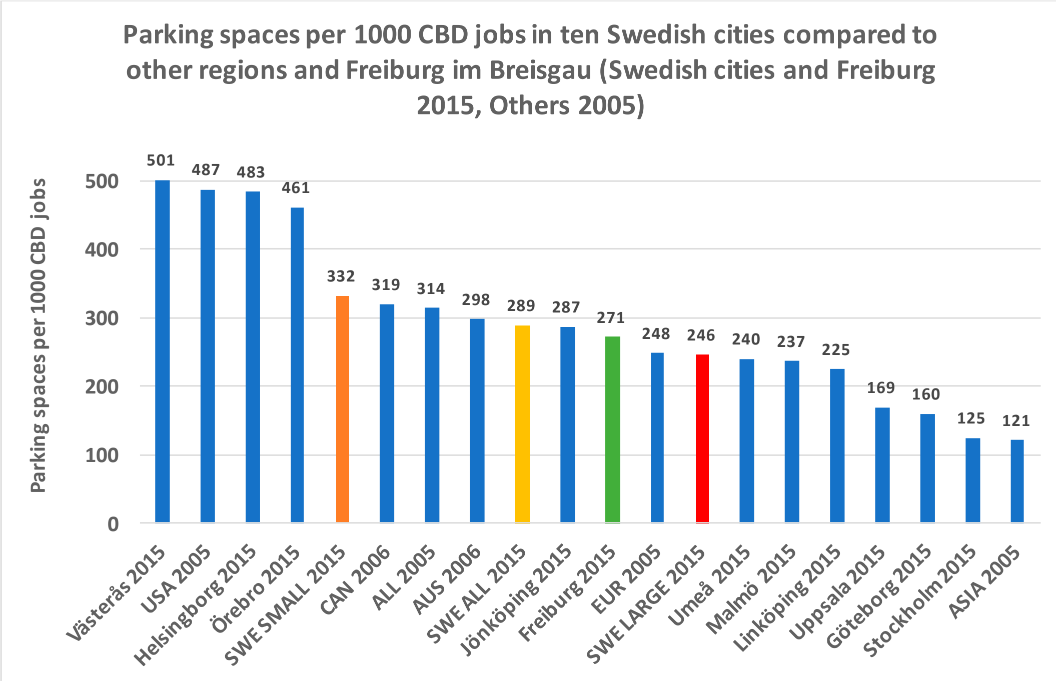

Figure 4. Parking spaces per 1000 CBD jobs in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

3.1.7. Passenger Cars and Motorcycles per 1000 Persons

Ownership of private vehicles is important in determining car use. So far, Swedish cities in density, roads, and freeways present themselves as being rather auto-oriented. However, in car ownership, interestingly, this picture begins to change a little.

Figure 5 presents car ownership statistics showing that Swedish cities in 2015 averaged a comparatively modest 431 cars/1000 persons, with the larger cities at 423 and the smaller having 440, so a relatively tight clustering. This is below the averages for almost all other groups of cities (Australian and American cities were 647 and 640 cars/1000 persons, respectively, and European cities had 463 cars/1000 persons in 2005), and the global sample overall was 512 cars/1000. Only the two large Asian urban regions have less, with a paltry 78 cars/1000. Uppsala has only 387 cars/1000 and Stockholm has only 398 cars/1000 or very similar to Freiburg at 393, while Jönköping has the highest at 481/1000. Swedish car ownership is thus in a tight and comparatively modest band generally between about 390 to 480 cars per 1000 persons. It would be expected that by 2015, the other cities would have increased a little more in car ownership, further emphasising the low result in Sweden. Car usage, a more important factor than car ownership *per se*, is considered later in the paper.

In Swedish cities, like in many other cities in the developed world, motorcycles play a relatively small role in urban transport. Motorcycles per 1000 persons in the ten cities averages only 30, (one motorcycle for every 33 people), which is less than in the European cities in 2005 (41/1000 persons), but quite a bit higher than in the US (16), Australia (21), Canada (15), and Singapore and Hong Kong (19). Motorcycle usage is also considered later in the report.

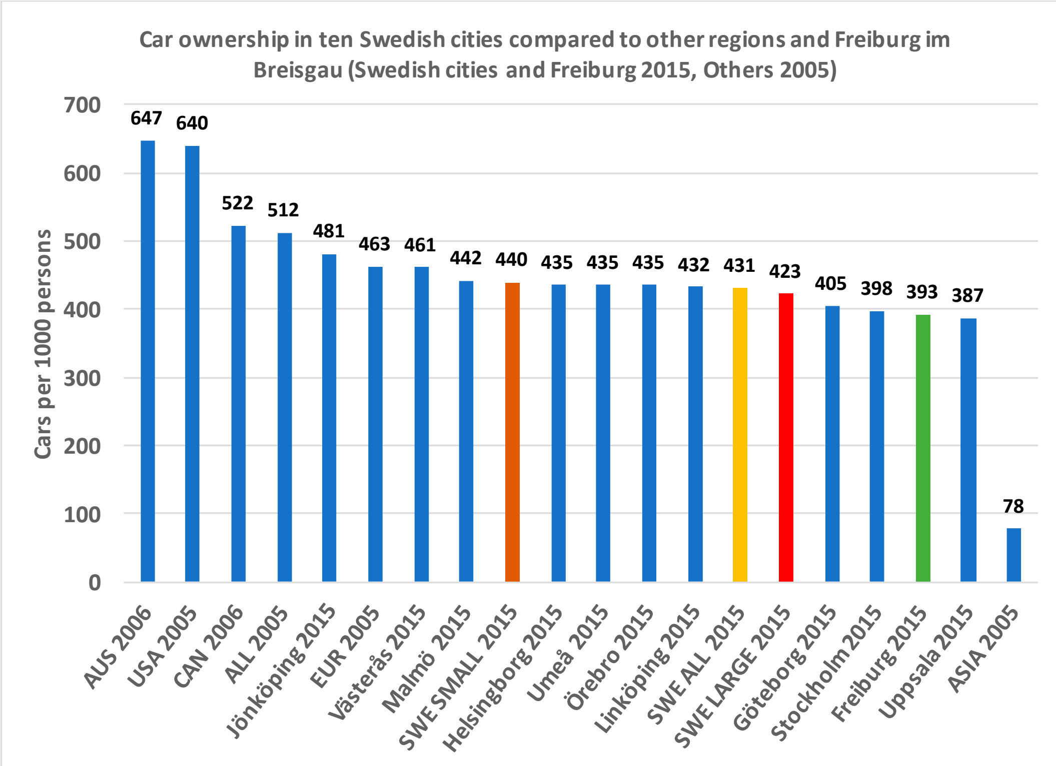

Figure 5. Car ownership in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

3.1.8. Average Road System Speed

One traditional traffic engineering measure of the effectiveness of any urban road system is its level of service, the key factor being average speed. Table 4 provides an average speed of 42.6 km/h for the ten Swedish cities, which, with all their freeways, is as expected, higher than other European cities (34.3 km/h) and the Asian cities. There is, however, a notable difference between the larger cities (37.3 km/h) and the smaller cities with presumably significantly less congestion (47.8 km/h). Road traffic is, however, generally slower than in North American and Australian cities, which collectively average 46.2 km/h. Freiburg's average traffic speed is only 29.9 km/h, which is highly commensurate with all the other data so far (much denser city with very much lower road and freeway provision than cities in Sweden, so slower traffic). A more important factor for sustainability and reduced automobile dependence, however, is the relative speed between public and private transport, which is covered later.

3.2. Public Transport Infrastructure and Service

Table 5 provides a set of indicators on public transport infrastructure and service features.

Table 5. Public transport infrastructure and service characteristics of Swedish and international cities.

Variable	Units	Stockholm	Malmö	Göteborg	Linköping	Helsingborg	SWE LARGE	Uppsala	Västerås	Örebro	Jönköping
Total length of public transport lines per 1000 persons	m/1000 persons	4,867	3,109	6,098	11,055	3,031	**5,632**	11,176	6,894	9,876	9,024
Total length of reserved public transport routes per 1000 persons	m/1000 persons	234	222	283	378	432	**310**	584	1,275	422	1,457
* Busway length per 1000 persons	m/1000 persons	42	43	92	37	80	**59**	0	0	1	14
* Minibus reserved route length per 1000 persons	m/1000 persons	0	0	0	0	0	**0**	0	0	0	0
* Segregated tram network length per 1000 persons	m/1000 persons	0	0	0	0	0	**0**	0	0	0	0
* Light rail network length per 1000 persons	m/1000 persons	54	0	86	22	0	**32**	0	0	0	0
* Metro network length per 1000 persons	m/1000 persons	48	0	0	0	0	**10**	0	0	0	0
* Suburban rail network length per 1000 persons	m/1000 persons	90	178	106	319	352	**209**	584	1,275	421	1,443
* Ferry network length per 1000 persons	m/1000 persons	0	0	0	0	0	**0**	0	0	0	0
Total public transport vehicles per 1000 persons	units/1000 persons	1.31	1.06	1.37	0.80	2.31	**1.37**	1.46	0.70	1.15	0.77
* Buses per 1000 persons	units/1000 persons	0.95	0.79	0.95	0.65	1.02	**0.87**	1.38	0.63	0.91	0.70
* Minibuses per 1000 persons	units/1000 persons	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00
* Tram units per 1000 persons	units/1000 persons	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00
* Light rail units per 1000 persons	units/1000 persons	0.09	0.00	0.27	0.04	0.00	**0.08**	0.00	0.00	0.00	0.00
* Metro units per 1000 persons	units/1000 persons	0.20	0.00	0.00	0.00	0.00	**0.04**	0.00	0.00	0.00	0.00
* Suburban rail units per 1000 persons	units/1000 persons	0.06	0.27	0.13	0.10	1.29	**0.37**	0.08	0.07	0.24	0.07
* Ferry units per 1000 persons	units/1000 persons	0.01	0.00	0.03	0.03	0.00	**0.01**	0.00	0.00	0.00	0.00
Total public transport vehicle kilometres of service per capita	v.km/person	114.2	66.0	150.8	61.0	99.0	**98.2**	116.5	54.5	51.3	82.0
* Bus vehicle kilometres per capita	v.km/person	56.3	50.6	120.1	50.5	88.6	**73.2**	84.7	44.7	46.8	51.9
* Minibus vehicle kilometres per capita	v.km/person	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0
* Tram wagon kilometres per capita	v.km/person	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0
* Light rail wagon kilometres per capita	v.km/person	6.5	0.0	17.2	2.8	0.0	**5.3**	0.0	0.0	0.0	0.0
* Metro wagon kilometres per capita	v.km/person	43.0	0.0	0.0	0.0	0.0	**8.6**	0.0	0.0	0.0	0.0
* Suburban rail wagon kilometres per capita	v.km/person	7.8	15.4	12.8	7.5	10.3	**10.8**	31.8	9.9	4.5	30.1
* Ferry vessel kilometres per capita	v.km/person	0.5	0.0	0.7	0.2	0.0	**0.3**	0.0	0.0	0.0	0.0
Total public transport seat kilometres of service per capita	seat km/person	8,294	5,837	9,376	4,647	6,321	**6,895**	7,115	2,677	3,642	4,330
* Bus seat kilometres per capita	seat km/person	2,796	2,276	5,529	2,811	3,921	**3,467**	4,320	2,009	2,436	2,374
* Minibus seat kilometres per capita	seat km/person	0	0	0	0	0	**0**	0	0	0	0
* Tram seat kilometres per capita	seat km/person	0	0	0	0	0	**0**	0	0	0	0
* Light rail seat kilometres per capita	seat km/person	493	0	1,156	184	0	**367**	0	0	0	0
* Metro seat kilometres per capita	seat km/person	2,011	0	0	0	0	**402**	0	0	0	0
* Suburban rail seat kilometres per capita	seat km/person	2,905	3,561	2,590	1,649	2,401	**2,621**	2,795	668	1,206	1,957
* Ferry seat kilometres per capita	seat km/person	88	0	100	4	0	**38**	0	0	0	0
Overall average speed of public transport	km/h	33.6	46.8	30.9	38.6	31.5	**36.3**	64.4	38.4	33.4	40.7
* Average speed of buses	km/h	24.8	27.8	28.0	31.3	23.6	**27.1**	46.0	28.0	30.5	31.5
* Average speed of minibuses	km/h	-	-	-	-	-	**-**	-	-	-	-
* Average speed of trams	km/h	-	-	-	-	-	**-**	-	-	-	-
* Average speed of light rail	km/h	30.5	-	23.0	16.2	-	**23.2**	-	-	-	-
* Average speed of metro	km/h	34.0	-	-	-	-	**34.0**	-	-	-	-
* Average speed of suburban rail	km/h	56.3	75.6	66.0	93.8	65.8	**71.5**	102.0	93.9	89.0	72.5
* Average speed of ferries	km/h	20.4	0.0	12.0	8.0	0.0	**13.5**	-	-	-	-

Table 5 cont.

Variable	Units	Umeå	Freiburg	SWE SMALL	SWE ALL	USA	AUS	CAN	EUR	ASIA	ALL
Total length of public transport lines per 1000 persons	m/1000 persons	18,969	5,131	**11,188**	**8,410**	1,382	2,609	2,496	3,183	2,614	2,576
Total length of reserved public transport routes per 1000 persons	m/1000 persons	1,878	411	**1,123**	**716**	72	160	67	298	34	188
* Busway length per 1000 persons	m/1000 persons	13	0	**6**	**32**	12	10	15	21	2	16
* Minibus reserved route length per 1000 persons	m/1000 persons	0	0	**0**	**0**	0	0	0	0	0	0
* Segregated tram network length per 1000 persons	m/1000 persons	0	0	**0**	**0**	0	3	0	22	0	11
* Light rail network length per 1000 persons	m/1000 persons	0	53	**0**	**16**	6	0	11	15	6	11
* Metro network length per 1000 persons	m/1000 persons	0	0	**0**	**5**	15	0	11	30	19	21
* Suburban rail network length per 1000 persons	m/1000 persons	1,864	358	**1,118**	**663**	39	146	30	211	6	131
* Ferry network length per 1000 persons	m/1000 persons	0	0	**0**	**0**	0	0	0	0	0	0
Total public transport vehicles per 1000 persons	units/1000 persons	1.33	0.83	**1.08**	**1.23**	0.76	0.93	0.92	1.51	1.50	1.2
* Buses per 1000 persons	units/1000 persons	1.30	0.57	**0.98**	**0.93**	0.39	0.64	0.76	0.77	0.93	0.7
* Minibuses per 1000 persons	units/1000 persons	0.00	0.00	**0.00**	**0.00**	0.22	0.00	0.00	0.00	0.32	0.1
* Tram units per 1000 persons	units/1000 persons	0.00	0.00	**0.00**	**0.00**	0.00	0.03	0.00	0.16	0.01	0.1
* Light rail units per 1000 persons	units/1000 persons	0.00	0.15	**0.00**	**0.04**	0.01	0.00	0.03	0.05	0.02	0.0
* Metro units per 1000 persons	units/1000 persons	0.00	0.00	**0.00**	**0.02**	0.10	0.00	0.09	0.23	0.17	0.2
* Suburban rail units per 1000 persons	units/1000 persons	0.03	0.11	**0.10**	**0.23**	0.04	0.25	0.03	0.30	0.05	0.2
* Ferry units per 1000 persons	units/1000 persons	0.00	0.00	**0.00**	**0.01**	0.00	0.00	0.00	0.00	0.00	0.0
Total public transport vehicle kilometres of service per capita	v.km/person	90.7	60.7	**79.0**	**88.6**	39.2	58.9	52.1	107.5	134.5	80.7
* Bus vehicle kilometres per capita	v.km/person	86.5	25.3	**62.9**	**68.1**	19.5	29.1	38.4	42.7	74.3	36.7
* Minibus vehicle kilometres per capita	v.km/person	0.0	0.0	**0.0**	**0.0**	6.0	0.0	0.0	0.0	28.4	2.9
* Tram wagon kilometres per capita	v.km/person	0.0	0.0	**0.0**	**0.0**	0.0	1.5	0.4	7.3	0.4	3.8
* Light rail wagon kilometres per capita	v.km/person	0.0	7.5	**0.0**	**2.7**	1.1	0.0	2.4	3.4	1.8	2.3
* Metro wagon kilometres per capita	v.km/person	0.0	0.0	**0.0**	**4.3**	9.9	0.0	9.7	21.1	20.4	14.9
* Suburban rail wagon kilometres per capita	v.km/person	4.2	27.9	**16.1**	**13.4**	2.7	28.1	1.2	32.9	9.0	20.0
* Ferry vessel kilometres per capita	v.km/person	0.0	0.0	0.0	**0.1**	0.0	0.2	0.0	0.1	0.2	0.1
Total public transport seat kilometres of service per capita	seat km/person	4,963	3,957	**4,546**	**5,720**	1,874	4,077	2,368	6,126	7,267	4,486
* Bus seat kilometres per capita	seat km/person	4,323	840	**3,092**	**3,280**	789	1,265	1,522	1,944	5,236	1,705
* Minibus seat kilometres per capita	seat km/person	0	0	**0**	**0**	66	0	0	0	455	38
* Tram seat kilometres per capita	seat km/person	0	0	**0**	**0**	1	77	20	352	20	183
* Light rail seat kilometres per capita	seat km/person	0	455	**0**	**183**	68	2	163	204	47	138
* Metro seat kilometres per capita	seat km/person	0	0	**0**	**201**	588	2	464	1,025	947	746
* Suburban rail seat kilometres per capita	seat km/person	640	2,662	**1,453**	**2,037**	349	2,682	194	2,575	466	1,649
* Ferry seat kilometres per capita	seat km/person	0	0	**0**	**19**	13	49	5	27	96	26
Overall average speed of public transport	km/h	34.0	32.1	**42.2**	**39.2**	27.3	33.0	25.7	29.8	26.3	28.8
* Average speed of buses	km/h	31.2	26.1	**33.4**	**30.3**	19.9	23.4	22.4	21.9	19.4	21.5
* Average speed of minibuses	km/h	-	-	**-**	**-**	36.4	-	-	-	20.8	36.4
* Average speed of trams	km/h	-	-	**-**	**-**	5.2	16.0	14.0	16.9	11.1	15.4
* Average speed of light rail	km/h	-	17.9	**-**	**23.2**	26.0	18.0	34.8	25.9	22.6	26.1
* Average speed of metro	km/h	-	-	**-**	**34.0**	38.9	21.0	36.4	33.5	46.3	35.7
* Average speed of suburban rail	km/h	90.4	50.6	**89.6**	**80.5**	57.3	47.6	44.7	52.1	50.8	51.7
* Average speed of ferries	km/h	-	-	**-**	**13.5**	19.3	14.7	13.5	16.2	22.4	17.5

3.2.1. Public Transport Line Length per Person

This item is the per capita total length of all public transport lines. Table 5 shows that these ten Swedish cities have a very high per capita provision of public transport lines (8,410 m/1000 persons), which is by far the highest on average of all cities in the global sample. They have a 2.6 times higher line length per person than the European cities, the next highest in the sample. However, it is the smaller Swedish cities that are contributing strongly to this picture with virtually double the line length person of the larger Swedish cities. Freiburg has a similar public transport line length per person as the larger Swedish cities in Table 5. Umeå seems to have an extraordinary line length of public transport services (dominated by extensive regional buses - the data were derived and checked in detail by local sources).

This high line length suggests that Swedish urban regions make a serious effort to provide their populations with some form of public transport service, regardless of the low density of the regions, which seems to be rather unique. Mostly when populations are very thinly spread, the public transport lines are commensurately very limited. But this item does not give an indication of how well-serviced the lines are. A line providing an hourly service is not of great utility compared to a line with a 10-minute service. A more detailed analysis would be required to measure the effectiveness of this high public transport line length per person.

3.2.2. Reserved Public Transport Route Length per 1000 Persons

A more revealing item is the extent of reserved public transport routes. This is a route that is fully protected from general traffic and therefore not subject to hold-ups due to congestion. It consists mainly of rail lines, some parts of tram/Light Rail Transit (LRT) systems, and of course busways. Table 5 shows the data by mode in each city. The magnitude of this variable is one measure of the likely quality of public transport services because such routes offer speedier travel and more reliable timetables, and the services operating on them often can compete with the speed of cars, which are frequently stuck in parallel traffic jams.

Table 5 suggests that Swedish cities are well-endowed with reserved public transport routes, exceeding by a significant margin even that of other European cities, including Freiburg. The larger Swedish cities are more in line with Europe on this item, but the smaller cities are significantly higher. This is mainly achieved by rail systems and much less so by bus lanes, except in Göteborg, where bus lanes are more common and represent a higher proportion of the reserved routes than in the other Swedish cities, especially the smaller cities where bus lanes are rare.

Figure 6 provides an overview of these data showing that Umeå and Jönköping have the highest provision, while Malmö has the least. It shows the lower density Swedish cities in a much better light than the low density American, Australian, and Canadian cities. Asian cities are also less well-endowed with reserved routes on a per capita basis, but this is partially explained by their high densities.

Note that it was extremely difficult to assemble data on the bus lane lengths in Sweden (and even sometimes the rail lengths). Each municipality controls bus lanes and there are further bus lanes provided nationally on larger roads. There is no single repository of this information. The data reported here represent a unique compilation in Sweden as it was collected carefully from 59 Swedish municipalities and for bus lanes on national roads from the national level.

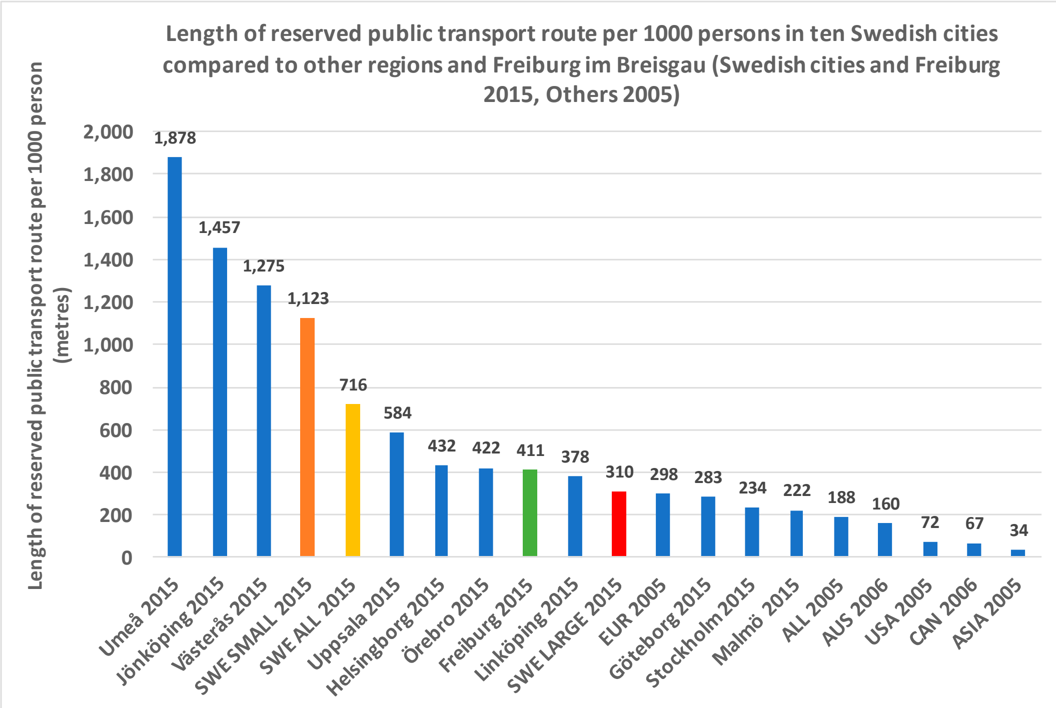

Figure 6. Reserved public transport route per person in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

3.2.3. Public Transport Vehicle Fleet per Person

This variable represents the number of public transport vehicles that are available for service per 1000 persons in the cities. A bus is counted as one vehicle, whereas wagons rather than train sets are used for rail modes. Table 5 shows that the Swedish cities have fewer vehicles than the European and Asian cities (1.23/1000 cf. 1.51 and 1.50 respectively) and the vehicles are dominated, unsurprisingly by buses, though the larger cities have more rail vehicles. The Swedish cities do generally have more public transport vehicles available than in American, Australian and Canadian cities. The larger Swedish cities have more public transport vehicles per person than the smaller ones (1.37 cf. 1.08/1000) and the range varies from a low in Västerås of 0.70/1000 to 2.31/1000 in Helsingborg.

3.2.4. Public Transport Vehicle Kilometres (VKT) of Service per Person

One measure of public transport service levels is the number of vehicle kilometres per person operated by each mode, where rail vehicle kilometres are wagon kilometres. This factor again shows Swedish cities (88.6 km/person) to be significantly lower than the service provided in European and Asian cities (18% and 34% less respectively) but with the larger cities having much more service than the smaller (98.2 cf. 79.0 km/person). However, the Swedish cities do provide more service by this measure than in Freiburg (60.7 km/person) and more than the American, Australian and Canadian cities, which average only 50.0 km/person. Overall, it appears that the large line length in Swedish cities is reasonably well serviced, but not as well as in other European cities.

3.2.5. Public Transport Seat Kilometres (SKT) of Service per Person

Seat kilometres of public transport service per person represents a better measure of the extent and capacity of public transport services by incorporating the size of each vehicle as specified by seat capacity. Swedish cities again distinguish themselves well (Table 5). Their average level of 5720 seat kilometres per person for all modes combined is 7% below the average European level of 6126 km but is much larger than in Australia, the USA, or Canada. The Asian cities with their extensive metro systems are the highest service providers. Swedish cities also provide much higher SKT per person than in Freiburg (only 3957/person). Again, the smaller cities are significantly below the larger Swedish cities on this factor (4546 cf. 6895/person), but are still more than in Freiburg. Rail overall is much more important in public transport service in the larger Swedish cities.

These patterns suggest that the inherent disadvantage for sustainable transport of lower density cities in Sweden is at least partially overcome or offset by a comparatively high commitment to providing public transport services, a quite unusual combination, given that it is harder for public transport systems to attract passengers in lower density settings (Figure 7). In other words, the public transport service provided appears to be limited in its usage by too low densities (see later data on public transport usage).

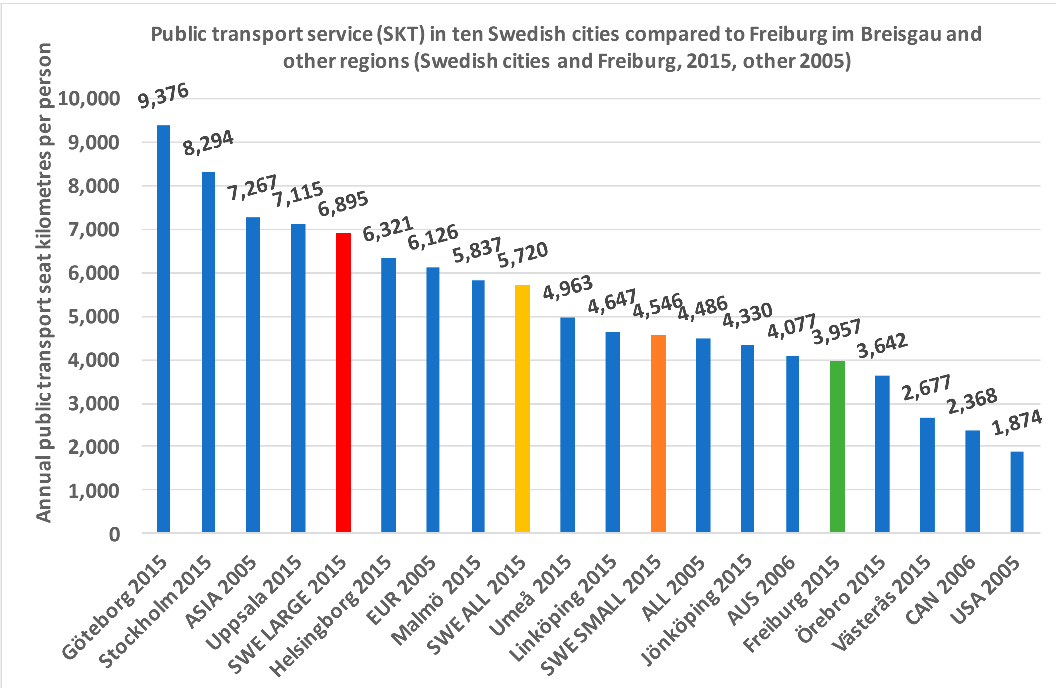

Figure 7. Annual public transport seat kilometres of service per person in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

3.2.6. Average Public Transport System Speed

Speed-competitiveness in public transport is an important factor in helping to determine public transport use. The relative speed between public and private transport is particularly important (Newman and Kenworthy, 1999b). First, the average speeds amongst the public transport systems must be compared. Table 5 contains the speed data by mode and reveals that Swedish cities, overall, have relatively healthy average speeds for their public transport systems (the overall speed of the entire public transport system is weighted by the passenger hours for each mode). At 39.2 km/h, the ten Swedish cities have the highest public transport speeds of all cities, ahead of the next highest, the Australian cities, which average 33.0 km/h. The global average here was only 25.1 km/h and the European cities are a little better at 29.8 km/h. In this case, the smaller cities have slightly better overall average speed (42.2 km/h) than the larger cities (36.3 km/h). Uppsala has exceptional performance here with 102 km/h average speed for rail and a world high 46.0 km/h for buses giving an unparalleled system average speed of 64.4 km/h.

The Swedish cities achieve these high average speeds predominantly because of the high average speed (80.5 km/h) of the suburban/regional rail trains that operate over long distances, with significantly higher speeds than the suburban rail systems in other cities (51.7 km/h for the global average), which mostly operate over smaller distances. However, the Swedish urban bus systems also have the highest speed in the global sample, averaging 30.3 km/h, which is very competitive when compared to the bus system average speeds in all other groups of cities (the range was 23.6 km/h in Helsingborg and 46.0 km/h in Uppsala, though most were between around 28 km/h to 34 km/h). The global average speed for urban buses was only 21.5 km/h, and the European cities only 21.9 km/h, so Swedish urban bus services clearly operate at healthy speeds compared to other cities, especially the regional buses.

3.3. Public Transport Use

Table 6 shows public transport use in the cities using four indicators, annual boardings per person, which does not account for travel distances, annual passenger kilometres per person, which builds in the travel distances by passengers and is an indicator that can be compared to car passenger kilometres and two measures of occupancy of public transport vehicles - vehicle occupancy in terms of the average number of passengers per vehicle and seat occupancy which measures the average percentage of seats that are occupied.

3.3.1. Annual Public Transport Boardings per Person

The annual public transport boardings per person is one measure of the usage of public transport. Table 6 shows that on average, these five Swedish cities are very moderate in their use of public transport (128 boardings/person) though the larger cities, especially Stockholm, reach significantly higher levels of use (average 195 boardings/person), while the smaller cities achieve less than 1/3 the level of usage of the larger cities (only 61/person). This average for the ten cities is considerably higher, however, than the average usage of public transport in American (67), Australian (96), but is below the Canadian cities (151), which are on average denser. When compared to Freiburg (192 boardings/person), the larger Swedish cities are roughly equivalent, though the smaller cities are 33% less.

On the other hand, European cities in 2005 had 386 boardings/person (or virtually double the larger Swedish level and three times the overall Swedish level) and the global sample average was 254/person. The lower density of these Swedish cities and their generous road and freeway networks probably explain at least some of this lower public transport usage, along with their lower levels of rail service.

The Swedish cities had 83 bus boardings per person while the European cities had 145 (again larger cities are better with 114 and the smaller cities are less than half that with 52). Notwithstanding this difference in bus use in favour of European cities, the big distinguishing factor was the use of urban rail modes (trams, light rail, metro, and suburban rail). While European cities had 240 annual boardings on all rail modes, Swedish cities had only 44 or less than one-fifth as much.

This is highlighted in the case of Freiburg which has 144 (75%) out of its 192 boardings/person on rail. Swedish cities overall have only 34% of their boardings/person on rail so are largely bus-based cities (except for Stockholm and Göteborg). Stockholm, where rail is much more abundant, had 214 rail boardings per person, even though, overall, it is a comparatively low density region (24 persons/ha). This overall lower orientation to rail use does generally put Swedish cities at something of a disadvantage compared to cities with strong rail systems (Kenworthy, 2008).

Stockholm has, however, developed at focused and significantly higher densities and mixed land uses around many rail stations on the tunnelbana network throughout the region, where such higher densities (and mixed land uses) support the use of rail (Cervero, 1995, 1998). Stockholm's relatively new and expanding tram/light rail lines are also in areas of high density. The very low per capita use of rail in the smaller cities and Malmö is noteworthy, being significantly lower than even the average in the ten US cities in this sample (Figure 8).

Table 6. Public transport use in Swedish and international cities.

Variable	Units	Stockholm	Malmö	Göteborg	Linköping	Helsingborg	SWE LARGE	Uppsala	Västerås	Örebro	Jönköping
Total public transport boardings per capita	boardings/person	359	111	285	64	158	195	108	53	39	60
* Bus boardings per capita	boardings/person	143	91	146	44	145	114	85	45	37	52
* Minibus boardings per capita	boardings/person	0	0	0	0	0	0	0	0	0	0
* Tram boardings per capita	boardings/person	0	0	0	0	0	0	0	0	0	0
* Light rail boardings per capita	boardings/person	22	0	115	12	0	30	0	0	0	0
* Metro boardings per capita	boardings/person	151	0	0	0	0	30	0	0	0	0
* Suburban rail boardings per capita	boardings/person	40	20	18	8	13	20	23	8	2	8
* Ferry boardings per capita	boardings/person	2	0	6	0	0	2	0	0	0	0
* Rail boardings per capita	boardings/person	214	20	133	20	13	80	23	8	2	8
Total public transport passenger kilometres per capita	p.km/person	2,579	1,451	2,463	877	1,590	1,792	1,765	884	367	809
* Bus passenger kilometres per capita	p.km/person	822	521	1,281	534	970	826	847	543	318	486
* Minibus passenger kilometres per capita	p.km/person	0	0	0	0	0	0	0	0	0	0
* Tram passenger kilometres per capita	p.km/person	0	0	0	0	0	0	0	0	0	0
* Light rail passenger kilometres per capita	p.km/person	130	0	518	38	0	137	0	0	0	0
* Metro passenger kilometres per capita	p.km/person	848	0	0	0	0	170	0	0	0	0
* Suburban rail passenger kilometres per capita	p.km/person	760	930	645	305	620	652	918	341	49	323
* Ferry passenger kilometres per capita	p.km/person	18	0	19	0	0	7	0	0	0	0
Overall public transport vehicle occupancy	persons/unit	22.6	22.0	16.3	14.4	16.1	18.3	15.2	16.2	7.2	9.9
* Bus vehicle occupancy	persons/unit	14.6	10.3	10.7	10.6	10.9	11.4	10.0	12.2	6.8	9.3
* Minibus vehicle occupancy	persons/unit	-	-	-	-	-	-	-	-	-	-
* Tram wagon occupancy	persons/unit	-	-	-	-	-	-	-	-	-	-
* Light rail wagon occupancy	persons/unit	20.0	-	30.0	13.8	-	21.3	-	-	-	-
* Metro wagon occupancy	persons/unit	19.7	-	-	-	-	19.7	-	-	-	-
* Suburban rail wagon occupancy	persons/unit	97.8	60.4	50.4	40.5	60.0	61.8	28.9	34.5	10.9	10.8
* Ferry vessel occupancy	persons/unit	33.5	-	28.1	1.8	-	21.1	-	-	-	-
Overall public transport seat occupancy	%	31%	25%	26%	19%	25%	25%	25%	33%	10%	19%
* Bus seat occupancy	%	29%	23%	23%	19%	25%	24%	20%	27%	13%	20%
* Minibus seat occupancy	%	-	-	-	-	-	-	-	-	-	-
* Tram seat occupancy	%	-	-	-	-	-	-	-	-	-	-
* Light rail seat occupancy	%	26%	-	45%	21%	-	31%	-	-	-	-
* Metro seat occupancy	%	42%	-	-	-	-	42%	-	-	-	-
* Suburban rail seat occupancy	%	26%	26%	25%	18%	26%	24%	33%	51%	4%	17%
* Ferry seat occupancy	%	21%	-	19%	10%	-	16%	-	-	-	-

Table 6 cont.

Variable	Units	Umeå	Freiburg	SWE SMALL	SWE ALL	USA	AUS	CAN	EUR	ASIA	ALL
Total public transport boardings per capita	boardings/person	45	192	61	128	67	96	151	386	450	254
* Bus boardings per capita	boardings/person	43	48	52	83	38	44	97	145	229	107
* Minibus boardings per capita	boardings/person	0	0	0	0	1	0	0	0	48	2
* Tram boardings per capita	boardings/person	0	0	0	0	0	10	4	59	6	31
* Light rail boardings per capita	boardings/person	0	98	0	15	3	0	12	24	13	15
* Metro boardings per capita	boardings/person	0	0	0	15	22	0	35	99	120	64
* Suburban rail boardings per capita	boardings/person	2	46	9	14	3	40	3	58	30	35
* Ferry boardings per capita	boardings/person	0	0	0	1	0	2	0	1	4	1
* Rail boardings per capita	boardings/person	2	144	9	44	28	50	53	240	169	144
Total public transport passenger kilometres per capita	p.km/person	1,117	1,375	988	1,390	571	1,075	1,031	2,234	3,786	1,644
* Bus passenger kilometres per capita	p.km/person	977	274	634	730	214	349	620	633	1,916	564
* Minibus passenger kilometres per capita	p.km/person	0	0	0	0	14	0	0	0	139	10
* Tram passenger kilometres per capita	p.km/person	0	0	0	0	0	36	22	131	10	71
* Light rail passenger kilometres per capita	p.km/person	0	293	0	69	25	1	101	101	47	70
* Metro passenger kilometres per capita	p.km/person	0	0	0	85	216	0	211	575	1,154	415
* Suburban rail passenger kilometres per capita	p.km/person	140	809	354	503	100	676	74	790	492	509
* Ferry passenger kilometres per capita	p.km/person	0	0	0	4	2	13	3	4	27	5
Overall public transport vehicle occupancy	persons/unit	12.3	22.6	12.1	15.2	13.1	18.1	19.8	21.0	28.1	19.0
* Bus vehicle occupancy	persons/unit	11.3	10.8	9.9	10.7	10.9	11.7	16.1	15.0	25.3	14.3
* Minibus vehicle occupancy	persons/unit	-	-	-	-	2.2	-	-	-	4.9	2.4
* Tram wagon occupancy	persons/unit	-	-	-	-	19.6	23.3	51.6	22.1	22.6	26.5
* Light rail wagon occupancy	persons/unit	-	39.0	-	21.3	24.9	18.2	28.7	27.9	28.2	24.7
* Metro wagon occupancy	persons/unit	-	-	-	19.7	22.6	30.3	21.6	26.3	56.6	27.4
* Suburban rail wagon occupancy	persons/unit	33.1	29.0	23.6	42.7	38.5	24.7	51.8	30.8	55.0	34.1
* Ferry vessel occupancy	persons/unit	-	-	-	21.1	183.7	52.4	229.7	38.6	150.6	91.0
Overall public transport seat occupancy	%	23%	35%	22%	24%	29%	27%	44%	39%	52%	37%
* Bus seat occupancy	%	23%	33%	21%	22%	27%	27%	41%	35%	36%	33%
* Minibus seat occupancy	%	-	-	-	-	20%	-	-	-	31%	21%
* Tram seat occupancy	%	-	-	-	-	63%	47%	105%	45%	51%	55%
* Light rail seat occupancy	%	-	64%	-	31%	39%	25%	39%	48%	97%	44%
* Metro seat occupancy	%	-	-	-	42%	39%	23%	48%	60%	122%	57%
* Suburban rail seat occupancy	%	22%	30%	25%	25%	30%	28%	30%	35%	106%	35%
* Ferry seat occupancy	%	-	-	-	16%	13%	25%	57%	21%	28%	22%

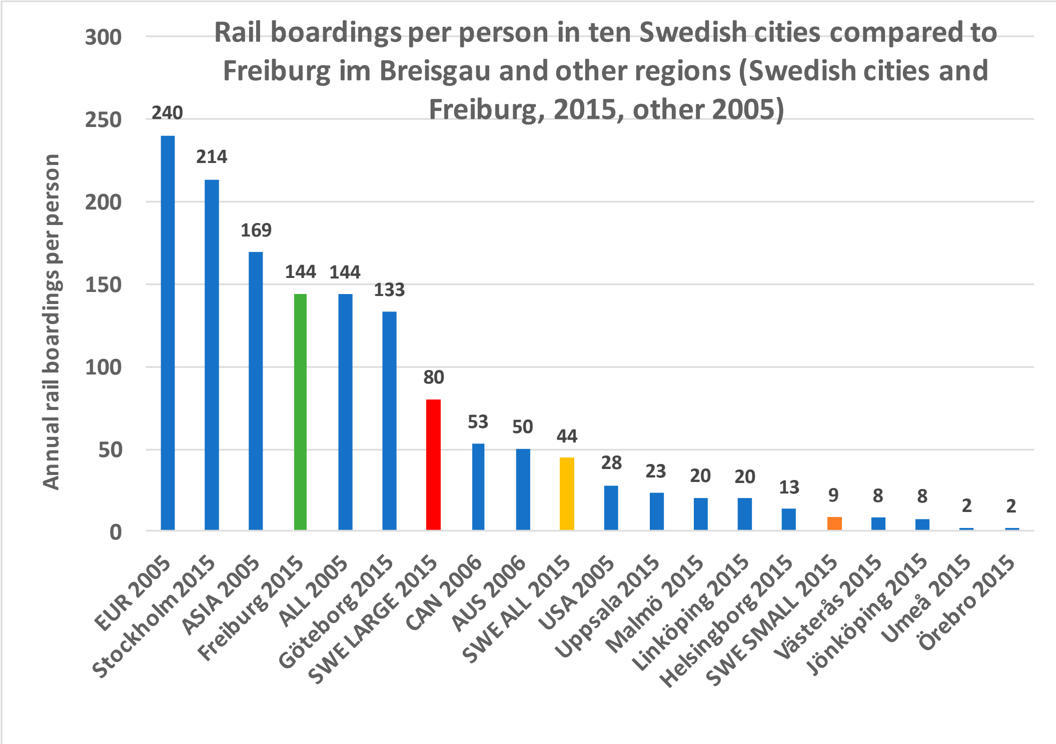

Figure 8. Annual rail boardings (tram, light rail, metro, and suburban rail) per person in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

3.3.2. Public Transport Passenger Kilometres per Person

When public transport passenger kilometres per person are examined, a slightly different picture emerges of public transport in Swedish cities. In this, Swedish cities have comparatively healthier levels of public transport use, possibly because of their lower densities, requiring longer trips on public transport. So, whereas boardings averaged only 128/person and were 67% lower than the European cities, passenger kilometres/person averaged 1390 in the Swedish cities compared to 2234 in European cities or only 38% less (Figure 9). The situation, as usual, is better in the larger Swedish cities with 1792 passenger km/person (only 20% lower than the European average), while the smaller cities have only 988/person. Interestingly, passenger km/person are only 1375 in Freiburg, a city with significantly more boardings, but with a more compact urban form that yields shorter travel distances.

Table 6 also shows that while rail only constituted 34% of total boardings/person in the ten Swedish cities, rail accounts for 47% of their total average public transport passenger kilometres/person Unsurprisingly, rail is used to travel longer distances by public transport in Swedish cities. Finally, the data also show that the Swedish cities greatly exceed the public transport passenger kilometres/person in the American, Australian, and Canadian cities. And continuing the pattern, this picture is even better in the larger Swedish cities and worse in the smaller cities. Clearly, and despite comparatively low densities, Swedish cities offer public transport systems that account for a lot more travel than in auto-oriented cities with the larger Swedish cities being only 20% less than in a large sample of other European cities.

One of the significant concerns is the poor showing of rail in the smaller Swedish cities, with only 36% of their total public transport passenger kilometres by rail, while in the larger cities rail passenger km constitutes 54%. Figure 9 displays these results.

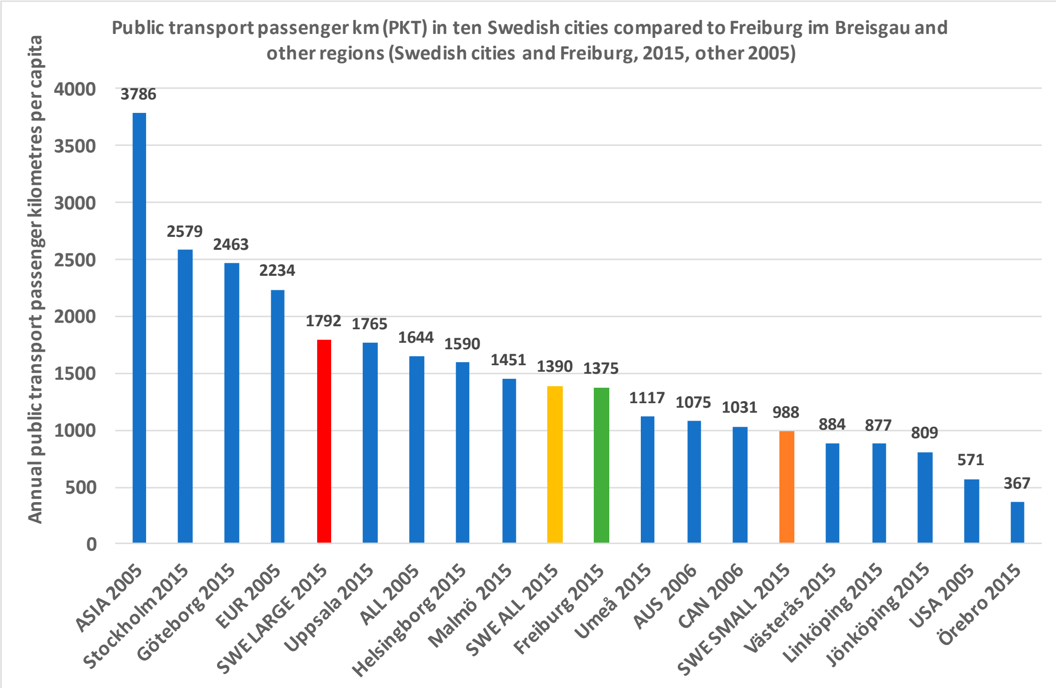

Figure 9. Annual public transport passenger kilometres per person in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

3.3.3. Public Transport Vehicle Occupancy

It is important to understand the intensity of public transport usage in relation to the service provided. One way of doing this is to examine the average vehicle occupancy. Table 6 shows that vehicle occupancy is low in Swedish cities. Overall, there are only 15.2 passengers per vehicle in the ten Swedish cities, with 18.3 in the larger and only 12.1 in the smaller. By contrast, Swedish cities are the lowest in this factor except in the American cities which average only 13.1 passengers per vehicle (Australian cities are 18.1, Canadian 19.8, European cities 21.0 and Asian 28.1 and Freiburg has 22.6 passengers per vehicle). Only Stockholm and Malmö have relatively good vehicle occupancy at 22.6 and 22.0 respectively. In all cases rail vehicle occupancies are higher than buses.

This probably shows that while Swedish cities are relatively well served by public transport, especially considering their lower densities, it is these lower densities and hence smaller catchment numbers that help to keep overall vehicle occupancy suppressed. This is not to say that on many services in the peak hours services are not crowded. On the contrary many services at critical times and to particular destinations like central cities or universities, vehicles, especially buses, can be very crowded. But as an overall system, especially in off-peak times there is a lot of spare capacity, more so than in other cities. Making use of this spare capacity is a challenge, especially for urban planning to ensure there is sufficient density and mixed uses around stops and in centres so people can make better use of the services that are provided and that back-loading can be achieved in the peak period so vehicles are not running full in the peak direction and empty in the reverse direcion.

3.3.4. Public Transport Seat Occupancy

Seat occupancy expressed as a percentage of available seats provides another insight into the intensity of use of public transport. Like vehicle occupancy, naturally Swedish cities are poorer performing in this factor too with on average over 24% of available seats being occupied in the ten cities (25% in the larger cities and 22% in the smaller cities). By contrast Freiburg has 35% seat occupancy and European cities 39%. In this variable even the US cities are better with 29% seat occupancy and Australian cities 27%, such that the Swedish cities are the lowest across the entire study. Rail seat occupancy is lower in Swedish cities than it is right across the world, with suburban rail in the ten Swedish cities averaging 25% and buses 22%. Freiburg's suburban rail seat occupancy is 30%. Low seat occupancy of course has its upsides, implying that the chances of getting a seat are overall higher, which in turn provides greater passenger comfort, which can help to retain passengers.

3.4. Car and Motorcycle Use and Modal Split

Table 7 provides the annual per capita car and motorcycle use in the cities (vehicle kilometres travelled or VKT and passenger kilometres travelled or PKT) and the modal split for all daily trips by all purposes. Table 8 presents some private-public transport balance indicators (Section 3.5).

It is important to understand the prominence of different transport modes and this is usually best expressed by modal split data from travel surveys (Table 7). The latest of these surveys were gathered from each Swedish city and the percentage of daily trips by non-motorised modes (walking and cycling), public transport, and private transport were collected. Taxis were classed as private transport.

3.4.1. Non-Motorised Modes Modal Share

Despite having cold weather for much of the year, the Swedish cities acquit themselves well in walking and cycling, averaging 30.0% of all daily trips by these modes. The best performing cities were Uppsala (46.8%) and Örebro (34.0%), which probably benefit from their small size and shorter travel distances, and relatively strong orientation to bikes (Uppsala also has a significant student population). In this case, the smaller cities performed better, which might be expected (32.8% of daily trips) compared to 27.1% in the larger cities. Jönköping and Stockholm were the lowest of the Swedish cities on this factor with 21.2% and 22.1% respectively, though Stockholm is by far the best for public transport (see next section). The Swedish cities were lower than the other European cities for walking and cycling, which were the best globally at 34.5%, but the smaller cities were similar and Uppsala exceeded the European average by a significant margin. As shown in Figure 10, compared to every other group, the Swedish cities were the next best for walking and cycling and continue to improve in this factor in selected cities (e.g. Löfgren, 2015)

Freiburg stands out here with 63% of daily trips by foot and bicycle, explained most likely by the relatively dense and mixed use urban fabric, the very significant student population as evidenced by the overwhelming number of bikes around the university campus and very good walking and cycling infrastructure. However, Swedish cities positively distinguish themselves much more in this factor than they do in public transport use.

3.4.2. Public Transport Modal Share

Public transport's share of daily trips in Swedish cities (14.3%) is much better on average than in the North American and Australian cities, but is much less than the European figure of 22.4% and less than 1/3 of the two Asian cities (46%). The larger cities are more than double the smaller cities on this factor (19.3% cf. 9.4%). The range on the public transport mode share within these ten Swedish cities was also large with Västerås having only 6.7% (just a bit more than in American cities), while Stockholm reaches 31.6%, much higher than the European average (22.4%) and the only Swedish city to achieve this. The Swedish cities were less than the global average of 16.8% and Freiburg (16.0%). Given their disadvantages of having a low density, high road and freeway provision, and a much lesser role for rail systems, Swedish cities achieve a reasonable public transport mode share (Figure 11).

Table 7. Car and motorcycle use and modal split in Swedish and international cities.

Variable	Units	Stockholm	Malmö	Göteborg	Linköping	Helsingborg	SWE LARGE	Uppsala	Västerås	Örebro	Jönköping
Passenger car vehicle kilometres per capita	v.km/person	5,100	5,343	5,068	5,180	5,279	**5,194**	4,790	5,421	5,258	5,986
Motorcycle vehicle kilometres per capita	v.km/person	54	58	77	55	63	**61**	51	53	61	78
Total private vehicle kilometres per person	v.km/person	5,155	5,401	5,144	5,235	5,342	**5,255**	4,841	5,474	5,319	6,064
Passenger car passenger kilometres per capita	p.km/person	6,630	6,839	6,689	6,734	6,862	**6,751**	6,131	7,048	7,361	7,902
Motor cycle passenger kilometres per capita	p.km/person	57	60	80	57	66	**64**	53	55	64	81
Total private passenger kilometres per capita	p.km/person	6,687	6,899	6,769	6,791	6,928	**6,815**	6,184	7,102	7,425	7,983
Percentage of total daily trip by non motorised modes	%	22.1%	31.2%	26.3%	33.0%	23.0%	**27.1%**	46.8%	32.7%	34.0%	21.2%
Percentage of total daily trip by motorised public modes	%	31.6%	17.6%	20.0%	9.7%	18.0%	**19.4%**	14.1%	6.7%	9.0%	9.6%
Percentage of total daily trip by motorised private modes	%	46.3%	51.1%	53.7%	57.2%	59.0%	**53.5%**	39.0%	60.6%	57.0%	69.1%

Table 7 cont.

Variable	Units	Umeå	Freiburg	SWE SMALL	SWE ALL	USA	AUS	CAN	EUR	ASIA	ALL
Passenger car vehicle kilometres per capita	v.km/person	5,022	5,267	**5,295**	**5,245**	13,100	8,698	6,519	4,937	1,333	7,312
Motorcycle vehicle kilometres per capita	v.km/person	74	89	**63**	**62**	76	72	53	123	242	104
Total private vehicle kilometres per person	v.km/person	5,096	5,356	**5,359**	**5,307**	13,176	8,770	6,572	5,060	1,575	7,416
Passenger car passenger kilometres per capita	p.km/person	6,680	6,899	**7,024**	**6,888**	18,703	12,447	8,495	6,817	1,975	10,234
Motor cycle passenger kilometres per capita	p.km/person	77	98	**66**	**65**	81	79	58	133	290	113
Total private passenger kilometres per capita	p.km/person	6,756	6,997	**7,090**	**6,952**	18,784	12,526	8,554	6,950	2,265	10,347
Percentage of total daily trip by non motorised modes	%	29.3%	63.0%	**32.8%**	**30.0%**	9.5%	14.2%	11.6%	34.5%	26.1%	23.2%
Percentage of total daily trip by motorised public modes	%	6.9%	16.0%	**9.3%**	**14.3%**	5.5%	7.5%	13.1%	22.4%	46.0%	16.8%
Percentage of total daily trip by motorised private modes	%	63.9%	21.0%	**57.9%**	**55.7%**	85.0%	78.3%	75.4%	43.1%	27.9%	59.9%

Table 8. Private–public transport balance indicators in Swedish and international cities.

Variable	Units	Stockholm	Malmö	Göteborg	Linköping	Helsingborg	SWE LARGE	Uppsala	Västerås	Örebro	Jönköping
Proportion of total motorised passenger kilometres on public transport	%	27.8%	17.4%	26.7%	11.4%	18.7%	**20.4%**	22.2%	11.1%	4.7%	9.2%
Ratio of public versus private transport speeds	ratio	0.91	1.14	0.79	1.27	0.81	**0.98**	1.25	0.79	0.71	0.90
Ratio of segregated public transport infrastructure versus expressways	ratio	1.69	0.96	1.26	1.41	1.51	**1.36**	5.48	10.34	2.32	7.67

Table 8 cont.

Variable	Units	Umeå	Freiburg	SWE SMALL	SWE ALL	USA	AUS	CAN	EUR	ASIA	ALL
Proportion of total motorised passenger kilometres on public transport	%	14.2%	16.4%	**12.3%**	**16.3%**	3.2%	8.0%	11.3%	24.5%	62.9%	18.0%
Ratio of public versus private transport speeds	ratio	0.73	1.07	**0.88**	**0.93**	0.55	0.78	0.57	0.88	0.86	0.75
Ratio of segregated public transport infrastructure versus expressways	ratio	-	19.10	**6.45**	**3.26**	0.56	1.98	0.56	5.51	1.42	3.16

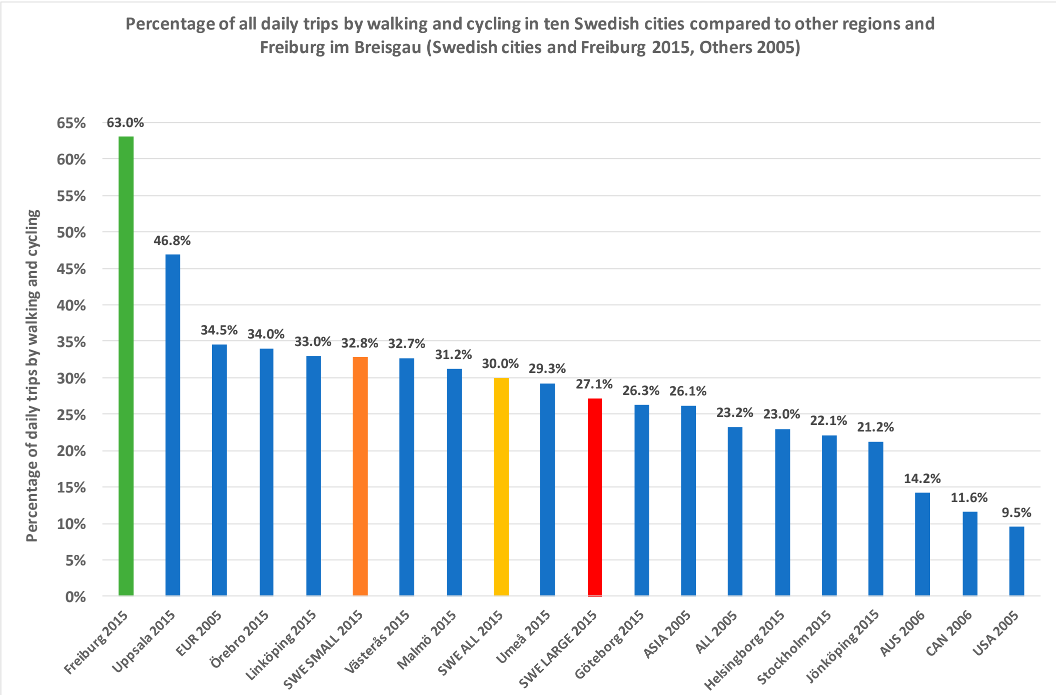

Figure 10. Percentage of daily trips by non-motorised modes in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

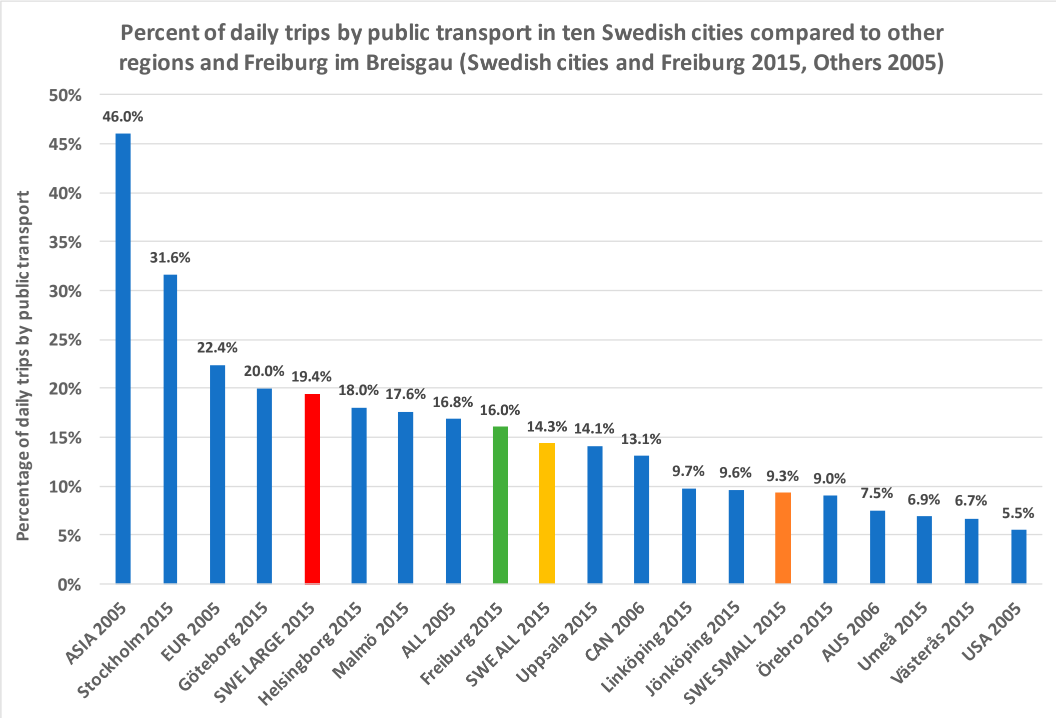

Figure 11. Percentage of daily trips by public transport in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

3.4.3. Modal Share by Private Transport Modes

This is the corollary of the previous two modal share variables. A bit over half of all daily trips (55.7%) in the ten Swedish cities are by private motorised modes. While this is not at the European level of only 43.1%, it is still an enviable modal split globally. American cities have 85% of all trips by private transport, Australian cities have 78%, Canadian have 75%, and the global average was 60% in 2005. Uppsala (39.0%) and Stockholm (46.3%) clearly have the lowest shares in private transport with a little less and a little more than the European level respectively, while Jönköping experiences 69.1% of daily trips by private modes. Malmö, in 2015, is split equally between the sustainable modes and private transport modes (51.1% private transport). Freiburg beats all the cities with only 21% of daily trips by private modes. Overall, the smaller Swedish cities have a little higher modal split (57.9%) to private transport than the larger cities (53.5%). While the trip making level and its split by private transport is important, the actual kilometres of driving by private transport is also critical to understand because it is driving that consumes energy, emits pollution, causes traffic accidents, and affects public spaces in a city.

3.4.4. Car Use per Person

Car use is effectively measured by two variables: vehicle kilometres of travel or VKT/person and passenger kilometres of travel or PKT/person. The first is a measure of how many kilometres of car travel there are per person (how far actual vehicles travel), while the latter measures the actual person travel in cars by considering the occupancy of cars. PKT is a factor that can then be compared to the equivalent for public transport (see Table 8 and discussion in later section).

Table 7 and Figure 12 show that the ten Swedish cities again revolve around a relatively tight mean for car VKT/person of 5245 with larger cities being 5194 and smaller cities 5295. Freiburg is virtually identical with 5267 car VKT/person, while the European cities overall were a fraction less (4937). The range is 4790 in Uppsala and 5986 in Jönköping, so reasonably tight across all cities. This car use result is comparatively low across the global sample, especially considering the relatively lower densities evident in Swedish cities.

A similar situation is evident with car PKT/person and due to the lower car occupancy in Sweden of 1.30 compared to 1.38 in European cities, car use per capita on this measure is essentially the same in Sweden as in other European cities (6888 in Swedish cities and 6817 in European cities) and virtually identical to car use in Freiburg (6899 car PKT/person). As a group, only the two Asian cities are significantly lower than any of the Swedish cities and the averages for the other groups of cities are all significantly higher than in any Swedish city. The next highest is the Canadian cities at 8495 passenger kilometres per person compared to Swedish cities with only 6888 (some 19% lower). Swedish car PKT/person ranges from a low of 6131 in Uppsala up to 7902 in Jönköping so the spread is still relatively tight (1771 PKT/person or 4.9 PKT/person/day maximum difference). These low results on car use for Swedish cities are discussed further.

3.4.5. Motorcycle Use per Person

Swedish cities are low in motorcycle use for both VKT and PKT/person. On average, they are the lowest of all groups of cities except Canadian cities which they exceed by a small amount. Motorcycle use in Swedish cities is about half what it is in other European cities and much lower than in Freiburg. Motorcycles are often seen as a way of countering cramped urban conditions and congestion which are definitely not characteristics of Swedish cities.

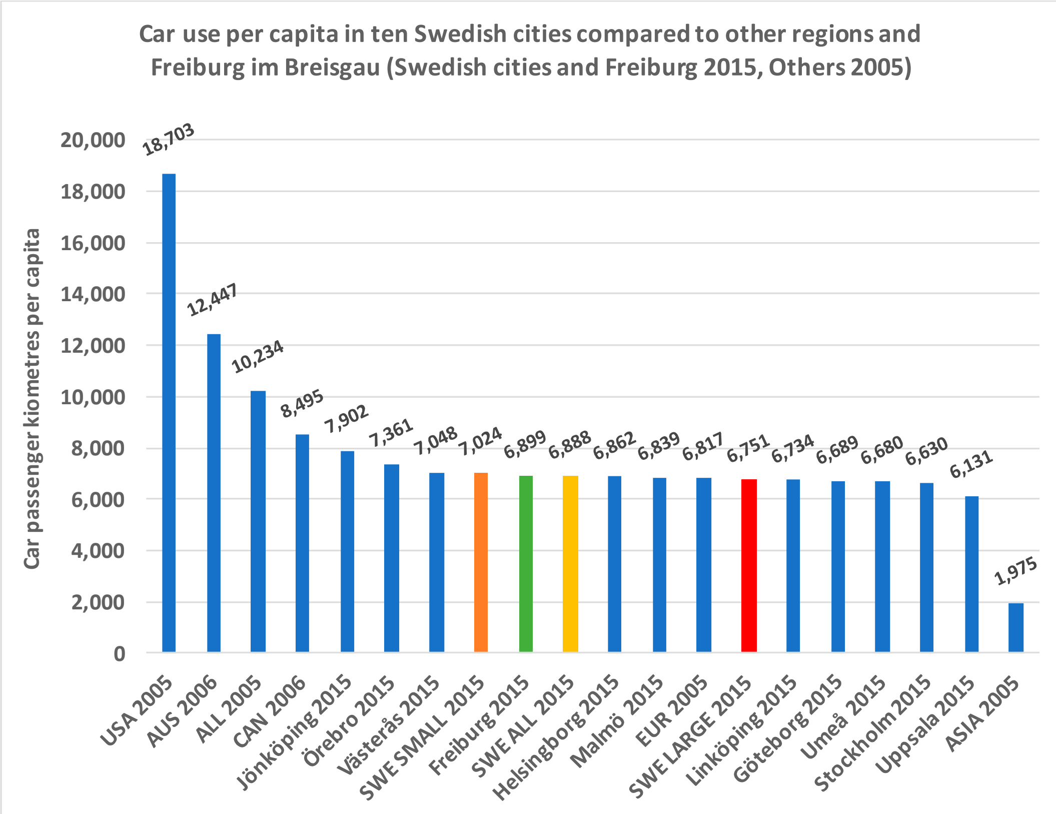

Figure 12. Annual car use per person (PKT) in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

3.5. Private–Public Transport Balance Indicators

Table 8, which was presented earlier alongside Table 7, shows three important indicators of the priority which public transport enjoys in cities.

3.5.1. Proportion of Total Motorised Passenger Kilometres on Public Transport

This indicator represents public transport's proportion of total car, motorcycle, and public transport passenger kilometres. Table 8 and Figure 13 show that Swedish cities average almost 16.3% in terms of their total motorised mobility by public transport, compared to 24.5% in other European cities, but a similar 16.4% in Freiburg. The smaller cities (12.3%) predictably fare worse than the larger (20.4%). The range within Sweden is significant from a low of 4.7% in Örebro to 27.8% in Stockholm, such that the role of public transport within total motorised travel demand is very different, but overall it represents less than 1/5 of all demand. Though this is less from a European perspective (1/4), it is much better than in the USA (3.2%), Australia (8.0%), or Canada (11.3%). Furthermore, Stockholm and Göteborg are higher than the European average with 27.8% and 26.7%, respectively. Again, Swedish cities acquit themselves relatively well in the big picture view of transport sustainability (at least in comparative terms at diminished densities), though much can still be improved. But no cities appear to have any foreseeable chance of reaching the heights of the two big and very dense Asian cities where public transport accounts for almost 63% of the total motorised mobility task.

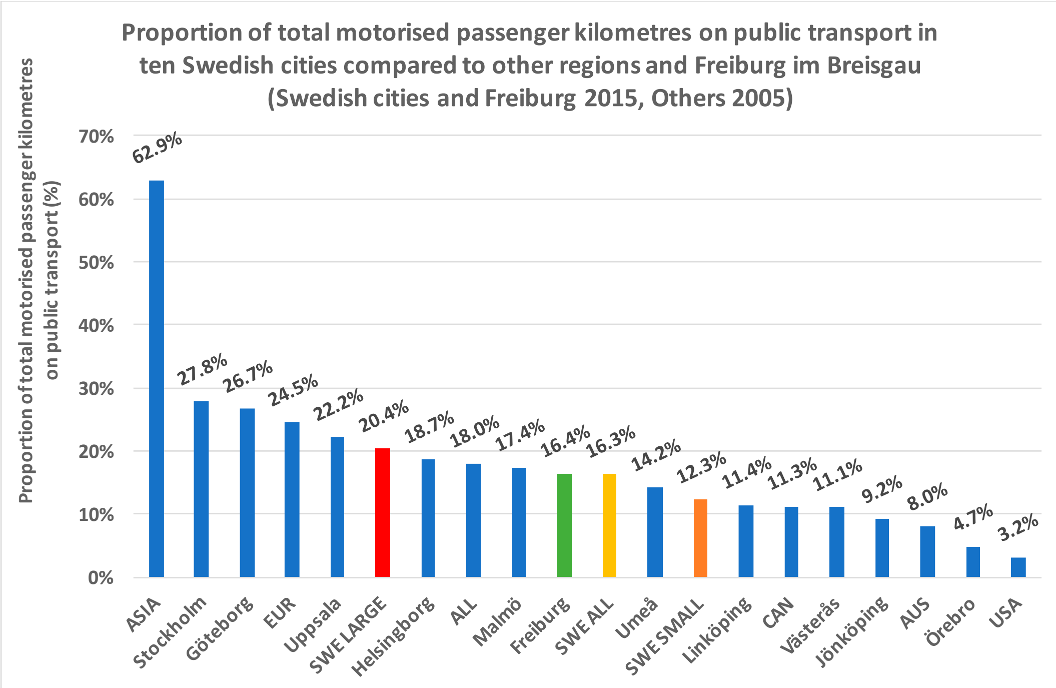

Figure 13. Proportion of total motorised passenger kilometres on public transport in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

3.5.2. Public versus Private Transport Average Speed

The relative speed between public and private transport (or general road traffic) is an important mode choice factor, since people generally prefer the fastest mode. However, it is possible that people do not always necessarily perceive the real speed of different modes correctly, especially if they are only familiar with one mode, the car, and have not tried public transport. Figure 14 shows that overall, public transport systems compete very well with cars in Swedish cities. The weighted data suggest a near parity situation, ranging from public transport being 27% faster in Linköping to it being only 71% as fast in Örebro. Compared to all groups of cities, including the European cities, Swedish cities do better on this item. European cities' public transport systems average at 88% as fast as cars and American cities are only 55%, such that their public transport systems do not compete well with cars in terms of speed. On the other hand, the Swedish cities average 93% as fast with the larger cities at 98% and the smaller cities at 88% the same as European cities generally.

3.5.3. Reserved Public Transport Route versus Freeways

One way of measuring the relative commitment in cities to cars versus public transport is through a comparison of their respective highest order, or premium transport infrastructure. For cars, this is freeways (Figure 3), and for public transport, it is reserved public transport routes, mostly rail lines (Figure 6). Table 8 and Figure 15 show the ratio of these two items. They reveal that the ten Swedish cities have 3.26 times more reserved public transport route than they do urban freeways. Although this suggests a greater priority to public transport, the value is low in this global sample and only better than the Canadian and American cities. Other European cities have 5.51 times more reserved public transport routes than freeways and the global sample has 3.16 times more. Although Swedish cities have comparatively good regional rail lines, this is unfortunately eclipsed by the extensive freeway systems (and a generally low level of bus lane provision).

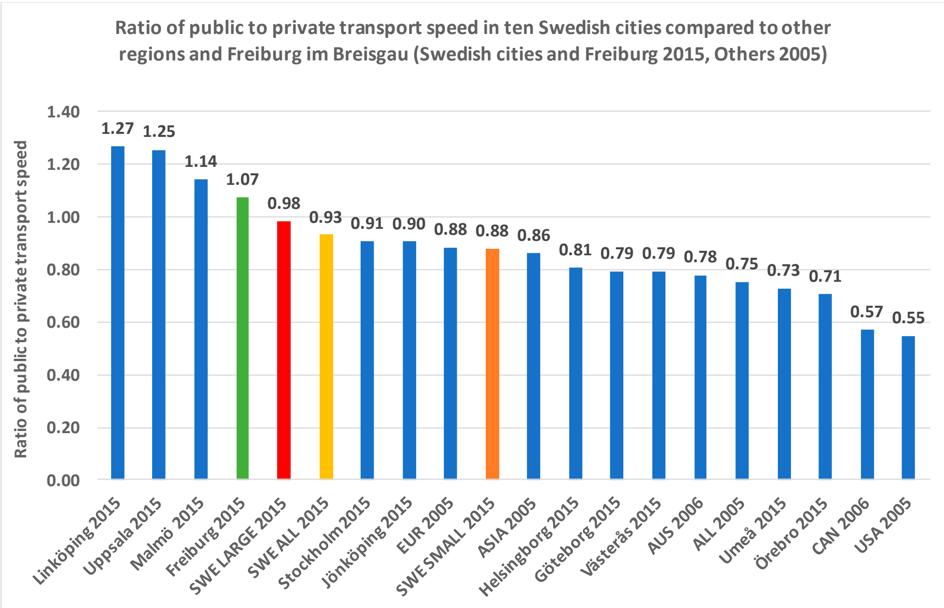

Figure 14. Relative speed of public transport versus general road traffic in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

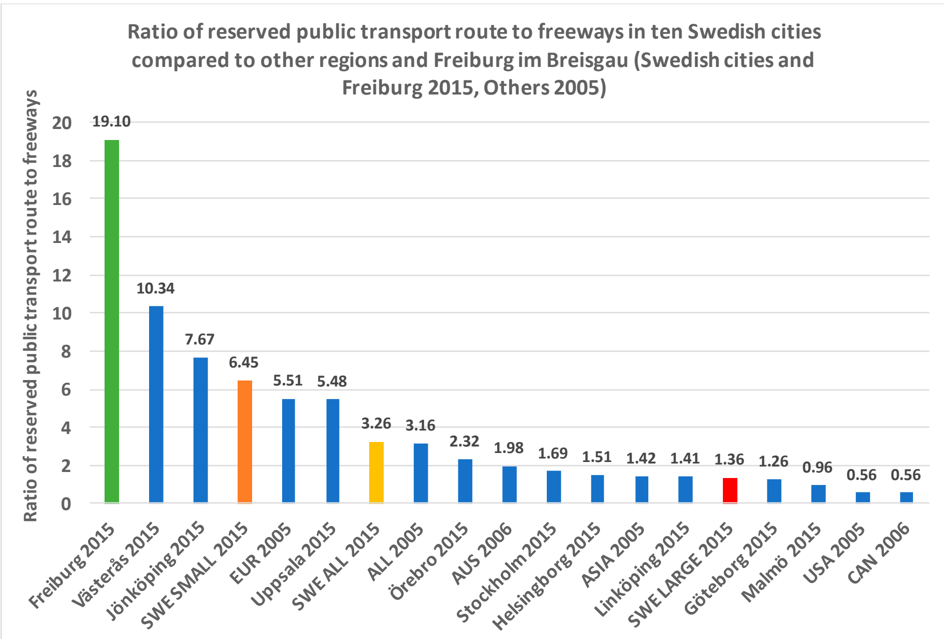

Figure 15. Ratio of reserved public transport route to freeways in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

The smaller cities also do much better on this factor than the larger cities (6.45 cf. only 1.36) with a very large range from 10.34 in Västerås to 0.96 in Malmö where freeways are more prominent than reserved public transport route. Freiburg has incomparably higher public transport reserved route compared to freeways at 19.10 times more!

3.6. Some Transport Outcomes

Private and public transport energy use, transport emissions, and transport fatalities are important impacts from urban transport and especially the degree of automobile dependence (Table 9).

3.6.1. Private Passenger Transport Energy Use per Capita

Energy use, with its attendant costs and local environmental impacts, as well as climate change implications, is an important characteristic of urban transport systems. The annual per capita energy use in private motorised passenger transport in Swedish cities was calculated backwards from the comprehensive emissions inventories that exist in Sweden for each municipality (Airviro, 2019). Transport is one of the sectors in these emissions inventories, which is further broken down into its component parts and provides CO_2 equivalent emissions, as well as all other transport emissions for each municipality (see next section). CO_2 was converted to energy use. The energy use figures here for private passenger transport are thus dependent on the accuracy of CO_2 emissions accounting by the Swedish government. There was no other direct source of fuel consumption for private transport.

Figure 16 shows that the ten Swedish cities in 2015 averaged 15,601 MJ/person, which is virtually the same as the average for the other European cities in 2005 (15,795 MJ). It is close to half the global sample average of 28,301 MJ and dramatically below the American, Australian, and Canadian cities (Table 9). In addition, there is hardly any difference here between the averages for the larger and smaller Swedish cities (15,886 MJ cf. 15,317 MJ respectively). Freiburg consumes 16,488 MJ/person or 8% more than in the smaller Swedish cities (one factor could be the significantly slower average speed of traffic in the denser urban fabric of Freiburg). Only the Asian cities as a group have a lesser energy use per person value for private passenger transport (6076 MJ), but they are of course radically denser than Swedish cities.

Uppsala, Stockholm and, interestingly, Umeå the least dense of the Swedish cities (!) consume the least energy, with 12,157, 12,051 and 11,622 MJ/person respectively. More in line with expectations, we see that Jönköping and Linköping, the next least dense of the Swedish cities do consume the most private transport energy use (21,678 MJ and 18,124 MJ respectively), but the pattern overall is confusing which may relate to the CO_2 data used. Swedish cities in 2015 performed comparatively well against other cities in the world, consuming only moderate quantities of energy in private passenger transport in this potentially energy hungry sector. Improvements are, however, always possible through less driving and better technology.

3.6.2. Public Transport Energy Use per Capita

The use of energy in public transport systems is important to understand and to compare with its private passenger transport equivalent. Public transport energy use data were obtained from each of the public transport operators by mode based upon the known consumption from fuel payments (Figure 17).

Swedish cities are identical to the other European cities in their energy use by public transport but significantly more than in the three auto-oriented groups of cities with their lesser public transport systems. Freiburg consumes a modest 1081 MJ/person. The larger Swedish cities on average consume 1787 MJ/person while the smaller cities consume a significantly lower 1281 MJ. Göteborg is the biggest per capita energy consumer in public transport (2680 MJ), which is surprisingly almost the same as the Asian cities, followed quite a bit behind by Jönköping (surprisingly high) and Stockholm (not surprisingly, also relatively high). The range of public transport energy use per person in Swedish cities is large (2680 MJ in Göteborg and 862 MJ in Örebro).

Table 9. Energy, emissions, and transport fatalities in Swedish and international cities.

Variable	Units	Stockholm	Malmö	Göteborg	Linköping	Helsingborg	SWE LARGE	Uppsala	Västerås	Örebro	Jönköping
Private passenger transport energy use per capita	MJ/person	12,051	15,670	15,905	18,124	17,681	**15,886**	12,157	14,030	17,095	21,678
Public transport energy use per capita	MJ/person	1,949	1,310	2,680	1,179	1,819	**1,787**	1,423	939	862	2,050
Total passenger transport energy use (private plus public)	MJ/person	14,000	16,980	18,585	19,304	19,500	**17,674**	13,580	14,969	17,957	23,728
Total emissions per capita	kg/person	17.6	17.5	17.5	20.6	16.2	**17.9**	9.2	16.0	17.4	25.9
* Emissions of CO per capita	kg/person	8.7	7.5	8.0	9.6	7.4	**8.2**	5.3	10.0	10.7	15.7
* Emissions of SO2 per capita	kg/person	0.1	0.0	0.1	0.1	0.1	**0.1**	0.0	0.0	0.0	0.0
* Emissions of VHC per capita	kg/person	5.0	5.5	4.3	5.5	3.8	**4.9**	0.9	2.1	2.2	3.4
* Emissions of NOx per capita	kg/person	3.7	4.4	4.9	5.4	4.9	**4.7**	3.0	3.9	4.5	6.8
Total emissions per urban hectare	kg/ha	413	349	344	284	355	**349**	140	273	238	326
Total emissions per total hectares	kg/ha	60	48	46	22	65	**48**	9	24	18	23
Total transport deaths per 100,000 people	deaths/100,000 persons	1.3	2.4	2.3	0.7	1.5	**1.6**	2.4	3.4	3.5	4.5

Table 9 cont.

Variable	Units	Umeå	Freiburg	SWE SMALL	SWE ALL	USA	AUS	CAN	EUR	ASIA	ALL
Private passenger transport energy use per capita	MJ/person	11,622	16,488	**15,317**	**15,601**	53,441	35,972	30,804	15,795	6,076	28,301
Public transport energy use per capita	MJ/person	1,132	1,081	**1,281**	**1,534**	963	1,036	1,190	1,532	2,691	1,360
Total passenger transport energy use (private plus public)	MJ/person	12,754	17,569	**16,598**	**17,136**	54,403	37,008	31,994	17,326	8,768	29,661
Total emissions per capita	kg/person	14.0	24.3	**16.5**	**17.2**	185.1	143.6	164.6	34.9	34.1	97.9
* Emissions of CO per capita	kg/person	7.5	16.0	**9.8**	**9.0**	145.7	111.7	130.1	22.3	19.8	74.1
* Emissions of SO2 per capita	kg/person	0.1	0.0	**0.0**	**0.1**	1.7	0.5	0.6	0.1	0.7	0.6
* Emissions of VHC per capita	kg/person	1.4	1.0	**2.0**	**3.4**	13.4	12.8	11.4	4.9	2.1	8.4
* Emissions of NOx per capita	kg/person	5.0	7.4	**4.6**	**4.7**	24.3	18.6	22.5	7.6	11.5	14.7
Total emissions per urban hectare	kg/ha	160	1,117	**228**	**288**	2,673	1,996	4,084	1,718	5,401	2,446
Total emissions per total hectares	kg/ha	7	353	**16**	**32**	962	519	1,511	858	2,117	991
Total transport deaths per 100,000 people	deaths/100,000 person	2.5	4.5	**3.3**	**2.4**	9.5	6.2	6.3	3.4	3.8	5.5

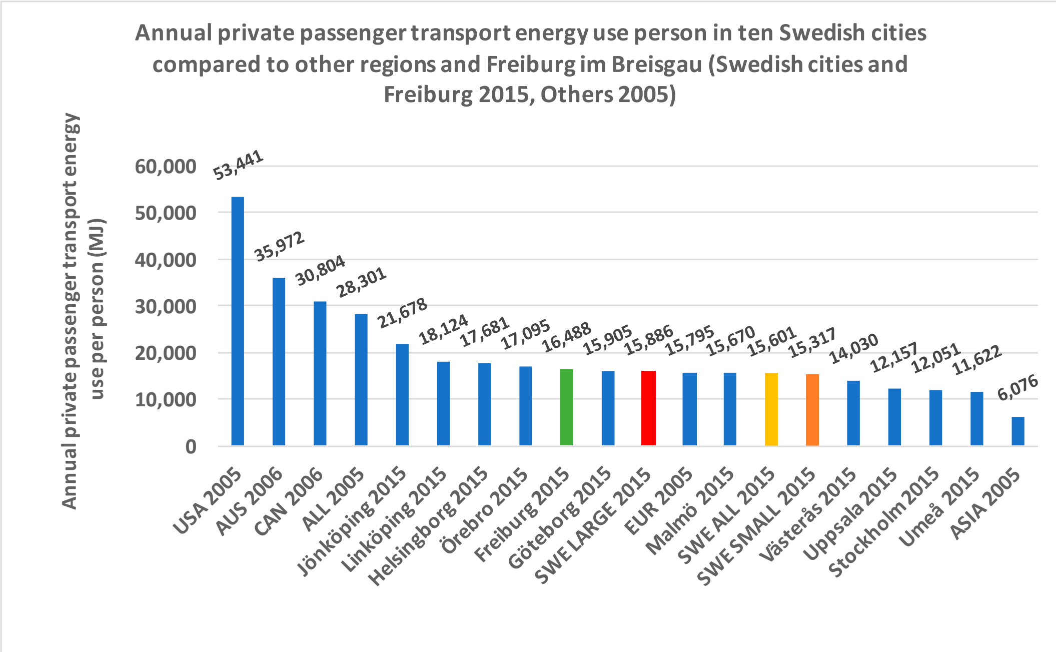

Figure 16. Annual private passenger transport energy use per person in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

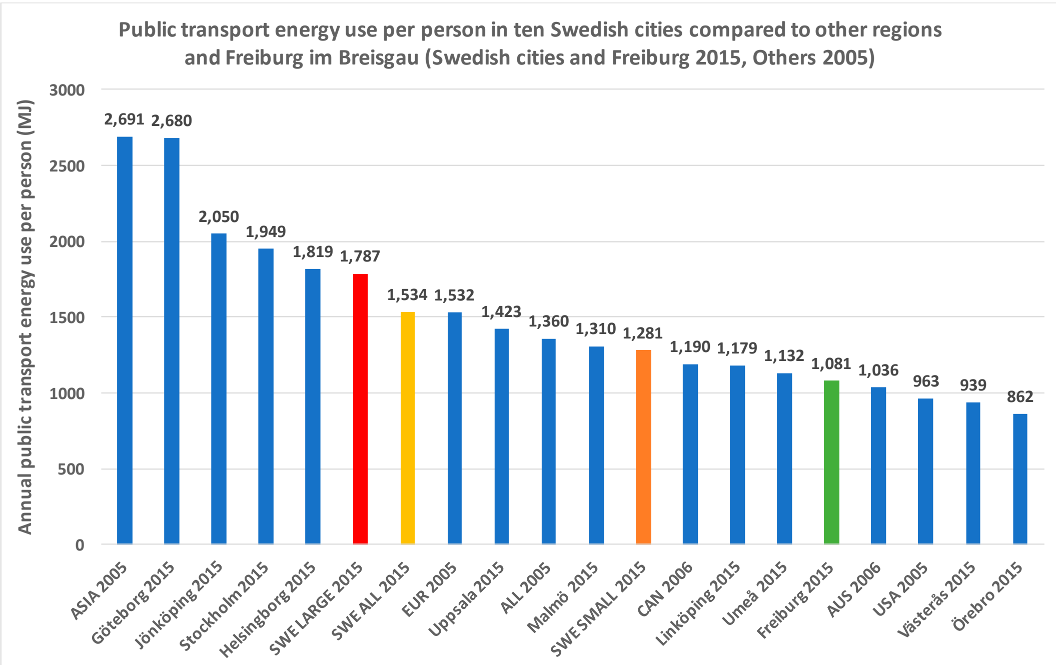

Figure 17. Annual public transport energy use per person in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

Compared to private passenger transport energy use, it shows how much less energy public transport consumes and how relatively energy-efficient it is on a per passenger-km basis (see Kenworthy (2018) for a full set of data on modal energy efficiencies in global cities).

3.6.3. Transport Emissions per Capita and per Hectare

Air pollution derived from transport systems is a very important source of emissions in urban areas. This research collected the annual emissions of four air pollutants, CO (carbon monoxide), NOx (nitrogen oxides), SO_2 (sulphur dioxide), and VHC or VOC (volatile hydrocarbons or volatile organics), and normalised them on both a per person and spatial basis (kg of combined emissions per person, per total ha and per urban ha of land).

Swedish cities do extremely well in this factor, averaging only 17 kg per person for the four pollutants combined, compared to the global sample average of 98 kg and the European average of 35 kg per person. The Swedish cities are also vastly better than the American, Australian, and Canadian cities (Figure 18).

It must be noted, however, that emissions from transport tend to be on a significant downwards trajectory due to tighter regulations and automotive technological advances, so it is likely that by 2015, the other cities would have reduced their emissions. The difference between Swedish cities and the rest will likely narrow significantly. Within Sweden, the per capita transport emissions are comparatively tightly clustered. Jönköping was the highest emitter with 26 kg per person and Uppsala was the lowest at 9kg. The smaller cities had less emissions (16 kg) compared to the larger cities (18 kg) but the difference is hardly significant. The Swedish cities were better than the benchmark smaller city, Freiburg, which had 24 kg/person.

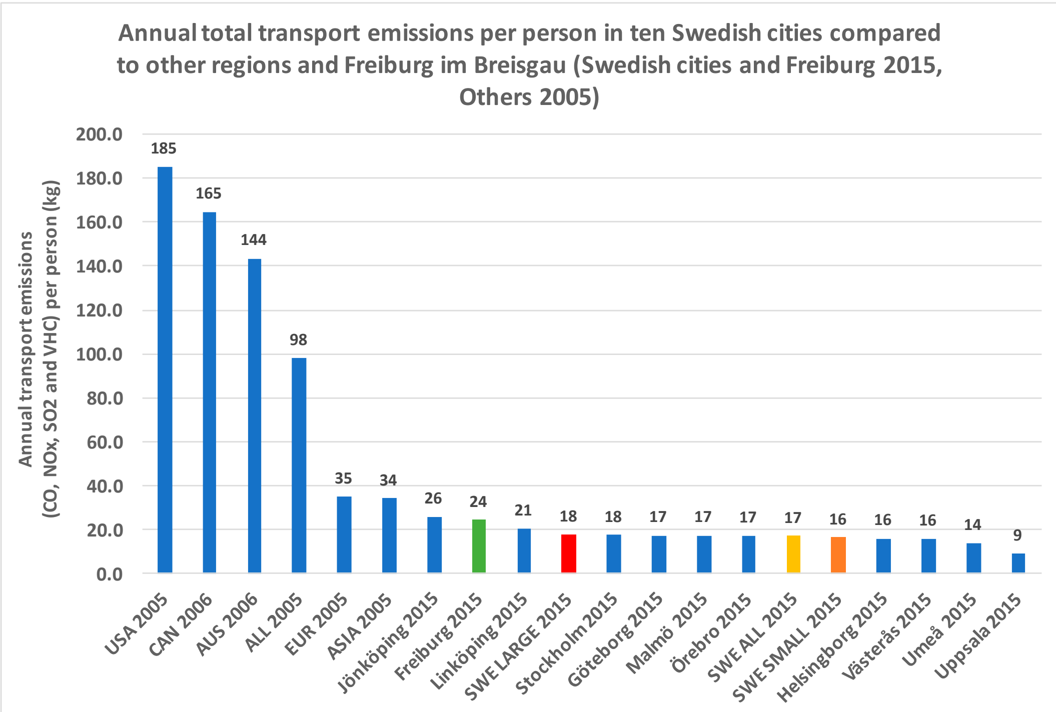

Figure 18. Annual transport emissions per person in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

The spatial intensity of transport emissions in Swedish cities is very low at only 288 kg per urban ha compared to European cities in 2005 of 1718 kg and the global sample of 2446 kg. There is somewhat of a difference between the large cities (349 kg) and the smaller cities (228 kg or 35% less). Freiburg's emissions per urban ha are much higher (1117 kg). The range is also quite large with Stockholm having the highest emissions per urban ha at 413 kg, while Uppsala is lowest at 140 kg, or threefold less. Part of the reason for these patterns is of course the low density of Swedish cities and the larger areas of urban land over which emissions are spread. Overall, this will tend to decrease the direct exposure of populations to air emissions and therefore lower any impacts. Contrastingly, in the Asian cities, where per capita transport emissions are low, the spatial intensity of emissions (5401 kg per urban hectare) is very high due to their very high densities, so population exposure will tend to be much greater. Emissions per total hectare of land follow the same pattern as the urban hectare variable, with Swedish cities being radically lower than all others.

Again, in both these factors, the difference between Swedish cities and the others will diminish as the per capita and per ha figures are very likely to have declined between 2005 and 2015 in the other cities.

3.6.4. Transport Fatalities per 100,000 persons

A major cost and source of human pain and suffering in cities is the loss of life in urban transport systems. This factor measures the transport deaths in cities using the World Health Organisation's (WHO) International Classification of Diseases codes (ICD10, V01-V99 codes), which are more accurate and reliable than police records, since they record the cause of death in hospitals in the case of transport accidents up to 30 days afterwards as being attributable to transport reasons. Police records typically only record deaths at the scene of an accident.

The Swedish cities perform excellently, recording a low 2.4 deaths/100,000 compared to 5.5 globally, 3.4 in the European cities, and an average of 7.3 in the American, Australian, and Canadian cities where exposure to automobiles, through sheer usage levels, is the highest. Freiburg is almost double the Swedish figure at 4.5 per 100,000 (Figure 19). Interestingly, the smaller Swedish cities have over double the death rate in transport as the larger cities (3.3 cf. 1.6/100,000), perhaps due partly to their greater reliance on non-motorised modes.

Within Sweden, the transport deaths vary, with Jönköping having the worst record in 2015 at 4.5 deaths/100,000 and Linköping the best at only 0.7. Sweden's national Vision Zero policy appears to have had an impact in reducing transport deaths to the lowest value in this global comparison. This factor, like emissions, will have narrowed as the other cities are also likely to have decreased in terms of transport deaths by 2015. It is also probably more representative to measure a 5-year rolling average for this factor, since transport deaths can fluctuate considerably from year to year, especially if there is even one significant multiple deaths incident.

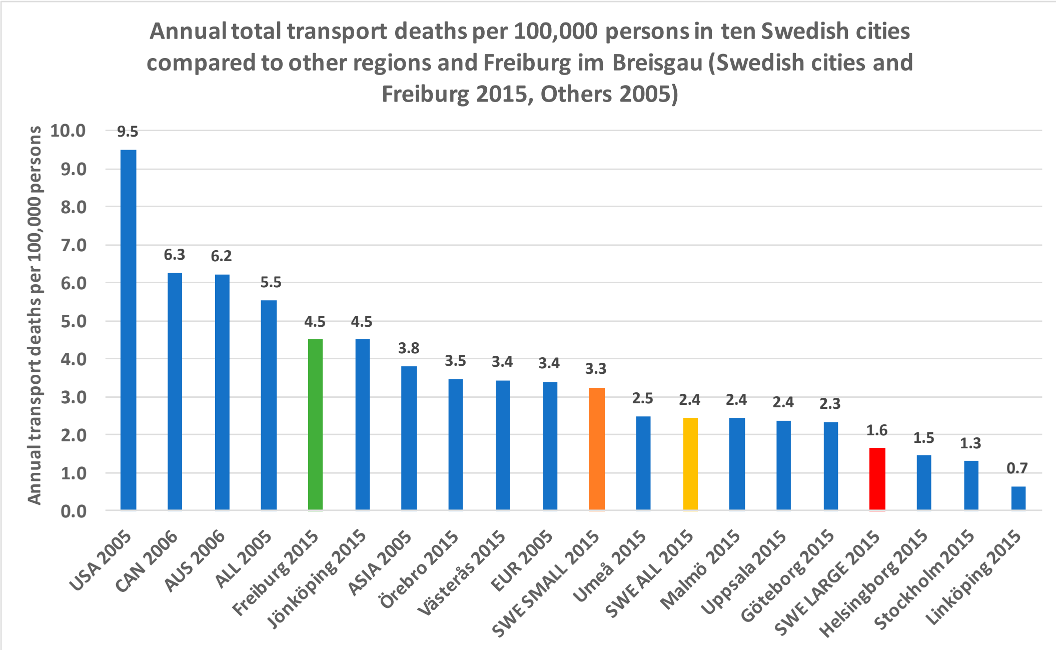

Figure 19. Annual transport deaths per 100,000 persons in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

3.7. Some Economics of Public Transport

It is important to understand the comparative economics of urban public transport systems and this research has tried to capture this partially through the collection of annual farebox revenues (with and without government reimbursements for concession fares for seniors and students etc) and the annual operating costs (with and without finance and depreciation). From this a range of standardised indicators are possible (Table 10), one of which is the operating cost recovery. The common norm here is to calculate this using farebox revenues including government reimbursements and operating costs minus finance and depreciation charges (i.e. the best-case scenario). This is the method adopted here.

3.7.1. Cost Recovery of Public Transport Operations

Table 10 and Figure 20 show the operating cost recovering as a percentage for the cities. Swedish cities recover an average of 43% of their costs from the farebox (46% in the larger cities, 40% in the smaller) ranging from a high in Stockholm of 64% down to lows of 33% and 34% in Helsingborg and Västerås respectively. US cities are the worst with only 31%, while Asian and European cities do best with 121% and 60% respectively. Freiburg shows a high recovery rate of 84% but there is uncertainty about the costs due some competitive secrecy surrounding this item in German cities. Swedish cities are below the global average of 54% but this factor is very limited in indicating the value of public transport to the community at large or the "subsidy" to public transport. Low cost recovery is not an indication of low worth (e.g. in relieving peak period congestion, even in auto-dominated, low public transport-using cities) as shown in the huge jump in congestion in all cities during public transport strikes. Such social benefits are unaccounted for in the conventional accounting balance sheets of public transport systems.

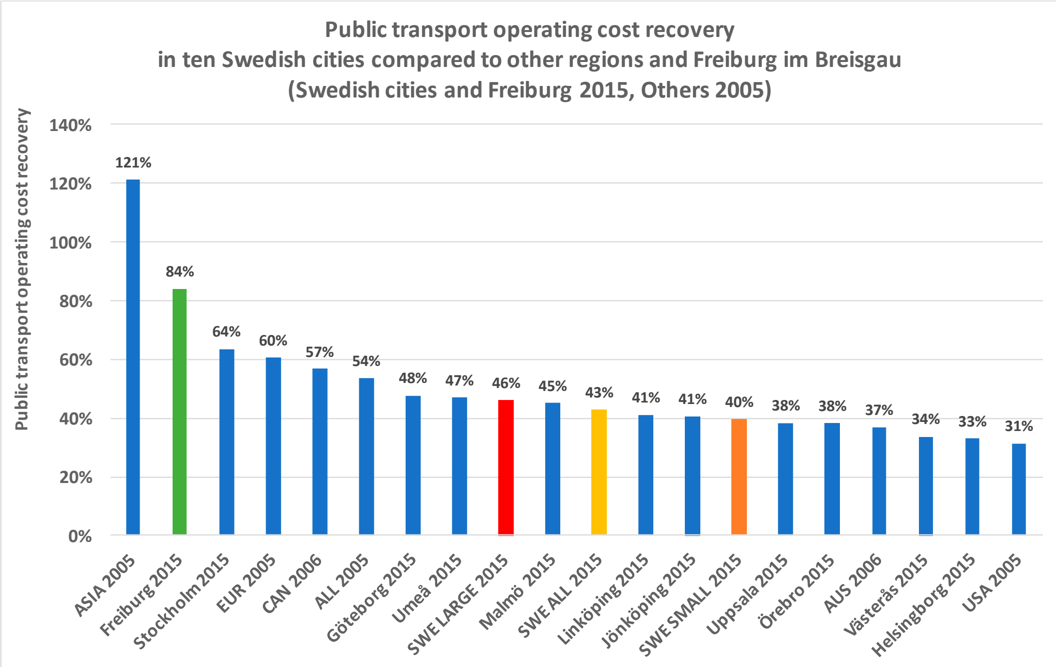

Figure 20. Public transport operating cost recovery in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

3.7.2. Public Transport Farebox Revenue per Passenger Kilometre (PKT)

Table 10 shows the public transport farebox revenue per boarding, passenger kilometre and vehicle kilometre. Depending on one's purpose these data can reveal different things. For this discussion, the focus is on farebox revenue per PKT since this item measures revenue based on how far people travel on public transport. Readers can exploit the other data in Table 10 as they need. Figure 21 shows this for the cities in US$1995 as this is the way currencies have been standardised in this comparative work since the 1990s. It reveals that Swedish cities collect 9 US cents per PKT (consistent for small and large cities) though with a range from Västerås of 6 cents up to 17 cents in Örebro. Similar figures between about 6 and 13 cents are found across the entire sample, with Freiburg similar to Swedish cities at 8 cents.

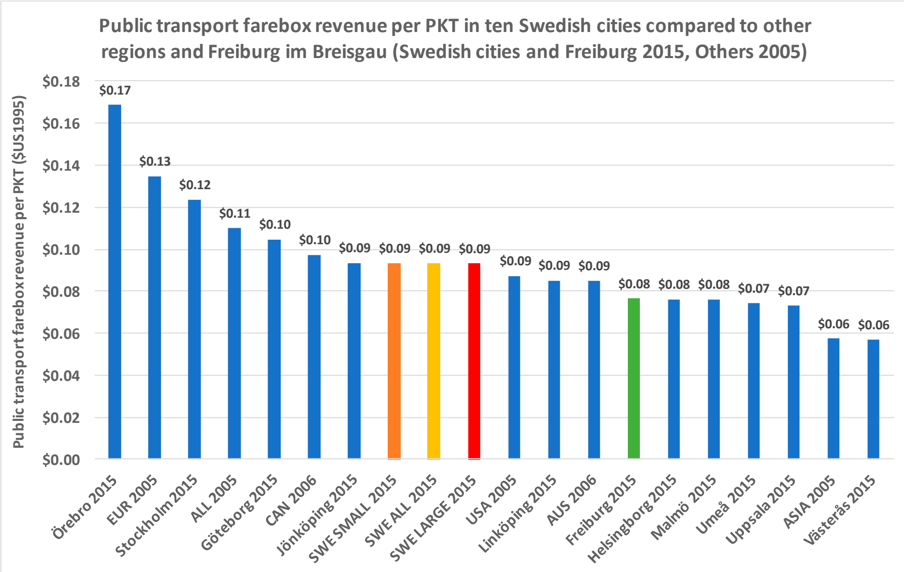

Figure 21. Public transport farebox revenue per PKT in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

3.7.3. Public Transport Operating Cost per Passenger Kilometre (PKT)

As with farebox revenue/PKT, there is a reasonable degree of consistency in this cost factor across the global sample (Figure 22), ranging most typically between about 20 and 28 US cents per PKT. Swedish cities average 24 cents with the larger cities having lower costs (23 cents) and the smaller cities experiencing 26 cents/PKT. Freiburg's costs are 10 cents/PKT but subject to the previously mentioned caveat. Costs of operating public transport using this factor are cheaper in Sweden than in the USA, Australia, Europe and the global average, but more expensive than in Canadian cities (20 cents per PKT). There is however, considerable range in the Swedish cities in costs per PKT from a low of 17 cents in Umeå to 48 cents in Örebro, but all the other Swedish cities are between 18 cents and 26 cents per PKT.

Readers can also utilise the operatings costs per boarding and vehicle km in Table 10 if this better suits their purposes.

Table 10. Economics of public transport operations in Swedish and international cities.

Variable	Units	Stockholm	Malmö	Göteborg	Linköping	Helsingborg	SWE LARGE	Uppsala	Västerås	Örebro	Jönköping
Public transport operating cost recovery	%	64%	45%	48%	41%	33%	**46%**	38%	34%	38%	41%
Average public transport farebox revenue per boarding	USD/boarding	$0.89	$0.99	$0.91	$1.17	$0.77	**$0.94**	$1.20	$0.94	$1.58	$1.27
Average public transport farebox revenue per passenger kilometre	USD/pass. km	$0.12	$0.08	$0.10	$0.09	$0.08	**$0.09**	$0.07	$0.06	$0.17	$0.09
Average public transport farebox revenue per vehicle kilometre	USD/v.km	$2.79	$1.68	$1.71	$1.22	$1.23	**$1.73**	$1.11	$0.92	$1.21	$0.92
Public transport operating cost per vehicle kilometre	USD/v.km	$4.67	$4.14	$4.10	$3.40	$4.14	**$4.09**	$3.25	$2.93	$3.45	$2.50
Public transport operating cost per passenger kilometre	USD/pass. km	$0.21	$0.19	$0.25	$0.24	$0.26	**$0.23**	$0.21	$0.18	$0.48	$0.25
Public transport operating cost per capita	USD/person	$533	$273	$618	$604	$410	**$488**	$378	$160	$177	$205
Percentage of metropolitan GDP spent on PT operating costs	%	1.08%	0.84%	1.52%	2.00%	1.42%	**1.34%**	1.18%	0.54%	0.61%	0.69%

Table 10 cont.

Variable	Units	Umeå	Freiburg	SWE SMALL	SWE ALL	USA	AUS	CAN	EUR	ASIA	ALL
Public transport operating cost recovery	%	47%	84%	**40%**	**43%**	31%	37%	57%	*60%*	121%	54%
Average public transport farebox revenue per boarding	USD/boarding	$1.83	$0.55	**$1.36**	**$1.15**	$ 0.75	$0.96	$0.67	$0.80	$0.48	$0.77
Average public transport farebox revenue per passenger kilometre	USD/pass. km	$0.07	$0.08	**$0.09**	**$0.09**	$ 0.09	$0.09	$0.10	$0.13	$0.06	$0.11
Average public transport farebox revenue per vehicle kilometre	USD/v.km	$0.91	$1.73	**$1.01**	**$1.37**	$ 1.23	$1.59	$1.91	$2.52	$1.62	$1.99
Public transport operating cost per vehicle kilometre	USD/v.km	$2.13	$2.32	**$2.85**	**$3.47**	$4.80	$2.62	$3.82	$5.05	$1.80	$4.44
Public transport operating cost per passenger kilometre	USD/pass. km	$0.17	$0.10	**$0.26**	**$0.24**	$0.37	$0.28	$0.20	$0.27	$0.06	$0.28
Public transport operating cost per capita	USD/person	$193	$141	**$223**	**$355**	$207	$309	$199	$560	$265	$391
Percentage of metropolitan GDP spent on PT operating costs	%	0.66%	0.55%	**0.73%**	**1.05%**	0.44%	0.98%	0.65%	1.50%	1.35%	1.08%

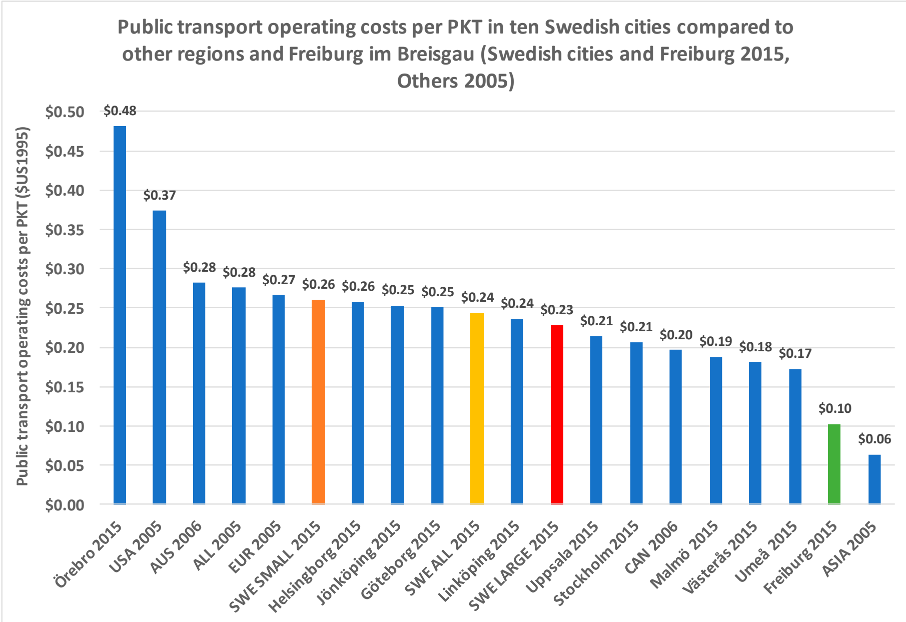

Figure 22. Public transport operating costs per PKT in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

3.7.4. Percentage of Metropolitan GDP Spent on Operating Public Transport.

The final item in Table 10 provides a perspective on how much of the urban region's GDP is spent on operating its public transport systems. This of course can be interpreted in different ways. It can reflect the degree of commitment to public transport, all other things being equal, or it can reflect cost efficiency or inefficiency, depending on interpretations of the data and other salient factors in each region. Figure 23 provides these data.

Swedish cities on average spend 1.05% of their annual GDP on operating their public transport systems compared to 1.50% in other European cities. They are, however, very close to the global sample of 1.08% of metropolitan GDPs. Freiburg on the other hand only spends 0.55% but this needs to be taken with caution due to data uncertainties. Larger Swedish cities spend almost double (1.34%) compared to their smaller counterparts (0.73%). The range is also very large with Västerås only spending 0.54% and Linköping spending 2.00%.

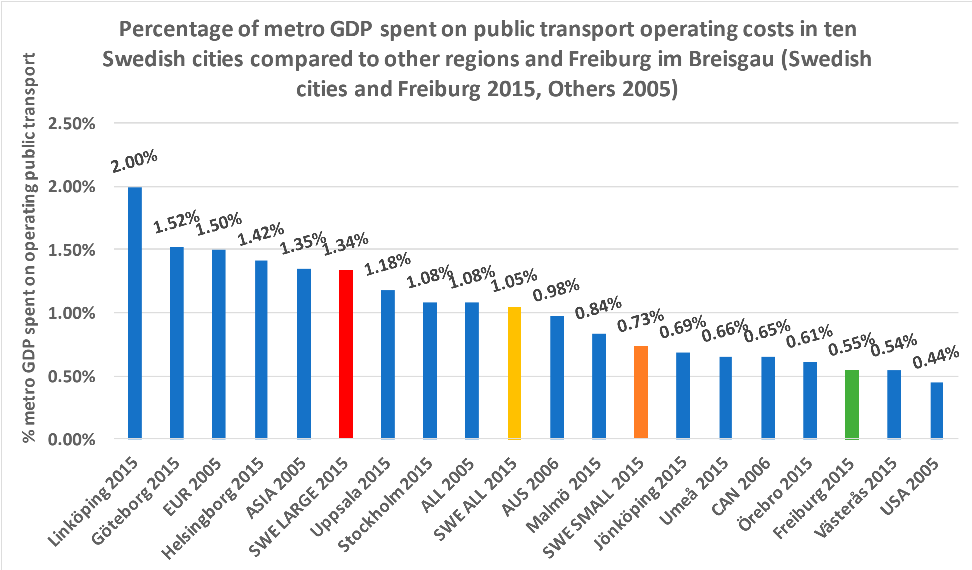

Figure 23. Percentage of annual metropolitan GDP spent on public transport operating costs in ten Swedish cities (2015) compared to a sample of global cities (2005–2006).

4. Analysis, Discussion, and Policy Implications

The discussion here follows the six research questions asked in the introduction to this working paper. The first and second research questions were: How do Swedish cities compare in land use, wealth, private, public, and non-motorised transport, as well as other transport-related factors? Do Swedish cities follow the patterns of European and other cities or are they different? These are dealt with together below.

4.1. How do Swedish Cities Compare in Land Use, Wealth, Private, Public, and Non-Motorised Transport, as Well as Other Transport-Related Factors? Do Swedish Cities Follow the Patterns of European and Other Cities or are They Different?

The data here suggest that as a group, Swedish cities are somewhat unique and distinguish themselves in particular from other European cities in a number ways. Car use per person is almost identical in car passenger kilometres per person compared to other European cities. Use of cars in Swedish cities is much lower than in the three auto-dependent regions of the USA, Australia, and Canada. This can be seen in the analysis of urban density versus per capita car use. Figure 24 shows the urban density of the global sample of cities regressed with the annual car use per capita (passenger kilometres) using a power function as the line of best fit (see Methodology section). The five larger Swedish cities are shown in red and five in blue within the circle. It can be clearly seen that the Swedish cities form an outlier, achieving lower car use than is typical in this global sample of wealthy cities at equivalent lower densities.

Fitting the power equation for the line of best fit ($r^2 = 0.64$ – this r^2 is 0.83 without the ten Swedish cities and 0.75 with only the five larger cities) to the average Swedish urban density of 16.9 persons per ha, we obtain a predicted annual PKT per capita of 11,124 km. However, the actual average is 6888 PKT per capita, or 38% lower than would be typical for this density. The generous provision of public transport services and the resulting better usage of public transport at these relatively low densities (e.g. compared to similar densities in Australia and the USA, even though relatively modest on a global scale), helps to reduce car use in Swedish cities.

In addition, the good performance of walking and cycling in the mobility patterns of Swedish urban residents (average 30% of daily trips compared to an average of 11.8% in US, Australian and Canadian cities), also helps to reduce car use to atypically low values for such low densities and appears to partly overcome the auto-dependence inducing effects of high road and freeway provision and relatively low use of urban rail systems. The ‘transit leverage effect’ (Neff, 2013), where one passenger kilometre on public transport replaces multiple passenger kilometres by car, is likely having some effect here (Newman and Kenworthy, 1999a). This substitution of car passenger kilometres appears to be primarily related to the trip-chaining behaviour of public transport users, achieving multiple trip purposes in one public transport trip (e.g. work, shopping, personal business, social/recreational needs during different trip segments in using public transport) that would be otherwise made in individual car journeys involving many more kilometres of travel.

The theory of urban fabrics possibly also helps to explain some of the results (Newman, Kosonen and Kenworthy, 2016). This theory shows that cities are all made up of different compositions and proportions of walking city fabrics, public transport city fabrics, and automobile city fabrics, the first two of which have higher densities and mixed uses and much more sustainable mobility patterns. Walking cities, public transport cities, and automobile cities are depicted graphically in Newman and Kenworthy (1999a).

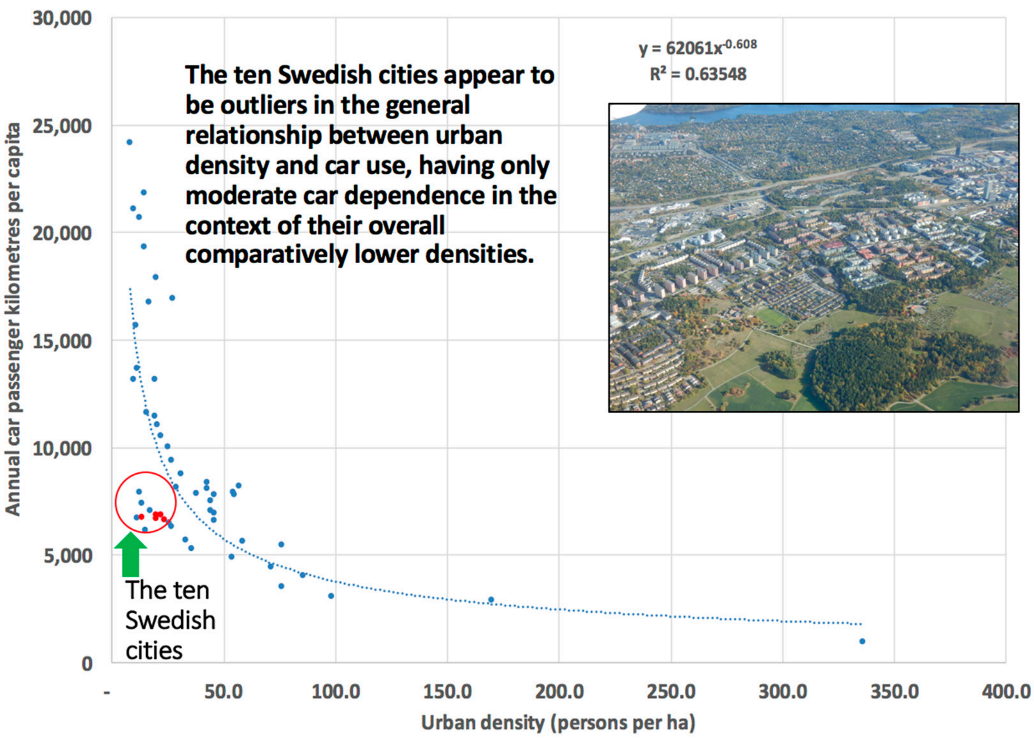

Figure 24. Annual car passenger kilometres per person versus urban density in a global sample of 48 cities (ten Swedish cities, 2015 in circle: larger in red, smaller in blue), remainder of data, 2005–2006).

While Swedish cities do have lower overall densities than is typical of European cities, they also still have significant areas of more typical European city urban fabric that are either walking or public transport in their orientation, with significantly higher urban densities and mixed land uses. In these areas, public transport is more effective and walking and cycling are more frequently used due to the shorter travel distances required and relatively good conditions for pedestrians and cyclists compared to other lower density cities in the USA or Australia.

There are other ways of investigating in more detail the differences in urban fabric typologies within individual cities, which may further explain why some areas achieve better outcomes in sustainable transport. A particularly useful approach is to use street-based metrics to characterise urban typologies (Hermosilla *et al*, 2014). This approach can distinguish, for example, differences in vegetation in different areas of cities, which can in turn have a significant effect on the attractiveness of neighbourhoods for walking and cycling. It is also useful in depicting in a quantitative way the relationship between streets and buildings.

Two important factors in urban design regarding streets and buildings are the level of horizontal and vertical enclosure, which affect the walking and cycling attractiveness of neighbourhoods, and even the propensity or willingness of people to access public transport stops on foot or by bike. Street metrics can help to reveal this in a systematic and quantitative way. In areas where streets are too wide relative to the height of buildings (bad vertical enclosure), poor walking environments are generally evident. In areas where streets have significant holes in the urban fabric due to, for example, surface parking lots (poor horizontal enclosure), they also detract from walking and cycling (Schiller and Kenworthy, 2018).

Therefore, urban density *per se*, while fundamental in determining transport patterns, has numerous mediating factors, such as building heights and volumes, that help determine the experiential quality of both higher and lower densities. In the case of this research on a broad scale comparisons of cities, it was not possible to compare cities on such a detailed basis. However, further research on street metrics might reveal additional supportive reasons why these ten Swedish cities achieve an overall lower car use at relatively low densities.

Given the above matters, it is important for readers to have at least some visual appreciation of the character of Swedish urban development and transport systems, which the numbers in this paper can only partially convey. Figures 25 to 33 show key examples of the differences in the urban fabrics for the Stockholm and Malmö metropolitan areas. Figure 25 shows a dense, traditional European five to ten-storey apartment development in Malmö, but with lower density neighbourhoods in the background. It is likely that these denser kinds of areas, which exist in all the Swedish cities to greater or lesser extents, are critical in explaining the relatively high rates of walking and cycling, as well as bolstering public transport use (though public transport use in such areas could likely be increased if these areas were to also have local, rail-based public transport, i.e. trams/light rail transit or LRT).

Figure 25. Walking and public transport-oriented neighbourhoods in Malmö in the foreground, with lower density areas in the distant background. Source: Jeffrey Kenworthy.

Figure 26 reveals the high-quality walking and cycling environments that can occur in such dense areas. A common theme in Swedish urban environments is to link urban development with a relatively good walking and cycling infrastructure. In Stockholm's satellite towns, such as Vällingby and Kista, pedestrians and cyclists are physically separated from traffic and it is possible to travel between these satellite centres by bike or foot, sometimes through areas of forest or farmland.

Figure 26. Quality walking and cycling environments in the inner city of Malmö. Source: Jeffrey Kenworthy.

Figure 27 shows the new West Harbour development in Malmö, which is based strongly around walking and a very good cycleway system. Such redevelopment of brownfield sites, for example, former dockland or industrial areas in cities, is often important in demonstrating new, more sustainable ways of urban development (Marshall, 2004). A significant issue for Malmö's West Harbour is that it is only served by buses and therefore lacks a clear centre or anchor point based around rail stops to give it more focus and a better sense of place. Much of the land, which is still vacant and awaiting build-out, is used for parking. This tends to set auto-oriented mobility habits somewhat early, rather than engendering a more positive public transport-oriented mobility culture from the outset.

Figure 28 depicts a much more car-oriented neighbourhood in Lund, which is only served by buses. It does, however, have rather good off-road cycling facilities, especially through farmland and other green areas, which are conducive to safe and attractive cycling that in turn helps to minimise car dependence. Cycling is, however, limited to a degree by a lack of mixed land uses near housing, which is in turn linked to too low density to support mixed land use. Without a critical mass of population to frequent local amenities, such as shops, medical facilities, and so on, it is not viable to provide them. Based on the author's own observations and cycling in this area, there is, nonetheless, significant recreational cycling, which, among other things, has health advantages.

Figure 29 illustrates how the Stockholm region has a mixture of very high density core areas around tunnelbana stations, which then taper off into much lower density, suburban-style housing areas. One of the original planning ideas for such sub-centres was to achieve a reasonable jobs-housing balance, but in practice, people who live in one sub-centre work somewhere else. The transport problems of this reality are, however, mitigated to a high degree by the excellent way these sub-centres are served by the tunnelbana to the city centre and other sub-centres along the lines, as well as the feeder buses that bring people from lower density areas to the tunnelbana stations (Cervero, 1995, 1998). Residents are not needing to resort to cars to get to work in other sub-centres but can link up through a series of reasonably convenient public transport trips.

Figure 27. New urban redevelopment in Malmö's West Harbour adds a new walking urban fabric, but lacks rail-based transport (e.g. LRT). Source: Jeffrey Kenworthy.

Figure 28. Lower density style neighbourhood in Lund in the Malmö metropolitan area. Source: Jeffrey Kenworthy.

Figure 29. Kista satellite town in the Stockholm region showing dense, mixed, walkable, and transit-oriented urban forms built at Kista tunnelbana station, but much lower, suburban style development in other areas. Source: Jeffrey Kenworthy.

Figures 30 and 31 show the dense central and inner areas of Stockholm with excellent public transport and walking conditions. Public transport here includes buses, trams, and tunnelbana, as well as regional rail services. The urban fabrics in these areas were created in the walking and public transport city eras and are thus ideally suited to these more sustainable modes. Stockholm has also pedestrianised significant parts of its central area, which makes it very conducive to walking (and cycling), though the winters make these modes much less attractive in colder months.

Figures 32 and 33 show the public transport orientation and walkability of both older satellite towns in Stockholm (Vällingby) and newer neighbourhood developments, such as Hammarby Sjöstad, which is serviced by a new tram line.

In the first case in Figure 32, the new centre is formed linearly into a transit-oriented development (TOD) due to the close spacing of the tram stops. Throughout the neighbourhood there are excellent conditions for walking and cycling, though shopping and other facilities can be some distance away for some residents of the area due to the less than ideal mixing of land uses.

Figure 33 shows a nodal form of TOD due to the much wider spacing of stations along the tunnelbana lines. These sub-centres are separated in some cases by open land with urban development being restricted to well-defined areas. They have a strong profile of increasing density towards the station, both for residential and non-residential development. They are also very well-served by extensive feeder buses, often having large bus interchanges for many different routes located at the stations. Within about 400 metres of these stations, the environments are generally well designed to support pedestrians.

Figure 30. Stockholm's old, dense, mixed use inner city based on tunnelbana, surface trams, walking, and cycling. Source: Jeffrey Kenworthy.

Figure 31. Stockholm's old mediaeval city (Gamla Stan) with its strong walking character. Source: Jeffrey Kenworthy.

Figure 32. The new Hammarby Sjöstad walkable neighbourhood in Stockholm built around a tram service. Source: Jeffrey Kenworthy.

Figure 33. Vällingby: The original transit-oriented new town in Stockholm built over the tunnelbana. Source: Jeffrey Kenworthy.

Overall, the urban comparative data on these ten Swedish cities suggest that they form an interesting and somewhat unique "cluster" of cities on a global scale, with at times some paradoxical results.

On the one hand, Swedish cities are atypically low in density, and very high in roads and freeways compared to most European cities. However, employment is still rather centralised, with 17.3% of jobs in their CBDs compared to 18.3% in Europe. Swedish cities are the second highest in this factor across the city groupings. This generally works in favour of public transport, at least for work-related travel. Additionally, for trips to the CBD, parking is comparatively limited in Swedish cities with only 289 spaces per 1000 jobs, theoretically meaning that only about one in three to four people working in the CBD would be able to park a car. It is a little better in other European CBDs (248 spaces per 1000 jobs). This also favours public transport, walking, and cycling access to Swedish city centres.

Other factors working in favour of more sustainable transport include the fact that Swedish cities have significantly lower car ownership levels than might be expected, lower even than other European cities. Average wealth levels as measured by metropolitan GDP are below typical European levels (though comparable to Australian and Canadian cities in 2006). Despite low densities, Swedish cities have developed relatively respectable and more extensive public transport systems than many comparable lower density cities.

There seems to be a generalised European cultural factor at work here, such that in Europe, public transport is more accepted and utilised across a wide range of incomes and even densities (Schiller and Kenworthy, 2018). Swedish cities have generous amounts of public transport lines compared to other cities and the highest amount of quite well-served reserved public transport route per person in the global sample. Unfortunately, this is offset by the very high per capita provision of urban freeways, which leads to a relatively low ratio of reserved public transport to freeways in Swedish cities, thus somewhat offsetting the advantages of their public transport systems. Service provision as measured by seat kilometres is lower than Asian and European cities, but still good on a global scale. The average operating speeds for public transport in Sweden seem to be higher than most other cities, which leads also to the best average ratio of public transport system speeds to general road traffic of all groups of cities (0.93, the next closest result being 0.88 in the other European cities).

However, despite some of the above favourable conditions for public transport, Swedish cities on average have much lower per capita public transport boardings than other European cities (1/3), but at the same time, this is much better than in the more auto-dependent regions in the USA, and Australia where densities are also low. This might be expected given the significantly lower density of Swedish cities compared to other European cities, but is somewhat unusual when compared to similarly lower density cities in the USA and Australia. Swedish cities also have much lower vehicle and seat occupancies, meaning that for the services provided there is overall, much more spare capacity.

On the positive side, public transport use measured by per capita passenger kilometres is a little closer to European levels compared to boardings, due to the longer distances travelled by public transport in Swedish cities, which again probably relates to low densities. Using total motorised passenger kilometres as a measure, these ten Swedish cities have on average a reasonable 16.3% of total motorised passenger kilometres on public transport, beaten only by their European neighbours (24.5%) and of course the Asian cities (62.9%). The modal split of daily trips is also 44.3% for public transport, walking, and cycling combined, meaning that the modal share in these ten Swedish urban regions is pivoted somewhat equitably between the more sustainable and less sustainable modes. As shown in Figures 25 to 33, Swedish cities have significant areas of urban fabric that are supportive of non-motorised modes and where walking and cycling is high, leading to 30% of daily trips in these Swedish cities being completed by these modes, despite a very cold climate. Only the other European cities have more with 34.5%. There are numerous areas in Swedish cities where bicycling is supported with reasonable infrastructure and walking is well catered for too in many areas.

Three key areas also perform well in these Swedish cities. Energy use in private passenger transport is commensurate with the other European cities and much lower than in the auto-cities of North America and Australia. The Swedish cities excel in their extremely low transport emissions per capita and per hectare compared to every other region in the world and even the worst Swedish cities are better than the best of the others. Of course, the other data are from 2005–6 so it is expected that the other cities would move closer to the Swedish cities in 2015, given the large advances in automotive technology and tougher air pollution regulations. Likewise, in transport fatalities per 100,000 persons, Swedish cities are the lowest in the world, and possibly would remain so due to Sweden's Vision Zero transport deaths policy (Government Offices of Sweden, 2019), even if the other cities were to be updated to 2015.

4.2. Are There Noteworthy Differences and Similarities Between the Sample of Smaller Cities and the Larger Ones?

The answer to this question can be summarised according to where the smaller and larger cities are similar, where they have moderate but interesting differences and where they have very large differences.

Smaller Swedish cities are quite similar to larger Swedish cities in that they:

- Are only 4% higher in car ownership and car use per capita and private transport energy use per capita
- Have similarly centralised work (18.3% of jobs in the CBD compared to 16.3%)
- Are a moderate 10% higher in freeway length per capita.
- Have a 10% inferior public transport speed ratio compared to cars
- Have similar public transport seat occupancy 22% cf. 25% in the larger cities.

- Have the same average farebox revenue per passenger km
- Have a moderate 13% higher operating cost per PKT
- Have an operating cost recovery which is 40% cf. 46%
- Have only 11% less transport emissions per capita

Smaller Swedish cities have interesting differences to the larger Swedish cities in that they:

- Have 30% lower density
- Are 18% less wealthy
- Have 35% more parking per 1000 CBD jobs
- Have 34% lower seat km of public transport service per capita
- Have only 9.3% of daily trips by public transport cf. 19.4%
- Have 32.8% of daily trips by walking and cycling versus 27.1%

Smaller Swedish cities are greatly different from the larger Swedish cities in that they:

- Have 3.6 times more reserved public transport route per capita
- Have 4.7 times higher ratio of reserved public transport route compared to freeways
- Are 69% lower in public transport boardings per capita
- Have 89% less rail boardings per capita
- Are 45% less in their public transport passenger km per capita
- Have a percentage of total motorised passenger km on PT that is only 12.3% cf. 20.4%.
- Have 33% lower public transport vehicle occupancy
- Have half as much of their GDP spent on public transport operating costs
- Are double in transport deaths per 100,000 persons (but still very low)

4.3. Do Swedish Cities Compare Well or Poorly with Freiburg Im Breisgau (Germany), which is often Portrayed as an Especially Good Example of Sustainable or Green Urbanism?

The answer to this question is summarised by grouping the variables according to the following scale of Freiburg relative to Swedish cities. Where there are differences in the comparison between the smaller and larger cities or overall, this is noted by repeating that variable in different categories. The scale is:

- Freiburg is very much higher
- Freiburg is significantly higher
- Freiburg is higher
- Freiburg is essentially the same
- Freiburg is lower
- Freiburg is significantly lower
- Freiburg is very much lower

The results are as follows. Whether the result is good or not against the Swedish cities depends on the variable and in some cases on the perspective one takes. For example, is higher traffic speed a "good" result or a "negative" result? Is lower spending on public transport operating costs a reflection of efficiency or of simply poorer, lower levels of service or commitment to public transport? Is higher public transport farebox revenue a reflection of higher fares or greater usage of the service delivered? Those factors in which Freiburg is deemed by the author to be more sustainable than Swedish cities, have been highlighted in *italics*. For those factors where Swedish cities are better than Freiburg underlining has been used. For the variables that are rated as essentially the same or quite similar, these are left in normal text. This applies also where the interpretation of the variable depends greatly on perspective (no judgment is made).

Freiburg is very much higher

- *Urban population and job densities*
- *Percentage of daily trips by non-motorised modes*
- *Percentage of daily trips by public modes (smaller cities)*
- *Public transport boardings per person (smaller cities and overall)*
- *Suburban rail boardings per person*
- *Public transport passenger kilometres per person (smaller cities)*
- *Public transport operating cost recovery*
- *Farebox revenue per vehicle kilometre of service (smaller cities and overall)*
- Transport emissions per urban ha
- Transport deaths per 100,000 persons
- *Ratio of reserved public transport route to freeways (extraordinarily)*

Freiburg is significantly higher

- Motorcycle vehicle kilometres per capita
- Motorcycle passenger kilometres per capita
- *Public transport vehicle occupancy*
- Transport emissions per person
- *Ratio of overall public transport speed to road traffic speed (overall and smaller cities)*

Freiburg is higher

- *Reserved public transport route per person (larger cities)*
- *Ratio of overall public transport speed to road traffic speed (larger cities)*

Freiburg is essentially the same

- Percentage of jobs located in the CBD
- Car vehicle kilometres per person
- Car passenger kilometres per person
- Public transport boardings per person (larger cities)
- Percentage of total motorised passenger kilometres on public transport

- Farebox revenue per passenger kilometre
- Farebox revenue per vehicle kilometre of service (larger cities)

Freiburg is quite similar

- Parking spaces per 1000/CBD jobs
- Motorcycles per 1000 persons
- Public transport lines per capita (larger cities)
- Percentage of daily trips by public transport (overall)
- Public transport passenger kilometres per person (overall)
- Public transport seat occupancy
- Private passenger transport energy use per person

Freiburg is lower

- *Cars per 1000 persons*
- *Public transport operating costs per person (smaller cities)*

Freiburg is significantly lower

- GDP per capita
- *Road length per urban ha*
- *Freeway length per urban ha*
- Public transport vehicles per 1000 persons
- Public transport service vehicle kilometres per person
- Public transport service seat kilometres per person
- Public transport speed
- Public transport passenger kilometres per person (larger cities)
- Public transport energy use per person

Freiburg is very much lower

- *Road length per capita*
- *Freeway length per capita*
- Public transport line length per capita (smaller cities and overall)
- Reserved public transport route per person (smaller cities and overall)
- *Percentage of daily trips by private transport modes*
- Suburban rail speed
- Average road traffic speed
- Farebox revenue per boarding
- *Public transport operating costs per vehicle kilometre*
- *Public transport operating costs per passenger kilometre*
- Public transport operating costs per person (overall)
- Percentage of GDP spent on operating costs

From these diverse results, it is difficult to make an all-encompassing conclusion about whether Swedish cities perform well or poorly against this chosen benchmark city, Freiburg. What can be said is that in many ways Freiburg has a more sustainable transport system and more supportive, much higher density land uses overall (it has 22 cases that are in italics and therefore deemed to be more sustainable than in Swedish cities and 14 cases underlined where Swedish cities are seen to be better than in Freiburg). It has generally higher use of public transport and public transport vehicle occupancy and extraordinary performance on non-motorised modes (double that of Swedish cities). Its superior use of public transport comes with less public transport line length per person, fewer public transport vehicles and lower levels of public transport service, measured by vehicle and seat kilometres per person. This seems to point to the advantages of higher densities whereby the catchment strength for the services provided is much stronger and the services therefore better utilised.

It also has some advantageous background conditions in having much less available road and freeway per person, a very much greater advantage in reserved public transport route compared to freeways and its overall public transport system speed compared to road traffic speed is 7% higher and exceeds the Swedish cities (even though they are good as well). It has lower car ownership overall. Despite all this, Freiburg has similar levels of car use (car VKT and PKT/person) as the Swedish cities and it has poorer performance on transport emissions and transport deaths.

The key takeaway lessons for Swedish cities from Freiburg seem to be that density (and concomitant mixed land uses) do matter. They provide the conditions for extraordinary levels of walking and cycling, especially when these modes are planned for and facilitated to a very high degree through excellent urban design of the public realm throughout the city, as they are in Freiburg.

It also shows the value added or multiplicative positive effect of density for public transport. Swedish cities do undoubtedly provide very reasonable public transport services regardless of the density of the fabrics through which they operate, but these services need to be better utilised for the most part.

And in this regard, there is another critical lesson from Freiburg. Out of its annual 192 boardings/person, 98 boardings (51%) are on its comprehensive light rail transit system that is used as the basic anchor and leader for all new urban development within Stadt Freiburg and land uses are closely integrated around its stops. Furthermore, there are another 46 boardings (24%) on suburban rail services, meaning buses are only accounting for 25% of Freiburg's public transport use. The ten Swedish cities overall have only 44 boardings by rail out of 128 boardings/person (34%) and 15 of this average 44 rail boardings/person across the whole sample, are from Stockholm's tunnelbana system! It appears that Swedish cities need to explore how to integrate some light rail systems, especially into those parts of their urban fabrics that are denser and to lead and anchor new development in the future with higher density mixed land uses.

4.4. Is it Possible to Explain Some of the More Atypical Patterns of Urban Land Use and Mobility Characteristics of Swedish Cities?

This fifth research question has been explored in the discussions already provided in Section 4 and throughout the paper in the individual variables. To answer this question more definitively an exploratory statistical analysis is needed which tries to bring together a range of dependent variables such as car, public transport and non-motorised mode use and see if the variability amongst the Swedish cities on these factors can be explained to a reasonable level of statistical reliability. This analysis can now be made since ten cities with identical data sets is enough to undertake meaningful statistical analyses. The database contains a host of potential independent or explanatory variables and there remains the possibility of collecting more variables that were not within the scope or budget of the two small research grants provided for this work to date.

4.5. Are There Any Policy Lessons that can be Learned from the Comparisons?

The sixth asked research question was: Are there any policy lessons that can be learned from the comparisons? Based on the data here, urban and transport policy for enhanced transport sustainability in Swedish cities could focus on four key areas.

4.5.1. Density

The cities would do well to focus on targeted increases in higher density, mixed use development that is especially linked to expanded and improved public transport, especially light rail, as supported by section 4.3 about lessons from Freiburg. Stockholm is by far the best of the Swedish cities in sustainable transport and although it is still a low-density region, it is bound together by strong and now diverse urban rail networks (light rail, metro, and regional rail), around which very high density, mixed use development has occurred in strong centres throughout the region. Such an approach could be emulated in other Swedish cities in ways that are appropriate to their size and scale.

Regarding this lower use of public transport, we find that vehicle and seat occupancy is generally lower in Swedish cities than elsewhere meaning unutilised spare capacity, mostly in the off-peak. This can also be addressed by better land use planning to ensure that there is more off-peak travel due to more activities that people need in the off-peak being clustered around public transport stops. More significant sub-centres for work and other activities can also create greater back-loading on reverse peak direction public transport, which ensures more balanced use of public transport and greater off-peak loadings.

4.5.2. Freeways

There is also a need to restrict further development of already abundant freeway and road systems in all Swedish cities and perhaps to consider some focused removal of freeways, especially to help green the cities and improve public spaces. The thought of removing freeways is a radical one and is usually met with claims that the existing traffic will simply flow over everywhere else and cause chaos. However, it has been shown repeatedly that traffic behaves more like a gas than a liquid, adjusting its volume according to the size of the "container" provided (in this case, road capacity) (Schiller and Kenworthy, 2018; Kenworthy, 2012). It is thus important in such endeavours to eliminate freeways to provide demonstrative projects of "disappearing traffic" so that other cities can learn from these experiences and feel more confident that such an approach can work. There are numerous examples of freeways that have been successfully removed. The Seattle Urban Mobility Plan (2008) provides a catalogue of case studies of these projects, such as the Embarcadero and Central Freeways in San Francisco, California and the Harbor Drive Freeway in Portland, Oregon.

However, one of the best examples to date (also included in the Seattle Urban Mobility Plan, 2008) is the Cheonggyecheon restoration project in Seoul (Figure 34), which removed 6 km of elevated freeway and surface road carrying collectively 170,000 vehicles per day and created a green river boulevard in their place. The average traffic speed *improved* in Seoul after the removal of the freeway (Schiller and Kenworthy, 2018; Seattle Urban Mobility Plan, 2008). This project stands as a landmark of both how traffic adjusts to a reduction in high capacity roads and the sheer attractiveness and beauty of the green environments that can replace such traffic corridors.

Figure 34. Seoul's Cheonggyecheon restoration project after freeway removal, resulting in improved not worsened traffic speed. Source: Jeffrey Kenworthy.

4.5.3. Buses Versus Rail

Swedish cities have an over-reliance on bus systems and a need for more extensive urban rail networks, which are critical in developing competitive public transport and achieving a wide range of other environmental, economic, and social goals (Kenworthy, 2008; Litman, 2004). A major difference between Swedish and European cities generally is that European cities have over five times higher rail use and this is a critical distinguishing feature in the lower public transport use in Swedish cities compared to other European cities. This is particularly true of Freiburg where its extensive light rail transit system forms the backbone of its well-performing public transport system, especially when compared to smaller Swedish cities.

4.5.4. Non-Motorised Modes

Finally, Swedish cities, especially the smaller ones, already perform well in walking and cycling with 30% of daily trips on average being by these modes across the ten cities and Uppsala has nearly 47%. This global advantage should be capitalised on by continuing to do more in infrastructure provision, urban design and travel behaviour modification programs to grow these modes. Freiburg shows what can be achieved when a concerted effort is made in this direction, especially when linked to higher densities and more mixed land use.

5. Conclusions

Through a wide-ranging investigation of 69 comparative land use, transport, and related indicators, ten Swedish cities were investigated in detail for their urban transport sustainability characteristics. They were shown to form a somewhat unique group of cities in the world with lower densities, but significant positive transport features, including only moderate car use compared to other cities with similar densities.

The strengths of the ten investigated Swedish cities lie in the following factors, which imply certain policy responses:

1) These Swedish cities have on average low CBD parking per 1000 CBD jobs, though some such as Västerås are high and need attention. Low CBD parking relative to jobs can change over time so that there is a need to limit the addition of new parking in the city centres of Swedish cities, which generally means changing parking regulations to require less parking in new non-residential land uses (and residential developments) in recognition of the access advantages of city centres by public transport, walking, and cycling. It is also possible to replace current parking lots and structures with other uses, especially residential, which in turn could be encouraged with special taxes on CBD parking.

2) These Swedish cities also have lower levels of car and motorcycle ownership than other cities, but this too can change unless consideration is given to active disincentives to acquiring more cars (and incentives for owning less cars). Incentives can include attractive car-on-demand and car sharing schemes, as well as more bike sharing schemes and recent new technologies such as the increasingly common dock-less e-scooters. All these sharing systems would benefit from electric options (pedelecs instead of regular bikes), which are generally more attractive to users. It can also mean considering placing car ownership deterrents, such as Singapore-style Certificates of Entitlement requiring bidding at an auction and paying a substantial sum just for the right to purchase a car (Schiller and Kenworthy, 2018).

3) Public transport in these Swedish cities is relatively well-developed in an infrastructure sense and has the multiple advantages of a very high line length and reserved route per person, mostly good seat kilometres per person, and a high average speed, both in absolute terms and in relation to car speeds. High bus average speeds are particularly noteworthy. It is important to maintain these advantages and one of the key ways is to introduce light rail systems, which are physically segregated from general traffic, such as what Lund (Malmö region) is developing now and Stockholm has been progressively doing over the last decade. Another important aspect is to stop building high capacity roads, which only favour more car traffic.

4) Walking and cycling in Swedish cities is comparatively high and can be further strengthened by increases in density and mixed land use, especially in sub-centres and through progressive extensions and upgrades to walking and cycling infrastructure. Increasing the use of pedelecs (e-bikes) and e-scooters will extend the range of cyclists, as will better integrating bikes with public transport (bicycle parking at stops and facilitating more bikes on board public transport). Buses are limited in how many bikes they can carry, whereas rail vehicles are less limited, which constitutes another good reason for the provision of more rail in Swedish cities. The Covid 19 crisis is now leading many cities around the world to want to retain some of the gains during this period by dramatically increasing the space allocation for pedestrians and cyclists all over cities (e.g. see Laker, 2020 and Johnston, 2020). Swedish cities should consider this trend.

5) Energy use in private passenger transport, the big energy user in the passenger transport sector, is of a typical European medium level in Swedish cities. However, there is scope for further improvement by reducing actual car use and by using less energy intensive automotive technologies. Electric vehicles are one option, but care needs to be taken to consider the embodied energy and other resources in electric vehicles, not just the operational use. Avoiding car use altogether is a better energy conservation strategy than any new technology.

6) Transport deaths are exceptionally low in Swedish cities, at least partly a reflection of Sweden's Vision Zero national policy. Transport deaths do, however, vary between the larger cities with fewer deaths per 100,000 persons compared with the smaller cities with on average almost double the deaths. Sweden can further strengthen its already significant global reputation in this field by further improvements in transport safety, and especially by enhancing conditions for vulnerable road users, mainly pedestrians and cyclists of all ages.

7) Transport emissions per capita are very low in these ten Swedish cities, the lowest in the world, and this advantage can be further pressed home by tightening emissions regulations, eliminating diesel use in cities, as is happening in the United Kingdom and Germany at present, and promoting the use of electric vehicles. Care again needs to be taken, however, in not treating electric vehicles as a panacea for the problems of cars in cities. Eliminating excessive driving is a far better solution for air pollution and air quality, as every city in the world has attested to during the Covid 19 virus pandemic.

The two key weaknesses of Swedish cities are their low overall density reflected in the lower levels of public transport use, especially boardings, than other European cities and the relatively low level of rail provision, except in Stockholm and to a lesser degree also in Göteborg. The use of rail in these Swedish cities is very low compared to other European cities and Malmö, and the smaller Swedish cities are even lower than the larger US cities in this comparison. Freiburg shows clearly some of the advantages of having LRT as a backbone for an urban public transport system. These problems can be solved simultaneously by densification and intensification through mixed land use in sub-centres (also accompanied by limiting parking) and the linking of new or existing rail services to these centres. Adopting this approach can also assist with greater back-loading of public transport services in the peak and enhanced off-peak usage by integrating a wide variety of land uses around stops.

The issue of funding for new rail lines is of course important and in this respect, value capture could be productively exploited to achieve more funds for rail investment, as well as providing more incentives for denser development for developers, planning authorities and transport agencies alike (McIntosh et al, 2015).

It is also worth highlighting that there are many problems in collecting data in Sweden, some of which resemble problems in other cities and some are peculiar problems of transport and land use data in Sweden. These have been mentioned in the report (e.g. lack of bus lane and line length data for bus and rail). If anything, the data collection process highlighted the great need within Sweden to have much better data availability and standardisation. Many of the problems encountered in this research could have been avoided if, for example, Sweden had national guidelines or even legislated requirements for all public transport operators and agencies to provide annual returns of a wide range of critical public transport data so that government and policymakers could much better identify strengths and weaknesses in different urban areas and address them. It is also important to have more stringent data-keeping requirements on matters such as parking, the reporting of travel survey data and a better methodology for collecting travel survey data that would reveal the critical car occupancy information for different areas in Sweden. Without this, it is hard to compare passenger kilometres for cars and public transport.

These ten Swedish cities are very different in size and are at very different stages in their evolution, though there are unifying aspects and commonalities, as well as points of departure, as revealed in this international comparison. The value of this international comparison of cities on an aggregate level, as well as comparisons within Sweden itself, was demonstrated and the ability of such research to highlight the strengths and weaknesses of specific cities and the needed policy priorities to improve cities was explained. The database that now exists for these ten cities can be exploited in a statistical sense to better understand if the different patterns of car use, public transport use and non-motorised mode use can be explained in a statistically significant way from the wealth of potential explanatory variables available here.

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