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Pedestrian Volume Studies

A case study in the city of Gothenburg

Master of Science Thesis in the Master's Programme Geo and Water Engineering

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Road and Traffic Group

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Cover:
A representation of pedestrian activities in the city.

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Abstract

Today, non-motorized traffic is getting more attention due to the lack of knowledge on this specific subject and the new shift to sustainable development. According to the literature review, general and established guidelines for pedestrians' studies do not exist. In this respect, the purpose of this study was to build up a basis for further studies related to pedestrians and to develop a methodology for counting them. Using the established methodology, the counts of pedestrians were performed using three different methods: manual counting, automatic counting and video counting.

The case study was performed in two streets located in a highly commercial zone in the centre of the city of Gothenburg: Drottninggantan and Kyrkogatan. The methods were all applied for these streets to obtain data of pedestrians. The obtained data was used to generate general statistics of the area (e.g. percentages of genders, volume directions, ages, etc.), create volume patterns and develop a model to find the optimal short count (e.g. 5 min, 10 min, 15 min, etc.) to expand it to hourly volumes. Furthermore, the data was used to calculate expansion factors, calculate the errors of the automatic devices used to get the data and also to make conclusions about how each counting method was performed.

The automatic devices were good indicators of the volume patterns of each day. However, the percentage errors in the volumes were considerable for these devices and must be taken into account to assess the accuracy of the results. Video counting was the most reliable counting methodology followed up by the manual counting. The streets measured had the same land-use and the volume proportions for each section of the streets were similar but they had small variations which could be attributed to errors in the automatic counters and to the intrinsic variations that could exist in each street. The model resulted in that larger sample intervals short counts account better for the variability of the volumes within the hour sampled.

Further studies are recommended because of the limitations of this study. Future research could be performed in subjects such as origin-destination surveys, use of other counting technologies, among others.

Key words: pedestrian counting, pedestrian volumes, pedestrian studies, pedestrian methodology, estimating pedestrians, short-counts pedestrians, measure pedestrian and counting non-motorized traffic.

Contents

Preface

During the development of this research, several methodologies are applied for counting pedestrians in two streets of the city of Gothenburg. The task is part of measuring the actual volumes of pedestrians walking in the city centre of Gothenburg. The project is carried out from September 2010 to February 2011 at the Department of Civil and Environmental Engineering, GeoEngineering division, Chalmers University of Technology and at the Traffic and Public Transport Authority of Gothenburg.

The project has been carried with Edwards Santana and Jorge Yannie as researchers, Professor Gunnar Lannér as examiner-supervisor and Anna-Lena Lindström as supervisor. All the materials used to develop and apply the methodologies are supplied by the Department of Civil and Environmental Engineering, GeoEngineering division, Chalmers University of Technology. We would like to thank Gunnar Lannér and Anna-Lena Lindström for their help and enriching comments and ideas. In addition, we express gratitude to Thomas Jonsson, David von Martens, Annika Nilsson, Marleny Lora, Ivannia Santana, Karin Björklind, Max Falk, Laura Lelliot, and the whole planning department of the Gothenburg's Traffic and Public Transport Authority for their help and involvement. In addition, we would like to thank Vectura Consulting AB for their contribution in the project by supplying us with the data from the automatic counters.

This project could have never been conducted without the help of Orlando Mezquita, a close friend from the Dominican Republic, who guided us through the statistical analysis of the obtained data. Finally, we would like to specially thank our family and friends for the support and help throughout the development of this research.

Göteborg February 2011

Edwards Santana

Jorge Yannie

Jorge Yannie:

“By observation one can define the underpinning patterns of things on Earth”.

Notations

α-value	The probability of rejecting the null hypothesis when the latter is true.
AF_i	Adjustment factor for day “i”.
EHF_i	Expansion hourly factor; for the specific hour “i” of study.
EHF_p	Expansion hourly factor for the peak hour.
NP_r	Number of pedestrians considered to be real (e.g. manual or video counts).
NP_x	Number of pedestrians counted by the automatic counter or field observers.
p	Number of periods within the hour.
p-value	Indicates how well the sample evidence supports the decision to reject the null hypothesis.
PHF	Peak hour factor
R^2(adjusted)	R^2 adjusted for the number of explanatory terms in a model.
R^2(predicted)	The proportion of the total variation in Y that is accounted for by the predictor variable X.
S	Residual standard deviation.
V_a	Average volume for the counted days in the control counts; pedestrians. (e.g. average for all Mondays, all weekdays, etc.).
V_{aj}	Adjusted volume representing an average of the days counted in the control counts study period, pedestrians (e.g. average volume for Mondays of month “x”).
V_c	Coverage count volume for the same hour as the EHF, pedestrians.
V_{dsi}	Volume for day “i” from the coverage/short counts, pedestrians (could be V_e).
V_{di}	Specific study day “i” volume from the control count study period; pedestrians (“i” represent each day individually counted, e.g. Monday 1, Monday 2, Tuesday 1, Tuesday 2, etc.).
V_e	Total volume expanded for the sample link, pedestrians.
V_i	Specific study hour “i” volume from the control count, pedestrians.

V_{mn}	Maximum volume for a "n" minutes period (e.g. 5 or 15 minutes, V_{m5} or V_{m15}) within the hour, pedestrians.
V_p	Peak hour volume, pedestrians.
V_t	Total volume from the control count for the full sampling period, pedestrians.

1 Introduction

The following chapter gives information of the background, aim, methods and limitations in the work. The study was performed on two streets of the city centre of Gothenburg and it is mainly related to pedestrian volumes studies.

1.1 Background

The city of Gothenburg is in a “state of change” in respect of its urban composition; it is growing and with it comes the necessity of a better transportation system. Growth in the transportation system can be related to environmental impacts and risk of more accidents if improper measures are taken. In these days, politicians are aware of these facts and have created new aims to avoid the latter. New projects have been developed, for example the K2020 with aiming to develop the public transport in the city and the Vision Zero project which targets to have no serious injured in the traffic environment. As a direct consequence the public transportation has to face a major reformation.

The Gothenburg public transport is a very versatile system in respect to the different modes of transportation. It is mainly composed by busses, trams, commuter trains and ferries (motorized modes). In addition, these modes are all interconnected by bicycles and pedestrians routes, making the whole system an interrelated unit.

The transportation field is a very broad field and during these last years it has been well documented, primarily in respect to motorized modes. However, non-motorized modes have been deemed as “less important”, as observed with the scarce information available today. A big obstacle facing the non-motorized field is the poor amount of documentation on usage and demand. This information is important to account for the benefits of projects related to these forms of transportation and to be able to evaluate them against other modes, for example private vehicles (Ragland & Jones, 2010).

Little attention was paid to the pedestrians until recent years; result of stringent safety regulations and a shift to sustainable development, see Figure 1. Today non-motorized transit is getting more attention; exemplified by the project conducted by the Gothenburg’s Traffic and Public Transport Authority in Drottninggatan and Kyrkogatan, two important streets located in the city centre of Gothenburg. The streets’ life in this particular area is characterized by being constantly active. This is an attractive area for pedestrians due to its availability of shops, restaurants and cafes where people can spend their day. Furthermore, they are important transportation corridors for non-motorized traffic.

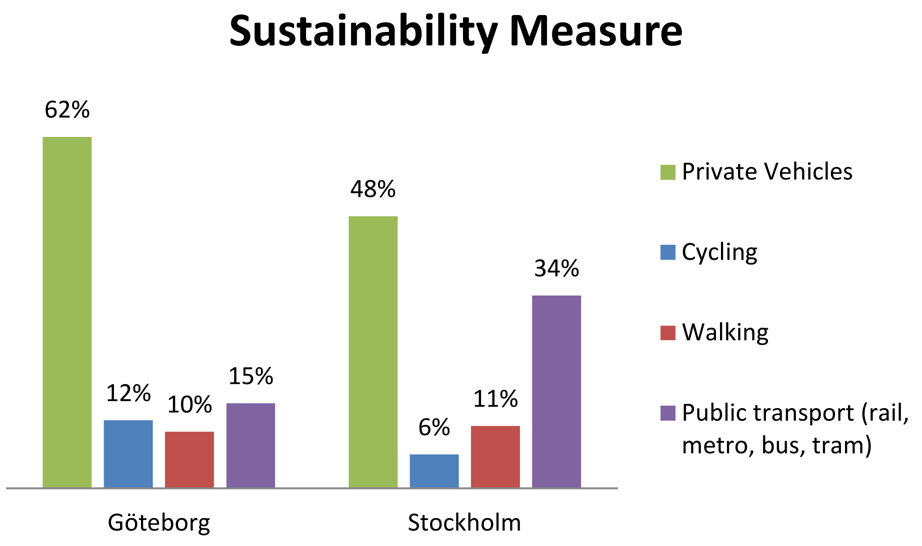


Figure 1. Modal split of the city of Gothenburg and Stockholm as a measure of sustainability (Urban Audit, 2004).

In general the city of Gothenburg is lacking information about the traffic of pedestrians. At the moment, more studies are being carried out due to the lack of knowledge on the behaviour and volume of pedestrians walking on the streets. One example that required pedestrian data was the study performed by Jonsson (2005) about predictive models for accidents on urban links involving vulnerable road users. Another is the investigation done by Niska et al. (2010) about the measures and methods for evaluating pedestrian and bicycle traffic.

1.2 Aim

The main purpose of this research is to build up a basis for further studies related to pedestrian volumes. One target is to evaluate methodologies for obtaining pedestrians volumes and how they could be more efficient. Three different approaches are assessed, manual, automatic and video counting; each of them having their own advantages and disadvantages, as further presented.

In addition, a comparison is done between the volumes obtained from applying the manual counting methodology and the automatic counters. The accuracy of the methodology and the extent of the validity of the undertaken assumptions are evaluated. Regression models are used to determine an efficient short count interval in order to save resources when performing a manual count sampling.

1.3 Method

The search for information was made using resources from the library of Chalmers University of Technology, databases such as the VTI's Transguide and TRIS. In addition, the use of online search engines was helpful to obtain scientific publications in the field. Key words used during the search were: pedestrian volumes, estimating pedestrians, pedestrian studies, pedestrian counting, and counting non-motorized traffic.

Data collecting was performed by the researchers themselves, in relation to manual and video counting. Automatic counters were supplied by Vectura Consulting AB. In addition, data analysis was performed by the help of softwares like Microsoft Excel, Minitab 16 and MathCAD.

1.4 Limitations

The investigation was focused on specific streets of the city centre of Gothenburg; namely Drottninggatan and Kyrkogatan. Both streets are within the same land use (commercial area) and they reflect similar characteristics, limiting the ability to relate the results to other land uses (i.e. residential areas, recreational areas, etc.).

Manual counting was performed in hours within the range of 12.00-18.00 due to time restrictions. A complete day or more than two straight hours were not manually counted. The complete study was performed for 2 months, only accounting for daily and weekly variations.

Most of the theory was derived from motorized traffic modes and modified as needed to fit non-motorized modes. The latter was due to the lack of documentation on pedestrians’ studies.

2 Literature review

The literature review helps to give the reader an insight of the main concepts related to pedestrian volume studies. In addition, it revealed the scarce information available on this topic. The major part of the accessible information was related to studies conducted in the United States. Furthermore, most of the documented theory related to volume studies is from motorized traffic.

2.1 Pedestrian volumes studies

As a way to explain the current status of the transportation system, engineers are required to collect diverse data and information (Roess, et al., 2004). In this manner, focus is set in collecting data related to the volume of pedestrians in the system. The data can have several applications, for example it can help to perform safety analysis studies, look for modifications in infrastructure, forecast future trends in society, business development, among others (Schneider, et al., 2008). The collected data is the basis for obtaining the information needed for the planning, designing and decision-making processes.

It is important to know the actual behaviour of pedestrians so future projects can be proper developed. For example, if the pedestrian's concentration zones are known, future bus/trams/metro stops could be created in order to distribute better the volumes.

In traffic engineering, volume studies are most of the time needed, for example to measure demand or usage of pedestrians. Roess, et al. (2004) defines **volume** as "the number of persons passing a point during a specified time period". The observed volumes can equalize the demand (pedestrian that desired to travel), the capacity of the studied segment (maximum rate) or none of them (Roess, et al., 2004), see Figure 2.

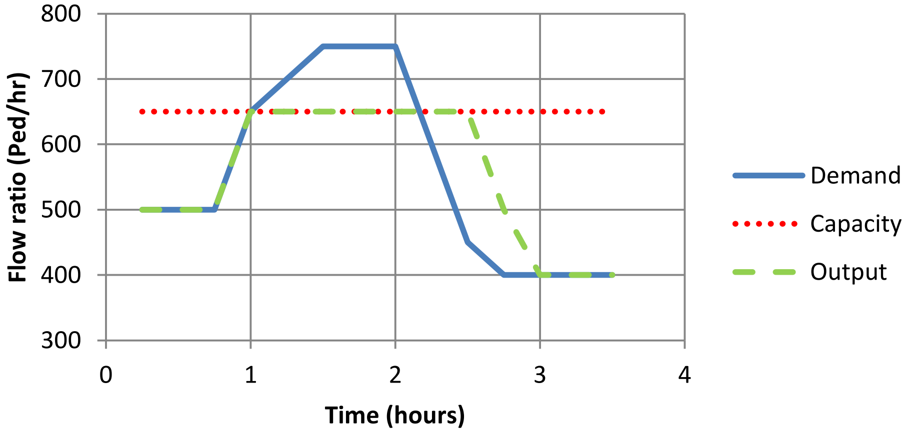


Figure 2. Demand versus Capacity for pedestrian traffic (modified from Roess, et al., 2004). The output reflects how the demand is delayed in time, increasing the usage time.

2.2 Volume characteristics

Volume proportion patterns will be the same even though actual volumes can change in a specific location, unless the site is drastically modified. Garber & Hoel (2002) stated that “regular observation of traffic volumes over the years has identified certain characteristic showing that although traffic volume at a section of a road varies from time to time, this variation is repetitive and rhythmic”. The demand is not a constant value; it changes together with the time (i.e. time of day, week, month or year). Moreover, it can be influenced by external factors (planned or unplanned) such as accidents, occasional events, detours, or even by the weather (Roess, et al., 2004). This is affirmed by Schneider, et al., (2008) and Aultman-Hall, et al., (2009), stating that pedestrian’s activity levels are variable during the day, by location and weather conditions.

With the help of volume patterns it is possible to develop proper design and control methods in a certain area (Roess, et al., 2004). According to Roess, et al., (2004), this is a difficult task for traffic engineers because “planning and designing is usually made for a demand that represents a peak flow rate within a peak hour on a peak day during a peak season”. This translates into the necessity of extensive knowledge of the situation in relation to time.

2.2.1 Time-of-day variation

Traffic changes as the day progresses, e.g. traffic volumes increase during the day and decrease at night. This behaviour is represented in a time-of-day pattern, where different patterns can exist within different places (FHWA, 2001), see Figure 3.

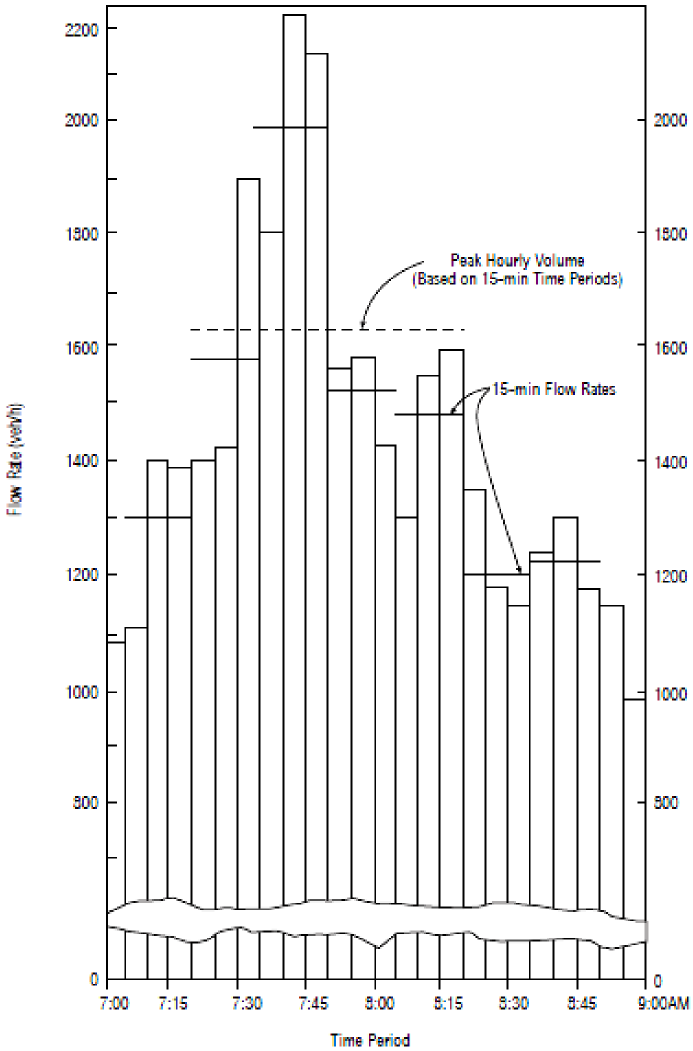


Figure 3. Two hour volume pattern variation from vehicle traffic, where each bar represent 5 minutes flow rate (veh/hr). It is expected to obtain similar patterns for pedestrians volumes (modified from Roess, et al., 2004).

2.2.2 Daily variation

According to Roess, et al., 2004, "daily variation patterns are caused by the type of land uses and trip purposes". Patterns will differ during the week, mainly because the different alternatives activities that can be done in a week; e.g. pedestrians will go more often to shops on weekends in contrast with weekdays when most of them are working, running errands or at school. Day-of-week patterns will also vary with land use, e.g. urban or rural areas, central business district (CBD), downtown, residential area, etc. (FHWA, 2001), see Figure 4.

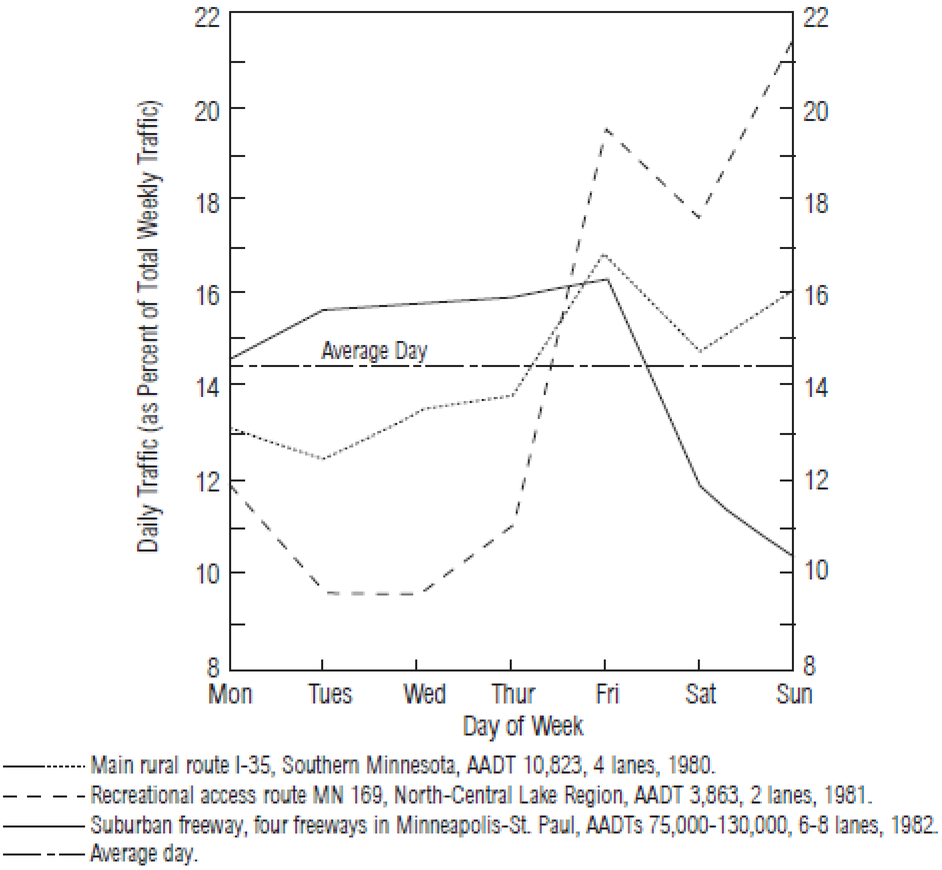


Figure 4. Day-of-week pattern for some roads in the United States for vehicle traffic. Pedestrians' volume pattern will present a similar behaviour during the week in relation to other factors, i.e. land use (modified from Roess, et al., 2004).

2.2.3 Monthly or seasonal variation

Volume patterns will vary during the year according to each season. For example, in summer most trips have recreational purposes whilst commuters' trips are less frequent (Roess, et al., 2004), see Figure 5.

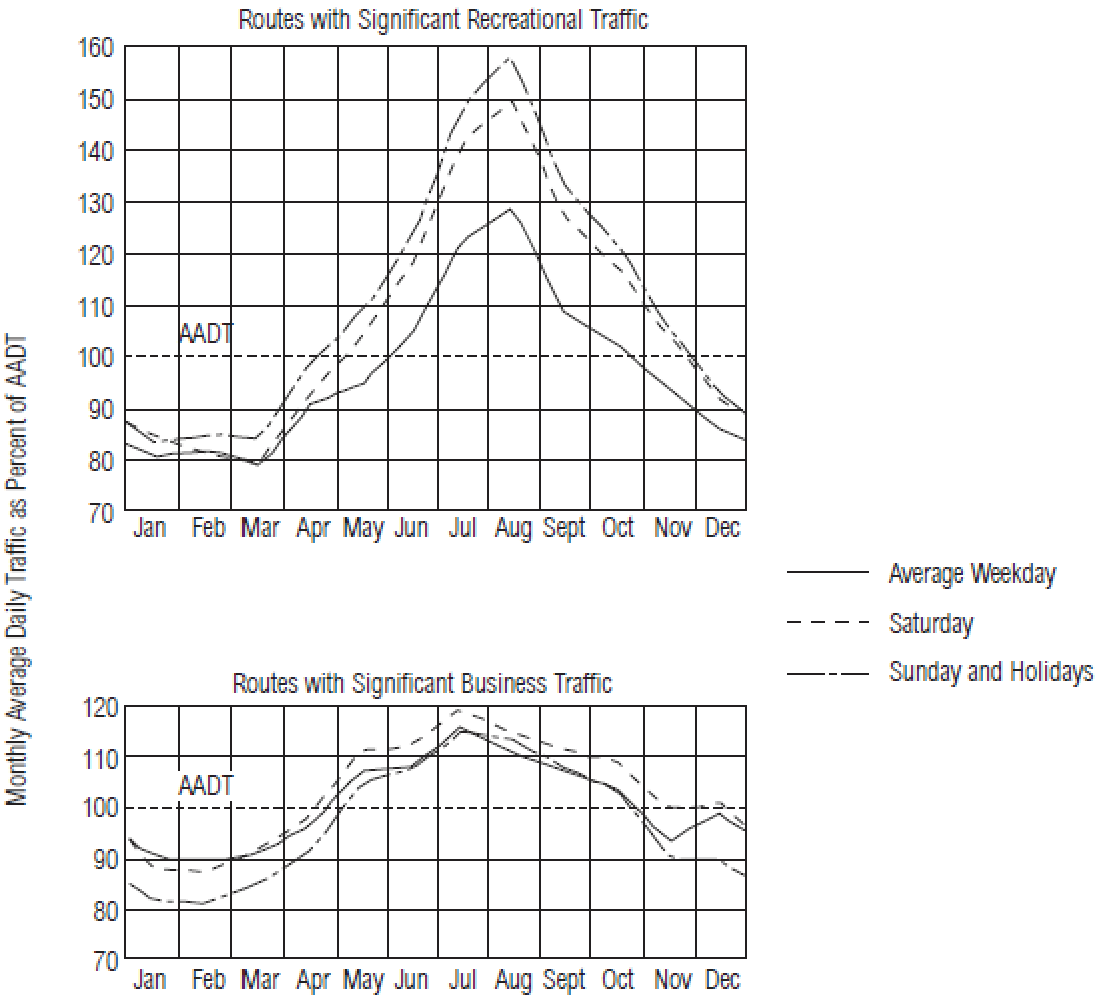


Figure 5. Monthly volume pattern variations for vehicle traffic. Once more it is believed that pedestrian volume pattern will reflect similar behaviour (modified from Roess, et al., 2004).

2.2.4 Directional variation

Most streets exhibit differences in flow by direction. In urban areas, peak traffic can be seen coming into the city early in the morning but in the afternoon the peaks are in the traffic that is leaving the city. The patterns can change depending on the use of the street/road (e.g. where there is recreational traffic) (FHWA, 2001).

2.2.5 Geographical variation

Volume patterns will differ significantly between different places (land uses), mainly because not all the various activities performed by the users are concentrated in one area (FHWA, 2001). It has been found in previous studies that pedestrian volume patterns are site specific (Aultman H., et al., 2009; Turvey, et al., 1987), see Figure 6.

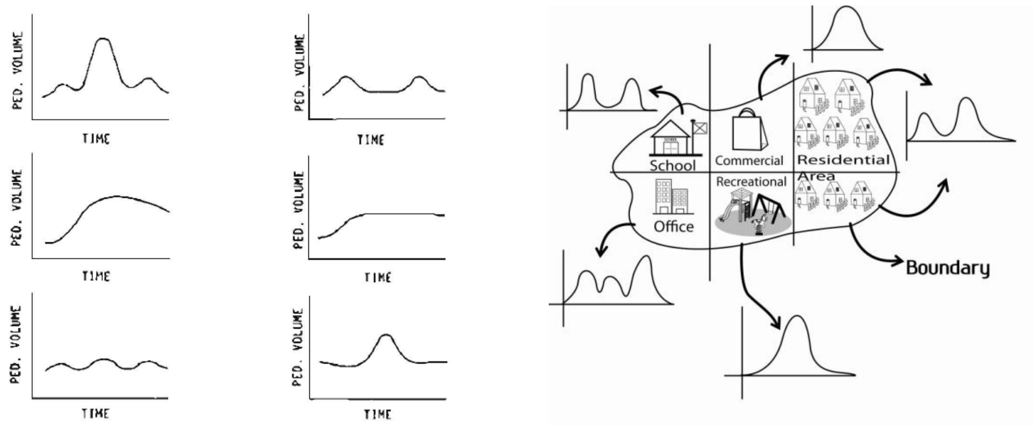


Figure 6. To the left, twelve hour volume patterns for different type of land uses (modified from Davis, et al., 1988) and to the right and illustration of the relation of the pattern with land use.

2.2.6 Weather variation

Severe weather conditions can alter the overall volume pattern within relative short times, i.e. some hours or even a day. Usually extreme weather conditions are not presented for long time periods and can be regarded as punctual fluctuations in the volume patterns.

Aultman-Hall, et al. (2009) found out that there is a weak relation between the weather and the volume of pedestrians. Furthermore, they discussed that the weather perception is more a restriction for the pedestrians than the weather itself.

2.3 Volumes within the hour

Facilities are generally designed to fulfil the peak hour demand. However, there are demands within the hour that reflect a peak that may surpass the capacity and thus generate a breakdown in the system (Roess, et al., 2004). Roess, et al. (2004) defines the **rate of flow** as “the rate at which pedestrians pass a point during a specified time period less than one hour, expressed as an equivalent hourly rate”.

For the above stated phenomena, the study and design of traffic facilities must be done for the maximum rate of flow within the peak hour. In general, 15 minutes periods are used as the base value for the rate of flow. To support the use of 15 minutes time intervals, it is said that collapses of the system for shorter intervals can dissipate and stabilize rather quickly (Roess, et al., 2004).

The mathematical relationship between the peak hour volume and the maximum rate of flow within the hour is defined by the peak hour factor (PHF) as follows (Roess, et al., 2004):

$$PHF = \frac{V_p}{p \times V_{mn}} \tag{1}$$

$V_p =$ Peak hour volume, pedestrians.

$V_{mn} =$ Maximum volume for a “n” minutes period (e.g. 5 or 15 minutes, V_{m5} or

V_{m15}) within the hour, pedestrians.

$p =$ Number of periods within the hour.

The PHF will tell how variable the volume is within the peak hour, e.g. a value close to one will represent a nearly constant volume in each time period. With this factor, the maximum rate of flow can be estimated for the peak hour volume.

2.4 Field methods for measuring pedestrian volumes

Factors like time, land use and weather are taken into account when performing volume studies. It is frequent to perform measurements within times of high pedestrian volume (peak hours). In addition, pedestrian counts are performed in good weather conditions; however there are special cases where the weather variation plays an important role for the study. The locations at which pedestrian counts are done include intersections, along sidewalks, and mid-block crossings (Garber & Hoel, 2002).

2.4.1 Manual counts

Manual counts can supply a large set of data if necessary, for example pedestrians' age, gender, physical handicap and behaviour (Robertson et al., 1994). Furthermore, they are quickly to set up and perform (Roess, et al., 2004). However, they require a lot of effort from trained personnel and collecting data manually for long periods becomes unfeasible due to economical reasons (Greene-Roesel, et al. 2008).

- Equipment for manual counts

There are several equipments used to perfom manual counts, for example tally sheets, hand-counters, board-mounted counters and electronic counters. Tally sheets are most commonly used in manual counts due to the fact that they provide the possibility to classify volumes and write observations, plus they are rather cheap.

- Personnel consideration

In order to obtain good quality data, all the personnel involved in the study and the field counting must be aware of the importance of the study and the final outcome that wants to be reached. A recommendation is to perform trainings on how to use all the material for the counting procedure, some days before it starts (Roess, et al., 2004). A study performed by Diogenes, et al. (2006) supports this fact and address it as a necessary step for obtaining data with good quality.

2.4.2 Automatic counts

Automatic count technologies help to create long-term volume variation patterns in a more efficient way than manual counting (e.g. they do not require man-hours). The most common technologies available for counting bicycle and pedestrian are listed in Table 1. Despite the variable available technology, there is a small amount of information at hand about the performance and reliability on these devices, especially on outdoor environments (Greene-Roesel, et al. 2008).

Table 1. Most common type of automatic counters in the market (extracted from Ragland & Jones, 2010).

Types of automatic counters
Passive infrared, detects a change in thermal contrast.
Active infrared, detects an obstruction in the ray beam.
Ultrasonic, emits ultrasonic waves and listens for an echo.
Doppler radar, emits radio waves and listens for a change in frequency.
Video imagining, either analyzes pixel changes or data are played back in high speed and analyzed by a person.
Piezometric, senses pressure on a material either tube or underground sensor.
In-pavement magnetic loop, senses change in magnetic field as metal passes over it.

2.4.3 Counting periods

The counting period depends on the purpose of the study and the equipment available to perform it. It could be as short as some minutes or as long as a year. The purpose of the study will tell which days and which specific hours within those days to count (e.g. typical weekdays from Tuesday to Thursday at peak hours) (Robertson et al., 1994).

- Continuous counts

Continuous counts give information about patterns, basically of a season, a week or a day. The data obtained with this type of counts is used to calculate adjustment and expansion factors that transform short counts data into other time range estimates or design values (FHWA, 2001).

- Control-counts

The data obtained from control-counts (or "key counts") also help to determine expansion factors. As continuous counts, they provide knowledge about seasonal and monthly volume variation patterns if set for long times (Garber & Hoel, 2002). Control-count stations support continuous count stations (Robertson et al., 1994) and they are established for less time than the continuous counts.

- Coverage counts or short counts

These counts are conducted in sample locations where data needs to be gathered and they are only performed in specific times of the study period (Roess, et al., 2004). Robertson et al. (1994) stated that "a number of studies that use pedestrian volumes often required less than 10 hours of data at any given location". Typical count periods for pedestrian are (Robertson et al., 1994):

- 2 hours; peak period.
- 4 hours; morning and afternoon peak periods.

- 6 hours; morning, midday and afternoon peak periods.
- 12 hours; daytime (e.g. 7:00-19:00).

Normally, count intervals are 5 or 15 minutes. If capacity analysis is required, a 15 minutes interval is preferable. In the other hand, if the study is based on finding a critical peak hour factor, 5 minutes can be selected (Robertson et al., 1994).

Several issues such as time and money do not allow performing counts for all the time periods, which is the reason for conducting short counts. The results from this counting are adjusted or expanded to know the total volume of pedestrians at the sampled location. The larger the variation in the volumes of the short count intervals, the longer the sampling period must be in order to obtain acceptable estimates from the expansion factors (Robertson et al., 1994).

2.4.4 Sampling and sampling theory

Statistical sampling procedures are generally required to be performed in random locations in order to avoid bias on the estimated statistics. However, a random approach is hard to apply due to most of the required data is site-specific (FHWA, 2001).

The amount of samples to take will be related to the level of activity within the selected location. Alta Planning & Design (2010) recommends 1 to 3 samples. If it is noticed that in the counting location the activity of pedestrian is high (e.g. 100 ped/hr) one sample could be sufficient for one weekday and one weekend day. However, if the volumes are low and the place present irregular activities, 2 or 3 counts should be performed on continuous days or weeks. Using several counting periods that are 1 week or more apart will preclude any unusual conditions occurring on a given day from causing a bias in the data (Robertson et al., 1994).

- Dates

Alta Planning & Design (2010) suggested that weekdays and weekend days should be sampled at least one day in order to assess the behaviour of these two time periods. Furthermore, to prevent skewness or bias of the data caused by different factors, counts can be performed on more than a weekday or weekend in a successive way.

In general, the best period to perform pedestrian counts is considered to be during September. This month have the characteristic that all the main activities in a city (i.e. works, schools, tourism, etc.) are active and that weather conditions are appropriate for walking (Alta Planning & Design, 2010). Nevertheless, this is a site-specific characteristic that must be known in advance.

- Time

The times for performing the counts are basically used to address the peak periods in the day. According to Alta Planning & Design (2010) the 12-hour range from 7:00 to 19:00 for both weekdays and weekends are suitable for counting. This time range, usually accounts for most of the volume of the complete day, however this characteristic is site-specific and must be evaluated beforehand.

2.5 Specific volume studies

A number of specific studies related to traffic volumes can be performed for the transportation system. A focus is set in two of them, screen-line counts and limited network volume studies; which are generally combined and performed together.

2.5.1 Screen-line counts

The count consists on creating an imaginary axis perpendicular to the pedestrians' path, where all pedestrians crossing the line are counted. Screen line counts can help to identify the movement of people from one place to another (Robertson et al., 1994). These counts are primarily used to obtain volume patterns and to assess the different factors that affect walking and bicycling in an area (Ragland & Jones, 2010).

2.5.2 Limited network volume study

When dealing with large networks (i.e. a city central street network), sampling procedures are applied assuming that the whole network or sub-part of it will have the same trends of volumes with time. These trends are measured at some locations of the network and then used for other locations inside it (Roess, et al., 2004), see Figure 7. The volume studies for limited network can be done in several ways, as explained below.

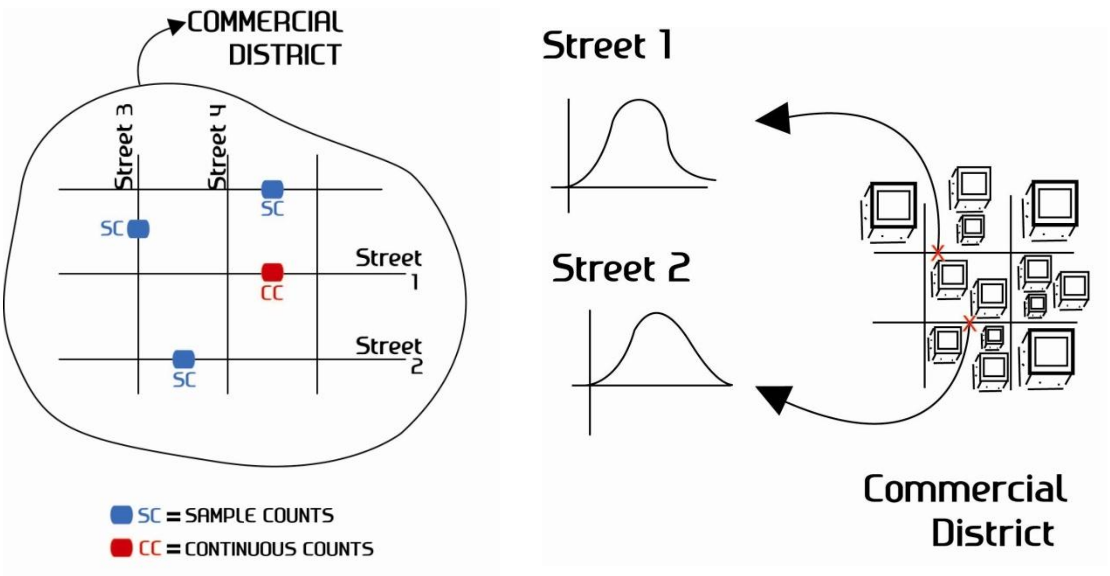


Figure 7. To the left, a representation of a limited network. To the right, an illustration of the correlation by land use.

- A one-day study plan

In this method, one control count is set in a representative place to determine the volume trends of the network (continuous count) and the other streets are measured (coverage counts) within the time of the study period. Coverage counts are expanded using the volume patterns from the continuous counts (Roess, et al., 2004).

A rule of thumb is that the control station must service the same type of street and variations of traffic being sample on the other streets. The control count gathers data for the whole study period. The resulting pattern from these data is quantified by finding out the proportion of volume for the same time intervals as the coverage count, in relation to the complete volume of the control count. This proportion is known as the "expansion factor". To obtain the complete study period volume (e.g. an hour, day, month or year) for a coverage count location, one must divide the coverage count by the expansion factor of the same time interval as it was taken (Robertson et al., 1994). The mathematical procedure for 1 hour is explained below (the same for different times in short counts, i.e. 5 or 15 minutes):

$$EHF_i = \frac{V_i}{V_t} \tag{2}$$

$EHF_i =$ Expansion hourly factor; for the specific hour "i" of study.

$V_i =$ Specific study hour "i" volume from the control count, pedestrians.

$V_t =$ Total volume from the control count for the full sampling period, pedestrians.

$$V_e = \frac{V_c}{EHF_i} \tag{3}$$

$V_e =$ Total volume expanded for the sample link, pedestrians.

$EHF_i =$ Expansion hourly factor; for the specific hour "i" of study.

$V_c =$ Coverage count volume for the same hour as the EHF, pedestrians.

The largest EHF will represent the peak hour within the time period of study. This factor can be used to find the peak hour volume for the other links after obtaining their total volume for the time period of study from expanding the short counts. Mathematically expressed, it is:

$$V_p = EHF_p \times V_e \tag{4}$$

$V_p =$ Peak hour volume for sample link, pedestrians.

$EHF_p =$ Expansion hourly factor for the peak hour.

$V_e =$ Total volume expanded for the sample link, pedestrians.

The expanded data represent the day on which the counts were taken. Daily and seasonal variations have not been accounted by this technique (Roess, et al., 2004).

- A multi-day study plan

Roess, et al. (2004) stated that "hourly variation patterns are not as stable as variations over larger periods of time"; meaning that is preferable to perform the short counts for the whole study period (e.g. from 7:00 to 19:00. Nevertheless, if the counts are performed for the whole study period for each link in the network, several days will be required depending on the amount of resources (e.g. man-working hours). In this matter, the days will have volume variability and to account for it, adjustment factors are applied (Roess, et al., 2004). The adjustment factors can account for a specific day's average, a weekdays' average, a weekend's average, a complete week average or any other time average. The computation of these factors is shown below:

$$AF_i = \frac{V_a}{V_{di}} \tag{5}$$

$AF_i =$ Adjustment factor for day "i".

$V_a =$ Average volume for the counted days in the control counts; pedestrians. (e.g. average for all Mondays, all weekdays, etc.).

$V_{di} =$ Specific study day "i" volume from the control count study period; pedestrians ("i" represent each day individually counted, e.g. Monday 1, Monday 2, Tuesday 1, Tuesday 2, etc.).

$$V_{aj} = V_{dsi} \times AF_i \tag{6}$$

$V_{aj} =$ Adjusted volume representing an average of the days counted in the control counts study period, pedestrians (e.g. average volume for Mondays of month "x").

$V_{dsi} =$ Volume for day "i" from the coverage/short counts, pedestrians (could be V_e).

With this method, the main purpose of the control counts is to obtain daily variation volume patterns, since the coverage counts are performed for the complete day accounting for the hourly volume variation. The goal of the adjustment factor is to regulate the daily variability in order to obtain an average volume for the desired days within the control count study period. It is good to group days in weekdays and weekend days if possible, to obtain an average volume for each. Seasonal variations are not accounted (Roess, et al., 2004).

- Mixed approach

When coverage counts could not be performed for the complete day, a mixed approach can be used. This consists in performing coverage counts for a specific time interval (e.g. 15 min, 1 hour, etc.) in order to expand the volume for the day. Thus, the daily volume is adjusted to account for the average of the control count study period. Again, seasonal variations are not accounted, only daily variation for the days in the study period (Roess, et al., 2004).

3 METHODOLOGY

The literature review has revealed that general and established guidelines for pedestrians studies do not exist. As an example, Schneider, et al. (2008) stated in their work that there is not a standard methodology for counting pedestrians. Most of the theory found is related to motorized traffic; however, more research and efforts to increase the knowledge of this field and set general guidelines is being done in different countries. For example in the United States a national program for counting pedestrians and bicycles is been developed called “The National Bicycle and Pedestrian Documentation Project” (Alta Planning & Design, 2010) and in Europe, programs like “Measuring Walking” (Sauter, 2010). In fact, available information is scarce and very specific.

Having created a standardized methodology sets a basis for future studies. Furthermore it can help to improve data collection efforts by having a consistent method that can be compared in time and improved every time it is executed (Schneider, et al., 2005).

The count of pedestrians was performed using three different methods: manual counting, automatic counters and video counting. The use of different methods was to support the result from each of them and to compare the outcomes.

3.1 Site description

The case study was performed in the city of Gothenburg, Sweden. Data collection was performed in two streets of the city centre, specifically Drottninggatan and Kyrkogatan. These were selected in accordance to the request of the Gothenburg’s Traffic and Public Transport Authority to investigate the actual pedestrian volumes, in order to assess the possibility of making them a shared space between motorized and non-motorized traffic. The two streets are located in a highly commercial zone, shown in Figure 8. Both sections are in the east side of Östra Hamngatan, the main avenue of the city centre of Gothenburg, and intersecting Fredsgatan. The latter street is a “pedestrian street” and is one of the areas where the majority of the people tended to walk. This area is characterized by large volumes of pedestrians shopping, eating and working around.

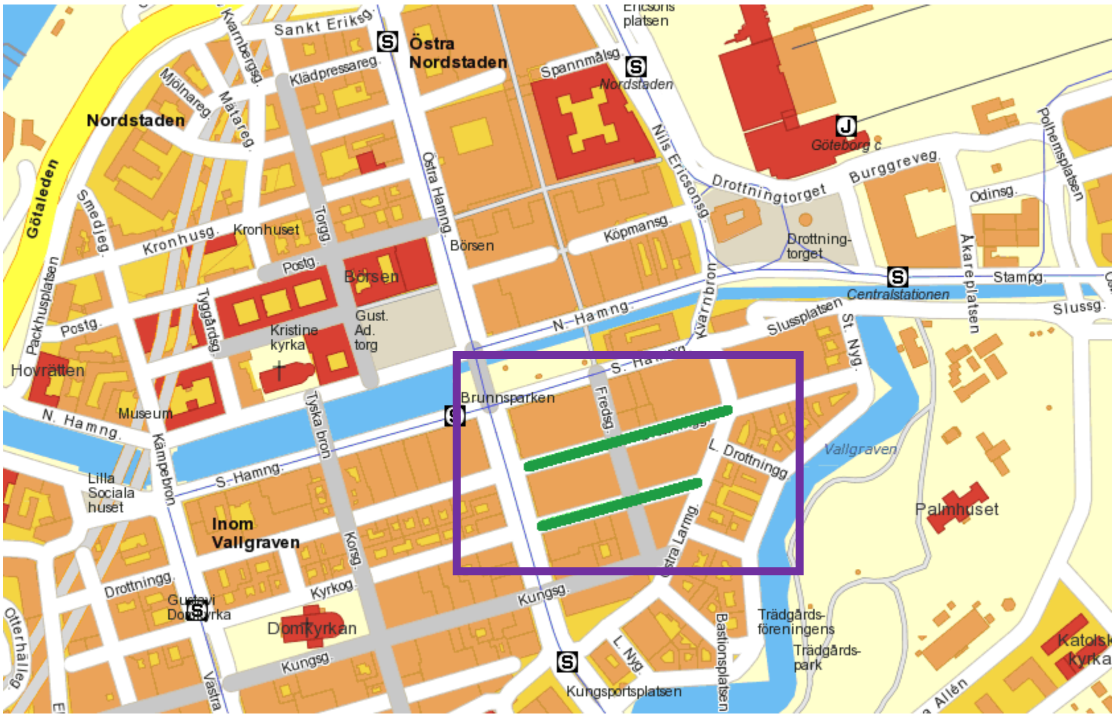


Figure 8. Drottninggatan and Kyrkogatan among the commercial squares of the city centre; counted sections marked by green lines and surrounded by a square (Eniro, 2010).

Each street was divided in two sections that were numbered according to the counting sequence (i.e. section 1 was the first counting place). Each section was composed by two sidewalks, side A and B, which were commonly arcades. The counting points were governed by the location of the automatic counters, which required a place free of obstacles, with a clear view and with the adequate height to count every type of pedestrian. The location of the automatic counters, the field observers, the video camera and each section of the streets are illustrated in Figure 9 (see Appendix 3 for a resized figure).

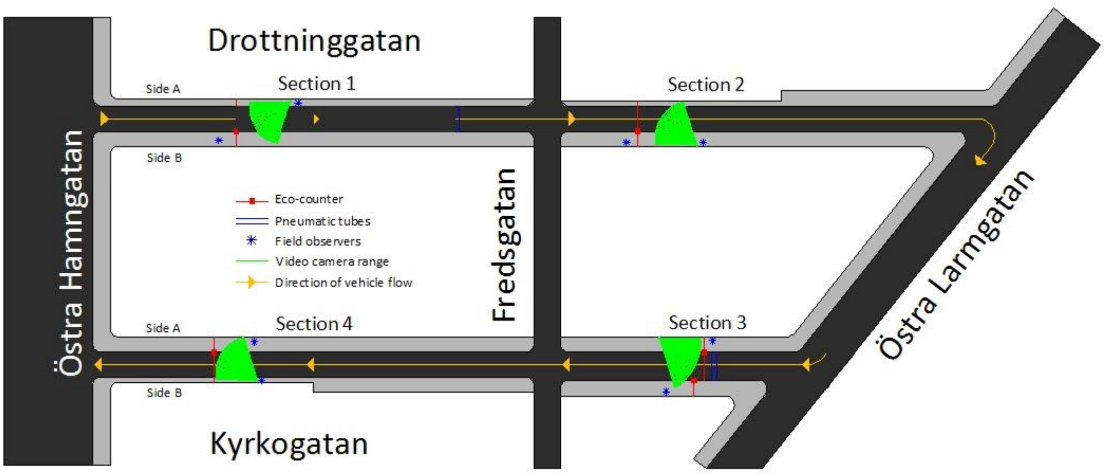


Figure 9. Location of automatic counters, pneumatic tubes, personnel counting and coverage range of the video camera for each section.

The studied segment of Drottninggatan has an approximate length of 200 m and an average street width of 5.70 m. The measured segment of Kyrkogatan has an approximate length of 150 m. The widths of the street are 6.30 m and 5.55 m for section 3 and 4, respectively.

The widths of each sidewalk for all the sections are shown in Table 2; where the arcades widths are measured as the available space for pedestrian to walk. In this table can be noticed that the side A is narrow in both sections of Drottninggatan. Side B is an arcade along the whole segment of this street; see Figure 10 and Figure 11. In the first section, side B gives the impression of a narrow hallway, since the width is almost the same as for side A. For the case of Kyrkogatan in section 3, both sidewalks are arcades, but in section 4, only side A has them.

Table 2. Width of the sidewalks for each street.

Width of sidewalks (m)			
Street	Section	Sidewalk A	Sidewalk B
Drottninggatan	1	1.50	1.60
	2	1.20	2.65
Kyrkogatan	3	2.40	2.35
	4	2.45	1.20

Figure 10. Arcades of section 1 in Drottninggatan. The arcade gives the impression of being inside a long tunnel.

Figure 11. A clear picture showing an arcade in side B in section 2 of Drottninggatan. On the left, the automatic counter (grey box) can be observed mounted to the pole surrounded by a red square.

3.2 Manual counts

Drottninggatan and Kyrkogatan are part of the city centre network. As stated in chapter 3.1, the area is a highly commercial zone with a large flow of pedestrians. The manual count procedure used in this section of the network was a screen-line count. The screen-line count is basically done by standing at a side of the sidewalk and counting every pedestrian that passes in each direction over an imaginary line, in this case along the automatic counter axis as illustrated in Figure 12. The imaginary line was further illustrated by the use of a yellow line in the ground surface in order to increase the accuracy and ease of the counting; see Figure 13. However, there were occasions were the line was drawn by the observers' eyes.

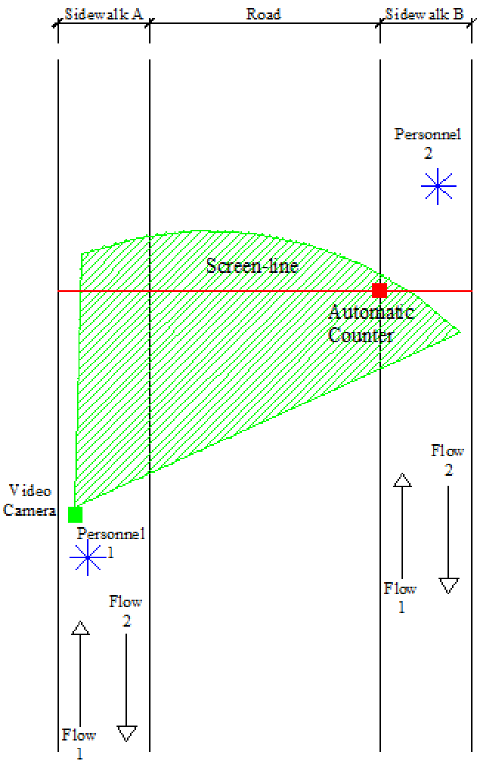


Figure 12. Elements of a counting section.

Figure 13. A yellow tape adhered to the pavement was used as the indicator for the imaginary line in the screen-line counting method.

3.2.1 Sampling

The collection of the field data was made for sample lengths of 1 hour and during good weather conditions, i.e. a sunny or cloudy day without rain. The hours in which the counts were performed, were the ones where the peak hour was expected to take place. It must be stated that some counts were performed for more than an hour, e.g. 2 hours. These hours were selected considering the background information of the place and previous records where the highest volumes of pedestrians have been observed (Bladh, et al., 1984). Specifically, the ranges selected were 12:00-13:00 (lunch time) and 16:00-17:00 (end of daily journeys). Furthermore, other periods of one hour between 12:00-19:00 were chosen to account for different volume scenarios that could be compared later on with the automatic counters.

3.2.2 Data log

For each sample period, the log intervals were set to 5 minutes. This small time was chosen to evaluate variations in the data and as a basis to generate other time intervals. For example, to compare the manual counts with the automatic counts, the smaller time interval possible was 15 minutes.

3.2.3 Days counted

The weekdays were used as the main sample days for this study. In this respect, random days among this group were chosen. From the literature review it was stated that Tuesdays, Wednesdays and Thursdays are days that are likely to have the same pattern of pedestrian volumes within the week (Alta Planning & Design, 2010). Mondays and Fridays were sampled as well because these days are supposed to have different volume patterns (Robertson et al., 1994). A special count was performed on a Saturday to see how the volume changed from that of the weekdays and to assess the fact that the area is a commercial zone with expected higher volumes on the weekends (Robertson et al., 1994).

There are several special days in which it is interesting to know the volume of people walking. For example, Fridays and Saturdays can be different due to traditional activities like "afterworks" and due to the night life. However, these days cause a bias on the volume of pedestrians in comparison to the remaining days of the week; consequently it is better to count in other days rather than these.

3.2.4 Weeks counted

The manual counts were performed during the same time period for which the automatic counters were set. The random sampled days and the time in which the manual counts were performed for each of the streets are shown in Table 3 and Table 4. A total of 27 samples were collected, from which 26 were measured for a whole hour and 1 for half an hour.

Table 3. Amount of manual counts performed in Drottninggatan.

Drottninggatan								
Peak Hour	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.	Sun.	Total
12:00 - 13:00	1	2*		1	2			6
13:00 - 14:00					2			2
16:00 - 17:00	1	1		1				3
17:00 - 18:00		1		2				3
18:00 – 19:00		1						1
Total	2	5	-	4	4	-	-	15

* One of the samples is for half an hour.

Table 4. Amount of manual counts performed in Kyrkogatan.

Kyrkogatan								
Peak Hour	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.	Sun.	Total
12:00 - 13:00	3		2		1			6
13:00 - 14:00						1		1
16:00 - 17:00	1	1				1		3
17:00 - 18:00		1		1				2
Total	4	2	2	1	1	2	-	12

3.2.5 Equipment used

The personnel were provided with all the required material to perform a systemized counting. Some of these included instruction forms, count forms, location map, clipboards, pen and pencils and time watches.

Tally sheets together with a time watch were used as the main tools for undertaking the manual counting. The former contained the basic details of the intersection involved and required information about the observer's name, day and date of the count, weather conditions, observer's location (sidewalk side), time of the count (starting and ending time) and the location of the counting study. See Figure 14 and Figure 15 to view the format of the tally sheet used for the counting. The data that was gathered included:

- The walking direction of pedestrians, i.e. heading east or west.
- Approximate age; this based on a subjective judgement. Children were considered to be below 14 years, adults between 14 and 60 years and the rest as elderly.
- Gender.

Sidewalk Field Sheet
Pedestrian Count

Observer: ____________ **Location:** ____________ **Day:** ____________

Date: ____________ **Start time:** ______ **End time:** ______ ***Sidewalk:** ____________

***Weather:** ____________ ***Temperature** ____________

***Refer to map for Sidewalk side; Weather conditions (can be a mix): sunny, cloudy, rainy, windy; Temperature: warm, hot, chill,**

Notes:

Count all bicyclists and pedestrians crossing your screen line under the appropriate categories.
Count pedestrians who walk on the street.
Pedestrians = people walking, walking a bike, being carried and handicaps using assistive devices (e.g. wheelchairs, children in strollers, etc.)
Bicycles and people using equipment such as skateboards or rollerblades should be included in the "Other" category.
For other observations during the counting period, please note it in the observations" column.

***Map**

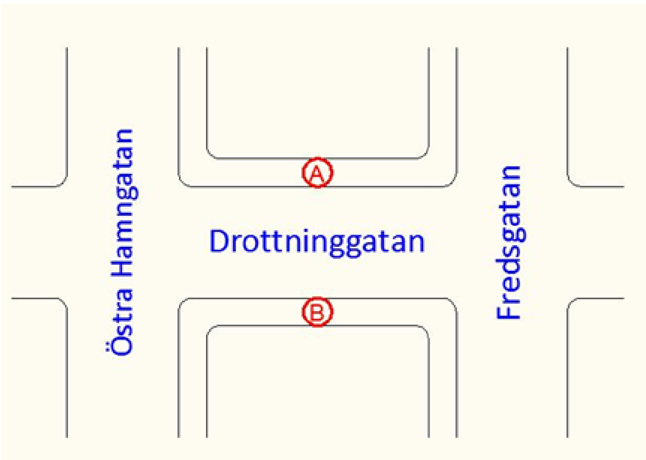


Figure 14. Front page of the tally sheet used. Location, current condition and observer information is registered.

	From ______ to ______ East							From ______ to ______ West							
	Male			Female				Male			Female				
Time Period	M1	M2	M3	F1	F2	F3	Other	M1	M2	M3	F1	F2	F3	Other	Observations
00-:05															
05-:10															
10-:15															
15-:20															
20-:25															
25-:30															
30-:35															
35-:40															
40-:45															
45-:50															
50-:55															
55-1:00															

Figure 15. Counting page of the tally sheet used. Pedestrian volume is classified by gender, age and by walking direction.

3.2.6 During the counting period

Some issues were considered during the counting period. This information was provided in the instruction forms for the observers. A list of these considerations is shown below:

- A person who crossed the imaginary line more than once was counted each time it passed by the line.
- People in wheelchairs or others using assistive devices, children in strollers, etc., were counted as pedestrians.
- Pedestrians that were walking on the streets were counted as well.
- Skaters and cyclists were included in the "others" category.
- Synchronization between the automatic counters, the video counting and the manual counts was verified prior to start the count.

In order to fulfil the curiosity of the people walking in the streets, a sign was set up with the following text: "Pedestrian Investigations from Chalmers University of Technology". Overall, it was enough.

3.2.7 Personnel

The amount of observers that were used for this specific study included 1 person on each sidewalk of the streets. In this case, both researchers assumed the role of counting. They performed the task of handling the video recording and register the pedestrians' volumes in their respective tally sheets. Furthermore, observers were present in the field 15-20 minutes before the counting started to get their proper location, fill the adequate information in the tally sheet and prepare themselves to perform a good count.

The personnel required proper training and a pre-test a couple of days before the counting procedure started. This was done in order to make them familiar with the details of the study and the expected results.

3.3 Automatic counters

Passive infrared automatic counters were used, specifically, the Eco-counter dual-sensor, see Figure 16. Some of the characteristics of this device included the counting in both sidewalks with the dual-sensor simulating a screen-line count, covering a range of 4 meters from each side of it. It logged the data in 15 minutes intervals, which could be extracted easily with a personal digital assistant, "PDA" (Eco-counter, 2010). This type of device is well adapted to perform screen-line sidewalk counts, however it must be placed where pedestrians do not congregate, e.g. in front of a bus or tram station, a shop or cafe, etc. (Schneider et al., 2009 cited in Ragland & Jones, 2010).

Figure 16. Automatic counter used, Eco-counter passive infrared dual-sensor (Eco-counter, 2010)

The automatic counters were scheduled to count for a period of approximately 2 months, as shown in Table 5. For each section, two weeks were counted and then the device was switched to the next section.

Table 5. Itinerary of the automatic counters. Location between the two streets indicated.

Week	Starting Date	Ending Date	Street	Location of the automatic counter	Section
33, 34	17-Aug-2010	30-Aug-2010	Drottninggatan	Östra Hamngatan - Fredsgatan	1
35, 36	30-Aug-2010	13-Sep-2010	Drottninggatan	Fredsgatan - Östra Larmgatan	2
37, 38	13-Sep-2010	27-Sep-2010	Kyrkogatan	Östra Larmgatan - Fredsgatan	3
39, 40	27-Sep-2010	11-Oct-2010	Kyrkogatan	Fredsgatan - Östra Hamngatan	4

To account for motorized traffic, pneumatic tubes were installed as well. Each car that passed over the tubes on the street was counted due to a difference in air pressure created in the tubes by the wheels of the vehicles passing over. Figure 17 illustrates how the equipment was set on the street. It is important to notice that the use of pneumatic tubes in urban areas allow them to be exposed to alterations and jeopardizes the ability to get proper data. Moreover, low speed traffic (e.g. 30 km/hr) can represent a limitation in the efficiency at the time of recording the volumes.

Figure 17. Pneumatic tubes sensors for counting vehicles in Drottninggatan; black tubes on the street.

3.4 Video counting

In random selected occasions, video recording was performed simultaneously with the manual counting in order to assess its accuracy and that of the automatic counters. The video provided more details that could be observed in a repetitive manner and with awareness. The video camera used was a Canon HG10 and the sampling period was for 1 hour.

The camera was set to record one sidewalk and the street; accounting for cars, bicycles and pedestrians. A total of 10 videos were used for the analysis as shown in Table 6.

Table 6. Videos used in the analysis.

Location	Side	Date	Time
Section 1	A	2010-08-20	12:00
Section 1	A	2010-08-27	12:00
Section 2	B	2010-09-06	12:00
Section 2	B	2010-09-07	12:00
Section 2	A	2010-09-13	12:00
Section 2	A	2010-09-14	17:00
Section 3	A	2010-09-22	12:00
Section 3	A	2010-09-23	17:00
Section 4	A	2010-09-29	12:00
Section 4	B	2010-10-05	16:00

4 RESULTS

The automatic counter was able to record a total of 1312 hours for both streets. For section 1 in Drottninggatan, 12 complete days were measured, as for section 2 a total of 13 days. Then, for section 3 in Kyrkogatan 13 days were fully counted as well as in section 4. Overall, 51 complete days were logged by the Eco-counter.

The pneumatic tubes recorded a total of 861 hours, which after a careful analysis of incomplete or not well recorded was reduced to 777 hours. For section 1 in Drottninggatan, 6 complete days were logged by the tubes, as for section 2 only 1 day. In addition, the tubes measured 8 days in section 3 for Kyrkogatan and for section 4 a total of 12 days. Overall, 27 complete days were measured by the pneumatic tubes.

4.1 General statistics

The following chapter will describe the results obtained for both streets from a total of 27 manual counts' samples. For Drottninggatan, a number of 15 samples of 1 hour and 1 sample of ½ hour were used. For Kyrkogatan, 11 samples were considered to evaluate the data. For the gender and ages classification, only 22 samples were used due to that in side A of section 2 it was not possible to classify. All the percentages that will be presented here are calculated as averages of the total samples for each street and for each characteristic assessed. In addition, these values are limited to the sampled hours previously displayed in Table 3 and Table 4.

4.1.1 Pedestrians' volumes on each sidewalk

As a need for assessing the amount of people that used each sidewalk, the average percentages of the volumes are presented beneath in Table 7. As stated in the site description, Drottninggatan's side B is an arcade along the whole measured segment. Side A has a small section that is an arcade, but mainly is a narrow sidewalk where people instead of walking on it, preferred to use the street beside to walk. The average percentages for the people walking in side A were considerably higher ranging between 54 – 63% for both sections, in comparison to side B ranging between 37 – 46%.

Table 7. Comparison of volume percentages for each sidewalk in both sections of Drottninggatan and Kyrkogatan.

Volume per sidewalk			
Street	Section	Side A	Side B
Drottninggatan	1	54%	46%
	2	63%	37%
Kyrkogatan	3	55%	45%
	4	40%	60%

The situation of section 3 in Kyrkogatan indicated that the differences in volumes for both sidewalks were not as high as for section 4. This may be because both sidewalks along this section are arcades with almost the same width. However, in section 4 the percentages of the volumes increased considerably in side B, being this a narrow sidewalk without arcades.

4.1.2 Walking direction

Taking into account the walking direction of pedestrians in the measured sections of Drottninggatan, the tendency of people to walk heading east varied within a range of 45-47%. Thus, people heading west varied within a range of 53-55%. The charts in Figure 18 display the average percentages of people walking to each direction in Drottninggatan, considering each studied section of the street and both sections together to get the average percentages of the whole street.

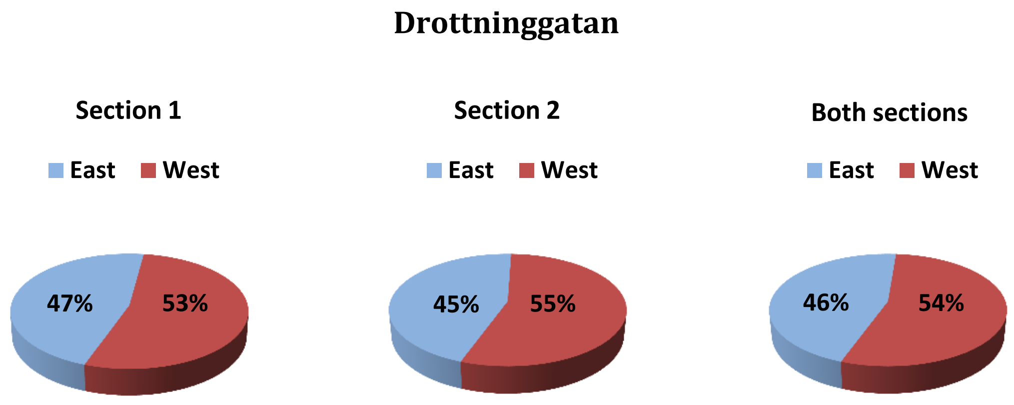


Figure 18. Pedestrian directions of each section of Drottninggatan. The right pie chart shows the average of the percentages for the whole street.

The same analysis was applied in the studied sections of Kyrkogatan. The volumes of people walking were lower, but these did not affect the percentages. The percentages of the direction of people heading to the east ranged between 40-47%. Subsequently, people heading west varied within a range of 53-60%. The charts are shown in Figure 19, in which can be noticed the percentages of people walking to each direction, for its two sections and for the entire street.

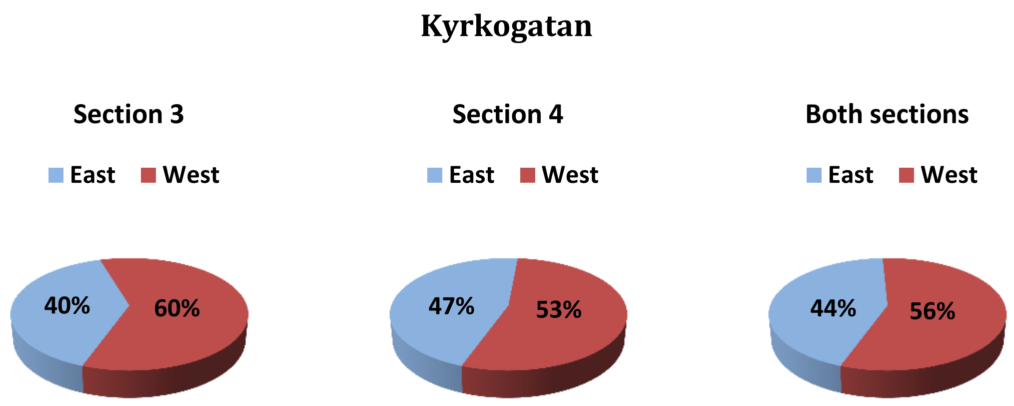


Figure 19. Pedestrian directions of each section of Kyrkogatan. The right pie chart shows the average of the percentages for the whole street.

The percentages of walking directions within the different sampled hours are shown in Table 8. This was considered in order to test the change in the percentages of walking directions at different times in the day.

Table 8. Percentages of walking directions for the different sampled hours in each section.

Hour	Section 1	Section 2	Section 3	Section 4
12:00-13:00	43/57*	45/55	40/60	46/54
13:00-14:00	47/53	-	-	-
14:00-15:00	-	-	-	-
15:00-16:00	-	-	-	-
16:00-17:00	53/47	45/55	-	48/52
17:00-18:00	43/57	45/55	40/60	-
18:00-19:00	58/42	-	-	-

* East/West percentages.

In the main two measured hours (12:00-13:00 and 16:00-17:00), great differences in the percentages of the volumes heading east and west for each section were not observed. It must be stated that this is a small scenario not representative for the whole day as it includes only the two hours with the higher volumes of the day.

The percentage distribution of the pedestrians' walking direction is shown in Figure 20 and Figure 21. For Drottninggatan, people heading west in section 1 is lower than in section 2; as for Kyrkogatan, people heading west in section 3 is more than in Section 4. In both streets, people tended to walk more to the west heading to Östra Hamngatan. In none of the cases above, "others" (e.g. bicycles, skaters, etc.) were considered since they could bias the study, because they tend to travel on the street, usually following the allowed way of it.

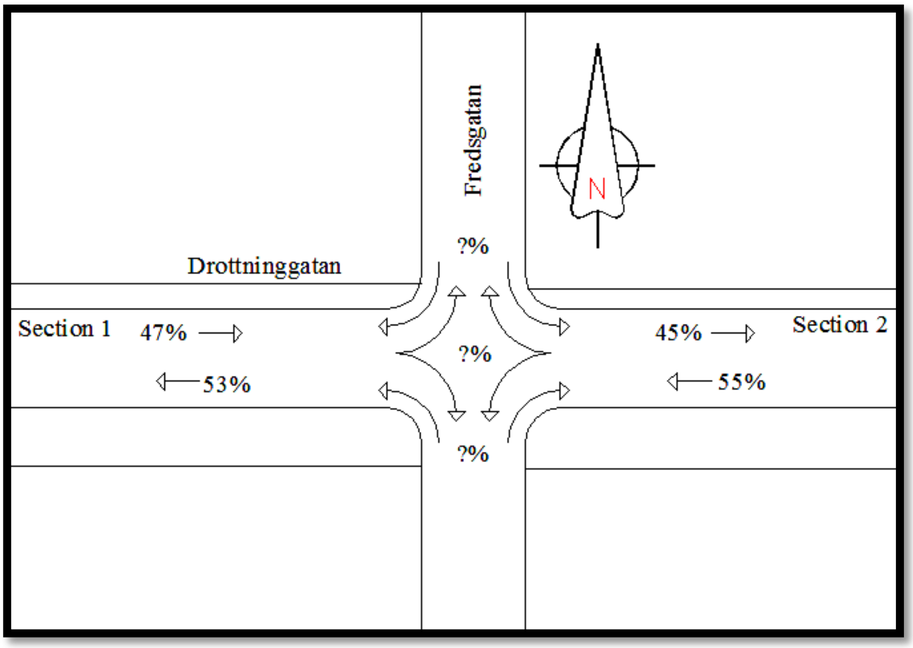


Figure 20. Percentages of flow directions between Fredsgatan and Drottninggatan.

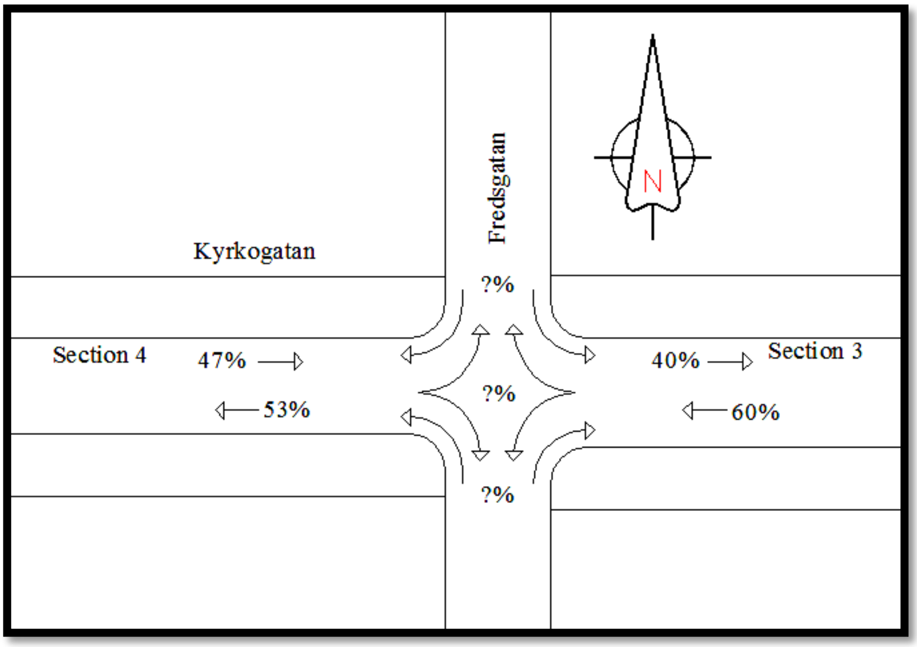


Figure 21. Percentages of flow directions between Fredsgatan and Kyrkogatan.

Dispersion between the people walking from one section to another was noticed in the differences of volumes shown in the illustrative example in Figure 22. It is good to clarify this in order to point out that Fredsgatan is a major pedestrian street where a lot of shops and businesses are available for people and also leads directly to the Nordstan commercial centre.

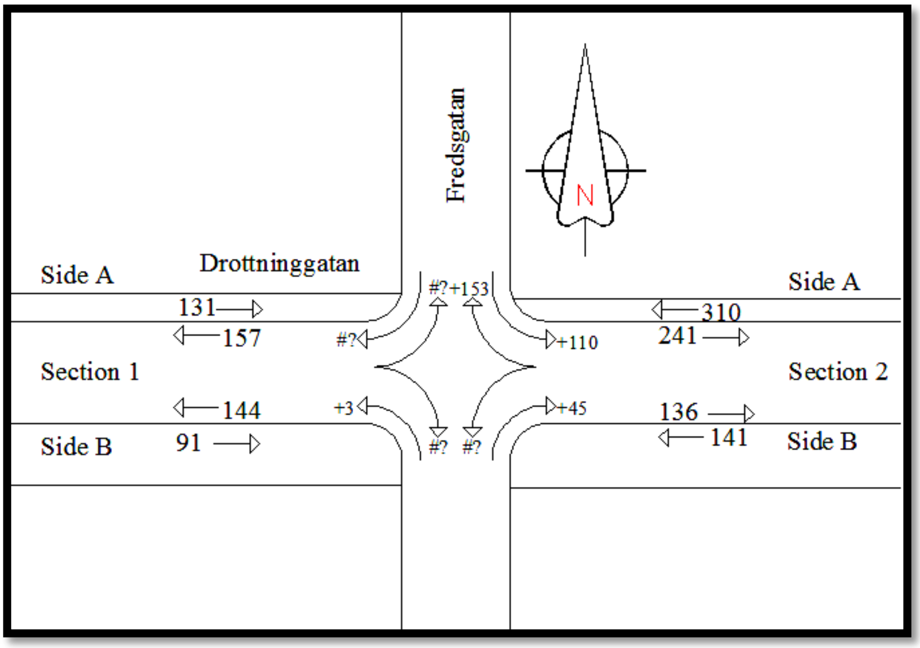


Figure 22. Illustrative example of the influence of Fredsgatan.

The volumes from one section were completely different in comparison to the others, showing the fact that there is an existing influence from the volumes of people walking from and to Fredsgatan. The values displayed in Figure 22 resulted from the averages of the total manual counts performed for these two sections of Drottninggatan within the hour of 12:00 – 13:00. In the illustration, the amount of people heading east in the side A of section 1 accounts for 131 people whereas in the same side but for section 2, the volume is 241 people. The latter explains that the volumes of people must come from somewhere. In this case, it is assumed that the volume comes from Fredsgatan indicated by the value of +110. The meaning of the plus sign is that the volume could be even more than the one stated if the volume from section 1 does not continue directly to section 2.

Due to the limitations of this study, it was impossible to know the amount of people that go from one section of the streets to Fredsgatan or continue walking in the same street to the next section. In this matter, it could be that a larger amount of pedestrians tend to go to Fredsgatan from Drottninggatan or Kyrkogatan and that the volumes balance themselves with the outgoing people from Fredsgatan to the latter streets. Origin-Destination studies could be suitable to perform in this case.

4.1.3 Classification by gender

The average percentages of pedestrians' genders for both streets are presented in Figure 23. The amount of females that walked through Drottninggatan was over the males even though almost equal in proportions; 48% of females and 45% of males. The differences in Kyrkogatan between the genders' percentages are more likely where approximately 53% of females and 43% of males walked through it. A small amount of "others" (e.g. bicycles, skaters, motorbikes, etc.) were using these streets; only 7% and 4% for Drottninggatan and Kyrkogatan, respectively.

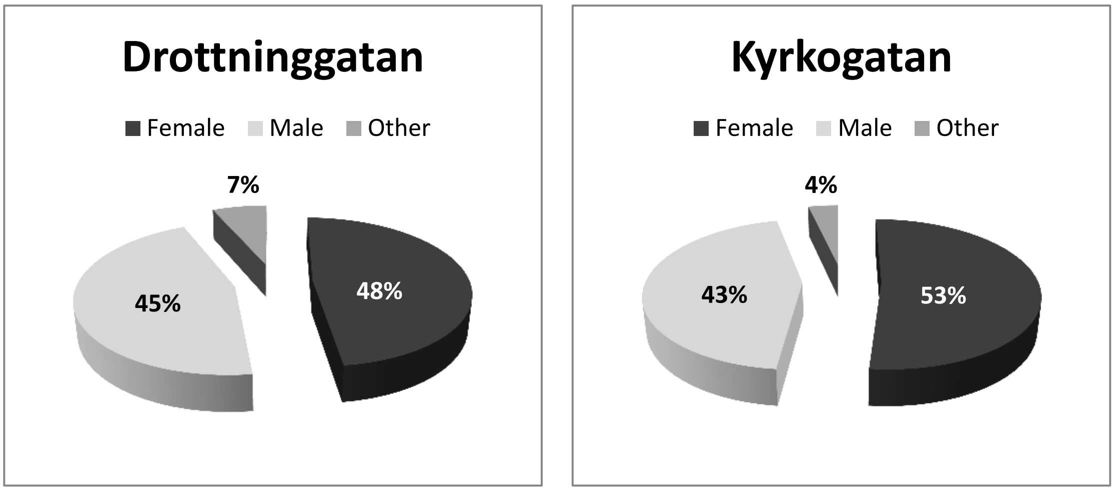


Figure 23. Average percentages of males, females and others in Drottninggatan and Kyrkogatan.

4.1.4 Classification by age

According to Figure 24, the major volumes of pedestrians were from a population that goes from 14 to 60 years old, which corresponded to the adult classification. In both streets, the dominating volume was represented by the adults, which corresponded to a 93-96% of the total population. The percentages of children were between 3-4% for both streets and elderly people were 3% and 1% for Drottninggatan and Kyrkogatan, respectively.

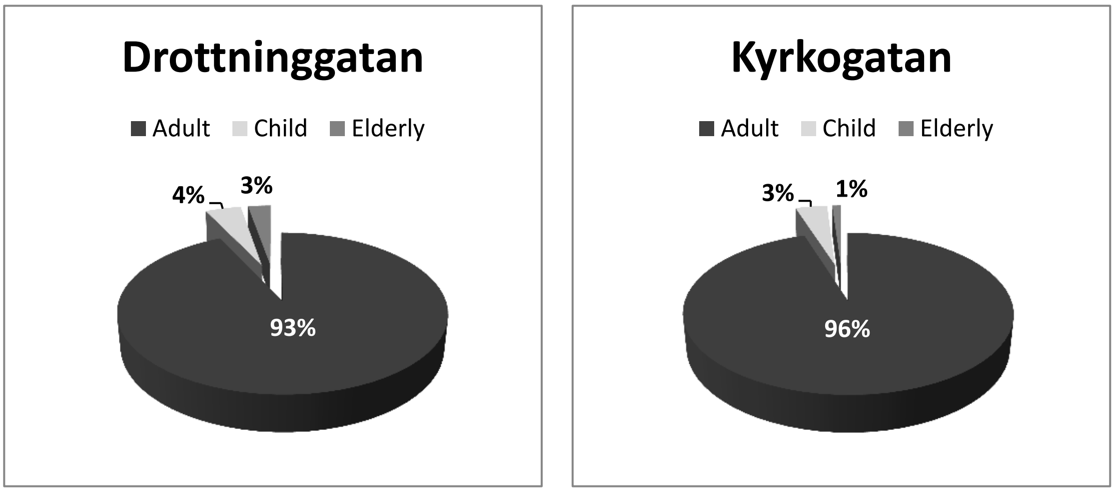


Figure 24. Percentages of ages in Drottninggatan and Kyrkogatan.

There were occasions where the classification of pedestrians was not possible to perform. The limitation occurred when the volume of people exceeded the average rate of 700 peds/hr per sidewalk. In this respect, the count was limited to classify pedestrians and "others" regarding only their direction; but still allowed counting cars. In order to address this issue, the possibility that both sidewalks had the same behaviour, independently from the volume of pedestrians, was analyzed.

The average percentages of males and females walking in each sidewalk (side A and B) of both streets are shown in Table 9 below. For Drottninggatan, these percentages were nearly the same for section 1 in which the classification was possible. In addition, for section 2, classification was made only for side B. A direct comparison between the two sections revealed similar results for both sides B. The percentage of variation between the different sections in these measurements was within the range of ± 1%. How acceptable is the error is always a subject of the level of accuracy that the study requires.

Table 9. Average percentages of genders in each side and section of both streets. The asterisks (*) in side A show where the classification was not possible.

Street	**Section**	**Side A**		**Side B**	
		Male	Female	Male	Female
Drottninggatan	1	47%	53%	48%	52%
	2	*	*	47%	53%
Kyrkogatan	3	45%	55%	41%	59%
	4	47%	53%	45%	55%

For Kyrkogatan, the classification was performed for both sidewalks and for both sections. Again, it can be seen in Table 9 that the percentages are almost the same in all cases, with a percent variation of ± 2-4%. The results showed that for streets that have the same characteristics, the classification can be performed just in one side and the same percentages of the different characteristics can be used for the other side, accepting a small margin of error.

4.2 Automatic counter accuracy

When assessing the accuracy of the Eco-counter, different error scenarios have been evaluated. The error calculations were performed using equation 7 and then analyzed by using boxplots, which allowed filtering outlier data. When an error resulted in a negative value, it indicated that the volumes were below the real ones and represented an undercounting behaviour.

$$Error = \frac{NP_x - NP_r}{NP_r} \qquad (7)$$

$NP_x =$ Number of pedestrians counted by the automatic counter or field observers.

$NP_r =$ Number of pedestrians considered to be real (e.g. manual or video counts).

An initial step was to compare the manual counts with the video counts (real volumes). For this, a total of 10 hours of video were compared with manual counts for the same time period. The average error from the manual counts was less than -1% indicating that manual counts are an accurate source for collecting data if performed with proper procedures and if the personnel are committed to perform the task, as previously stated in chapter 2.4.1.

The second step was to compare the Eco-counter versus the manual counts, since the latter were considered to be accurate enough to represent the real volumes. Three scenarios were defined; the first consisted in comparing the manual counts with the raw data from the Eco-counter. The second was based on refining the data of the Eco-counter by subtracting the cars from the pneumatic tubes or from the manual counts of cars when the former was not available. The third was to subtract the "others" category (e.g. bicycles, skaters, etc.) obtained through manual counts to the second scenario data. A total of 21 hours on week days (the remaining 5 hours had incomplete data or were on weekend days) were used for the analysis and the various error scenarios are presented in Table 10 and illustrated with Figure 25. The percentage of error is a quantity that can be accepted or not by the judgment of the user or the expected use to be given to the data.

Table 10. Eco-counter 15 minutes volume averaged errors.

Location	**Samples (hr)**	**Average Error (%)**		
		Scenario 1	Scenario 2	Scenario 3
Section 1	6	1.1%	-29.9%	-36.8%
Section 2	7	-26.9%	-38.5%	-43.8%
Section 3	3	21.0%	-7.1%	-12.6%
Section 4	5	-5.2%	-19.9%	-24.6%

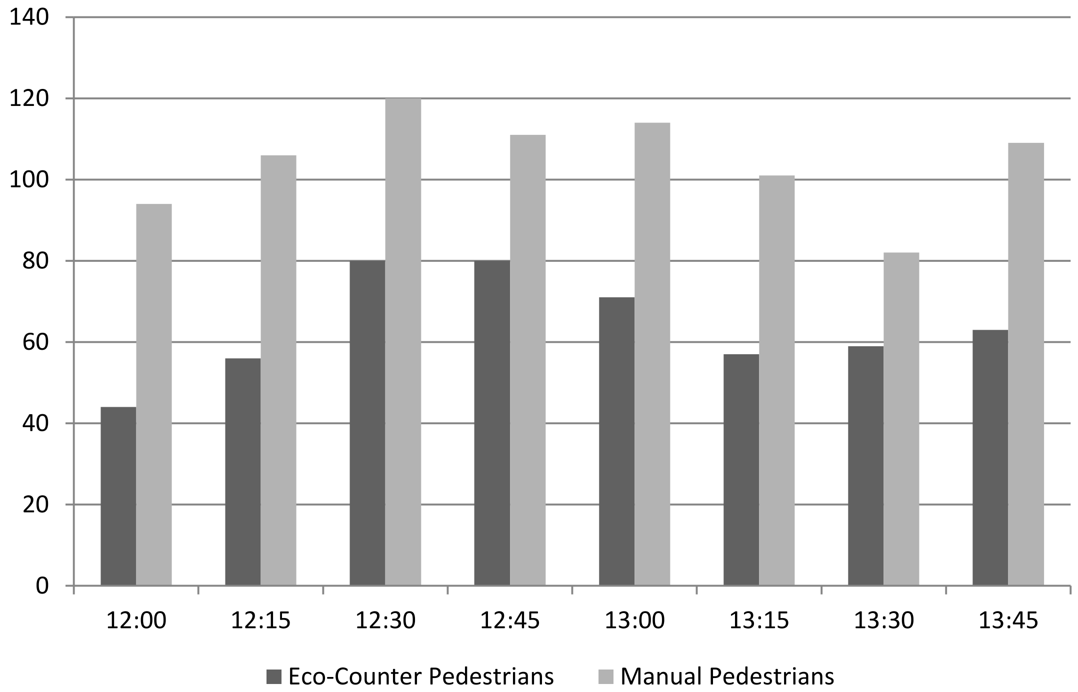


Figure 25. Difference in volumes between the Eco-counter and manual counts; scenario 3. Section 1 in Drottninggatan the 2010-08-20 from 12:00 to 14:00.

The raw data from the Eco-counter could give misleading results if not properly refined, see Figure 26. It is important to notice that if the Eco-counter data had not been refined, the error could be much lower giving a first impression of high accuracy. The above errors could vary more since the data from the pneumatic tubes used to refine the Eco-counter presented errors itself, as shown in Table 11. Here, is observed that the error is positive, resulting in an over counting of vehicles.

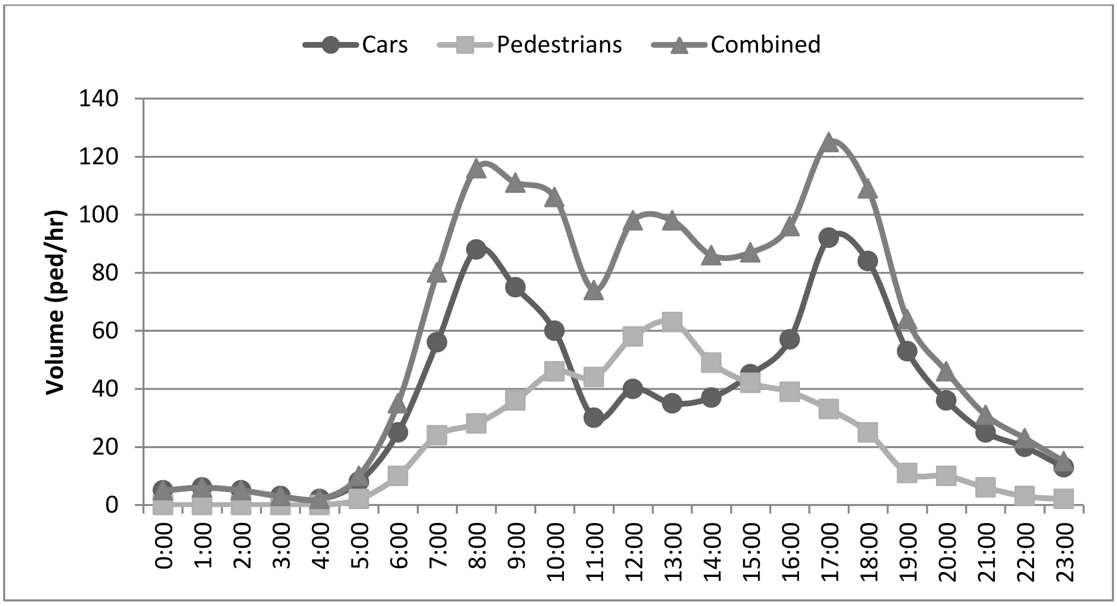


Figure 26.Ilustration of the resulting pattern from combining both cars and pedestrians data. The cars pattern presented two peaks, one in the morning and one in the afternoon. The pedestrians' curve shows only one peak at noon. The combined curve shows a different behaviour from the real case.

Table 11. Pneumatic tubes average error for 15 minutes intervals.

Location	Samples	Error%
Drottninggatan	2	32%
Kyrkogatan	4	9%

The variability of the error in the pneumatic tube is represented by the large range of the interquartiles in the boxplot of Figure 27. In Drottninggatan, the interquartile range is from 12.2 to 51.5% and for Kyrkogatan is from -4.5 to 19.5%. One possible reason of these errors could be attributed to the fact that pneumatic tubes were used in urban areas as stated in chapter 3.3.

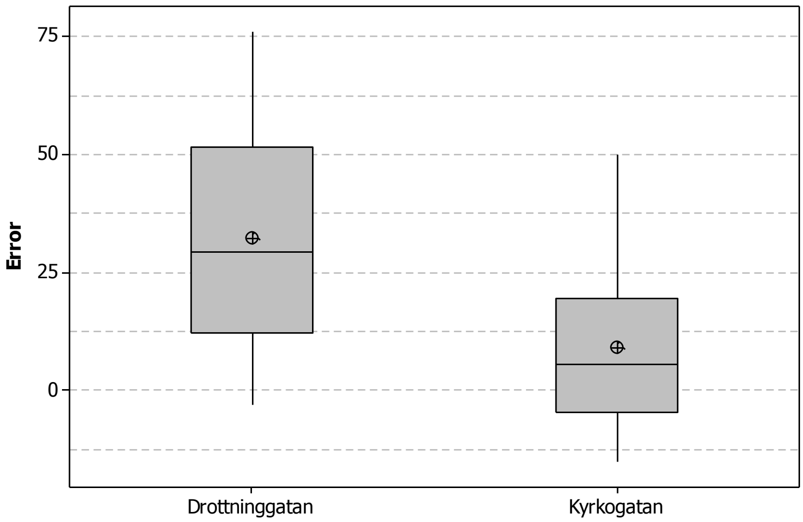


Figure 27. Boxplot of the errors of the pneumatic tubes.

If a real volume of only pedestrians is wanted, the Eco-counter can return it with an error ranging from -12 to -44%, where the minus sign indicates undercounting by the Eco-counter; the latter behaviour correlating with that stated by Greene-Roesel et al. (2008) in their work. The analysis for scenario 3 is plotted in a boxplot in Figure 28, showing the error variability for each section. The values for the interquartiles are shown in Table 12 for the third error scenario. The big range for section 3 can be related to the fact that two counters were set in the place and that a small number of samples were used for the calculations.

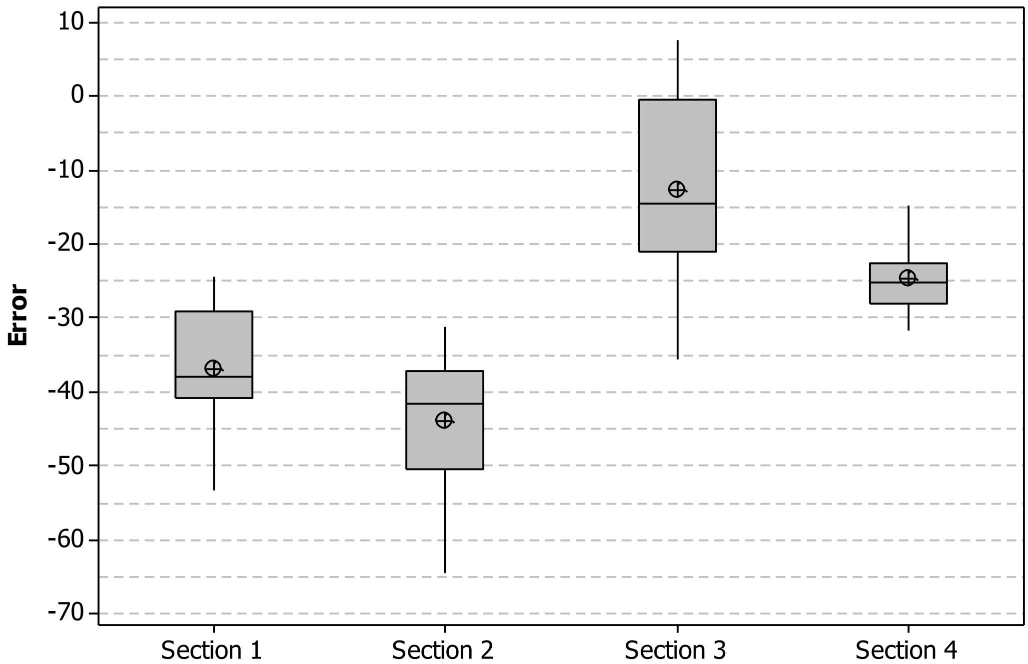


Figure 28. Boxplot of errors between the Eco-counter and the manual counts for the four sections. Cross-Circles represent the mean value.

Table 12. Interquartile values (50% of the total data) from the 15 minutes errors from the Eco-counter.

Location	Samples	Interquartile range
Section 1	6	-29.2/-40.9 %
Section 2	7	-37.1/-50.4 %
Section 3	3	0/-21 %
Section 4	5	-22.5/-28.1 %

Errors cannot be considered to be totally constant as previous studies did (Schneider, et al., 2008). When errors are not constant during the whole day, the proportions of the volumes can be variable and thus bias the results; see Figure 29. However, if a range of variability for the error is accepted (e.g. ±10%) one can still have a good approximation of the real scenario and thus volume proportion patterns can be used for expanding/adjusting manual counts.

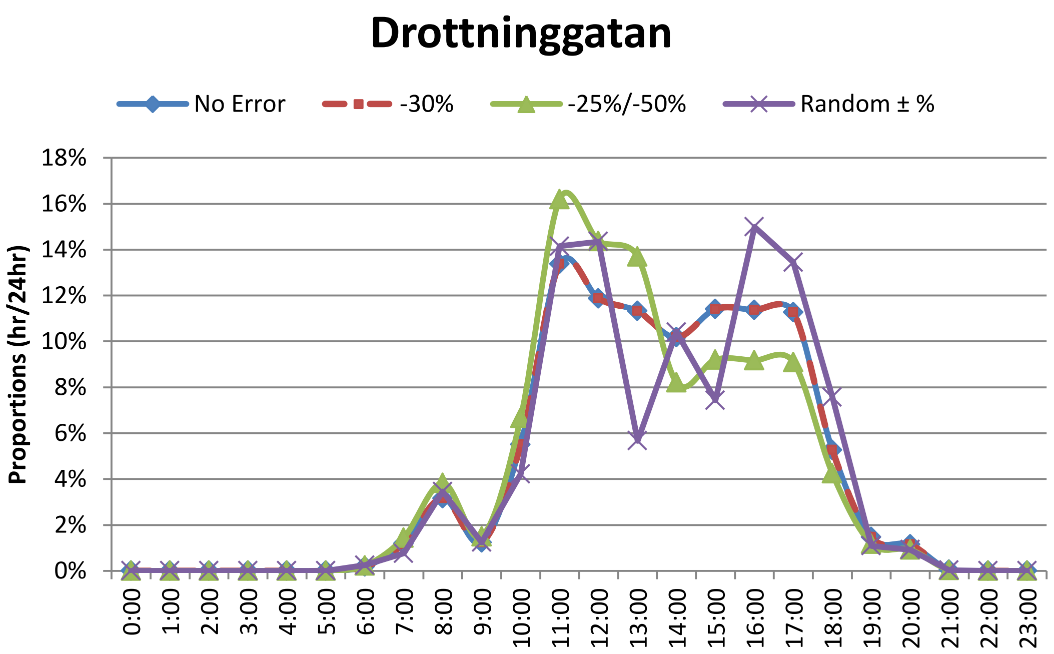


Figure 29. Average Thursday for section 1 in Drottninggatan. Simulated scenario of constant (-30%) and variable errors in the Eco-counter. The volume proportions of the real pattern are altered with the variability of the error.

It can be noticed that if the error of the Eco-counter is constant during the whole day, the patterns will overlap the "no error" volume proportions. However, if the error is variable during the day, the actual trend on the pattern can be altered and results in a different behaviour. This means that the decision of grouping days and locations with similar trends could be biased by the inconstant error in the Eco-counter. Moreover, expansion/adjusting procedures will give deviated results since the volume proportions will be different from the real ones.

The relation of the error with the volume was assessed with the use of scatter plots, see Figure 30. It could be observed that the relation is poor between both variables, as stated in previous studies (Greene-Roesel et al., 2008; Schneider, et al., 2008). The error will depend on how dense the pedestrians walk in the area (Schneider, et al., 2008) and the influence that could exert other traffic modes to the counter as well as other external factors (i.e. blocking objects), see Figure 31.

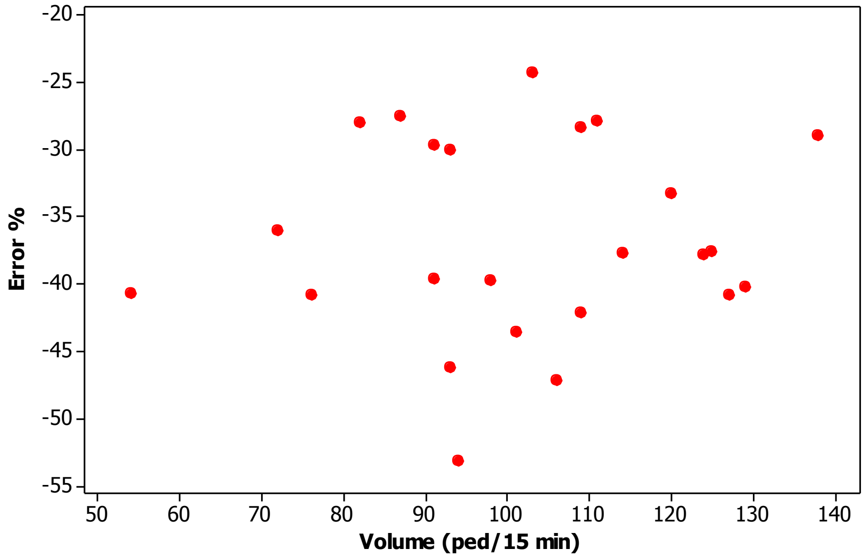


Figure 30. Volume in 15 minutes intervals for the 6 hours sampled in Drottninggatan versus the percent of error of the Eco-counter. A poor relation is observed with the large scatter of the data.

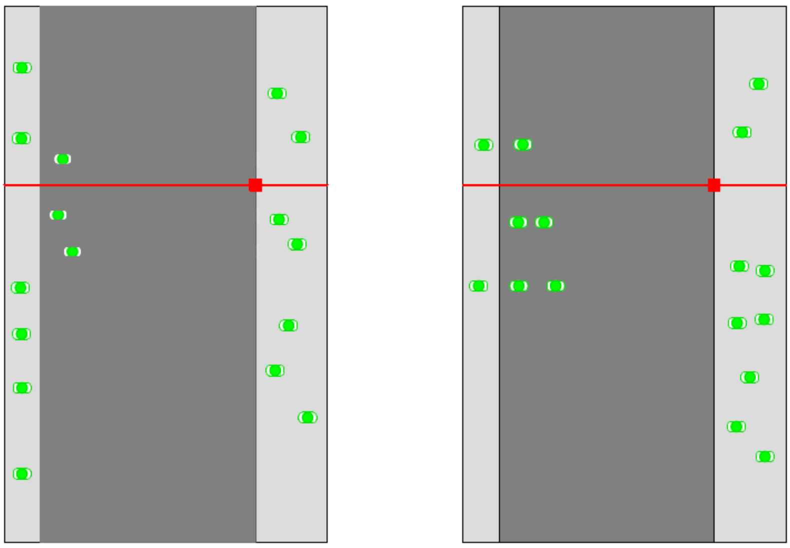


Figure 31. Ilustration showing the same amount of people walking in a section of a street (red line = screen line). To the left people are walking in a single pattern, but to the right people tend to walk in groups.

The density of pedestrians in the area was assessed with the help of 10 hours of video counts, as shown in Table 13. Furthermore, the frequency of group arrival in 15 minutes intervals was obtained, see Table 14.

Table 13. Percent of people walking in group from total volume in an hour.

Location	Samples (hr)	Group percentage (%)			
		Two-ped	Three-ped	Four-ped	Total
Section 1	2	17%	4%	0%	21%
Section 2	3	14%	1%	0%	15%
Section 3	3	18%	2%	0%	20%
Section 4	2	14%	1%	1%	16%

Table 14.Average frequency of people arriving in groups in 15 minutes intervals.

Location	Samples (hr)	Group frequency		
		Two-ped	Three-ped	Four-ped
Section 1	2	11.9	1.5	0
Section 2	3	8.6	0.3	0
Section 3	3	6.8	0.4	0
Section 4	2	8.6	0.6	0.3

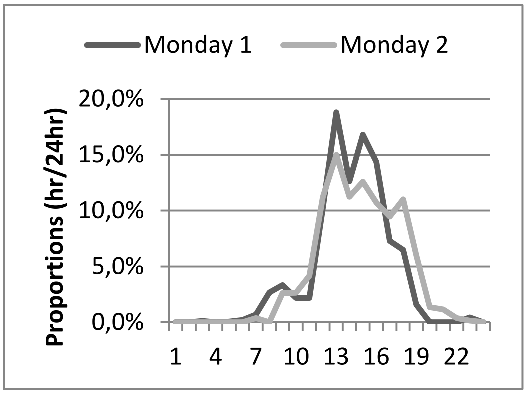
If these percentages are compared to the total error in Table 10 it could be seen that there are other factors that influence the undercounting in the Eco-counter. As Schneider et al. (2008) mention in their work, data from the automatic counter must be analysed with detail since it could be deviated by external factors. In general the automatic counters are susceptible to be blocked by cars, objects, or other external factors.

4.3 Volume Pattern

Volume patterns help to identify what is the trend in the volume of pedestrian within a day, week, month or year. Furthermore, they are used to expand and adjust data from short counts as stated in chapter 2.2.

To create the volume patterns, the first step was to average the Eco-counter data for every day of the two weeks in each section to obtain a single week with seven daily volume patterns. In this case, for each section it was found that the volume proportions within the same day were almost equal and thus the average could be made, as exemplified in Figure 32. Moreover, due to the inconsistent data of the pneumatic tubes, an average was performed to obtain a single week of daily car volumes for each complete street. Then, to refine the figures, the pneumatic tubes data was subtracted from the averaged week of the Eco-counter volumes of each section.

This resulted in an averaged week with seven daily volume patterns of pedestrian plus “others” for the 4 studied sections. “Others” represented a small percentage from the total volume (as stated in chapter 4.1.3). It is important to bear in mind that the Eco-counter and the pneumatic tubes have errors as stated in chapter 4.2.



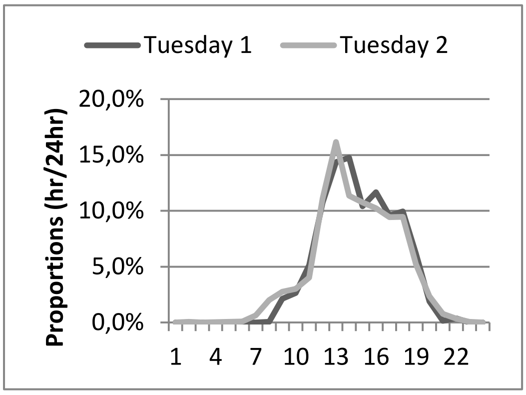


Figure 32. Data from the two weeks of section 2 in Drottninggatan. An example showing the volume proportions similarities for the same day (the same behaviour was noticed in the other days).

The second step was to analyze the weekly volume pattern for both Drottninggatan and Kyrkogatan, as shown in Figure 33 and Figure 34. The weekly volume pattern was derived from two weeks for each section. As can be observed, every section has its own pattern; in some cases with similar trends (see Figure 7), i.e. the drop of volumes on weekends or stable volumes on weekdays. This indicates that each section has a daily volume difference from the others, and thus adjustment factors are necessary for every section individually. One cause of this may be that each section is enclosed by different streets and have diverse activities/attractions.

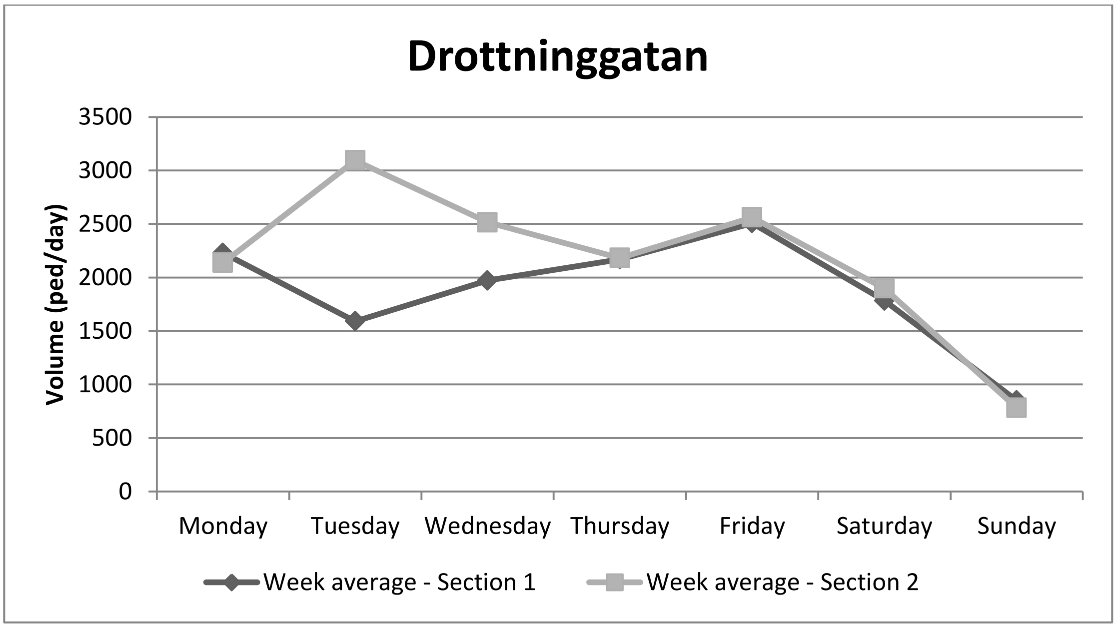


Figure 33. Average data for all days in the week for pedestrians plus “others” volumes in Drottninggatan. Data from the Eco-counter was available from 2010-08-17 to 2010-09-13.

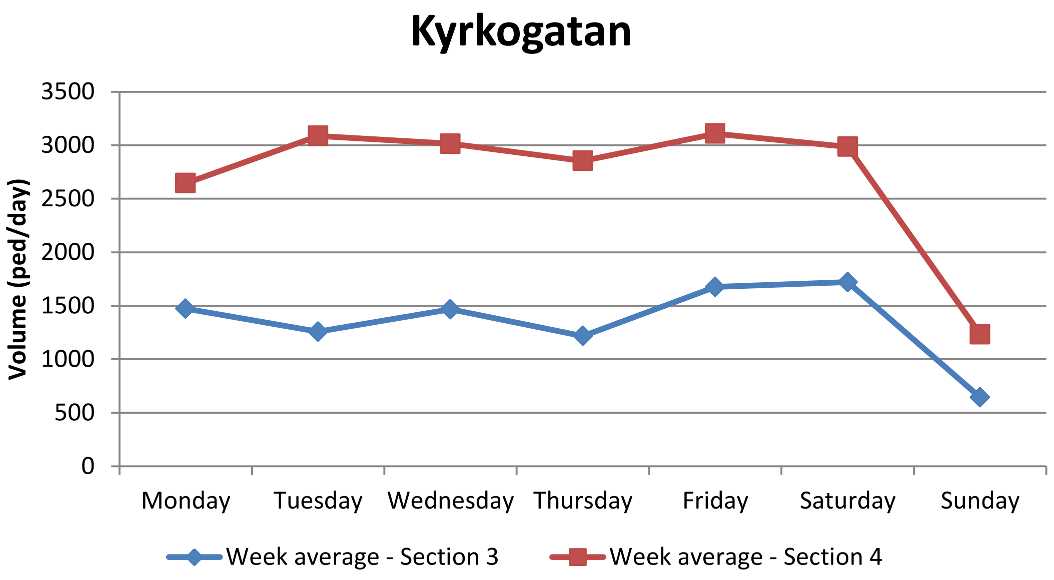


Figure 34. Average data for all the week days for pedestrians plus "others" volumes in Kyrkogatan. Data from the Eco-counter was available from 2010-09-13 to 2010-10-11.

The third step in the analysis was to plot the daily volume proportions for each section in order to assess the variability between the different days of the week, as illustrated in Figure 35 for the weekdays (others sections in Appendix 1). After this, it was observed that two main groups could be obtained due to similar volume proportions. It was decided to group weekdays from Monday to Friday, and weekend days Saturday and Sunday.

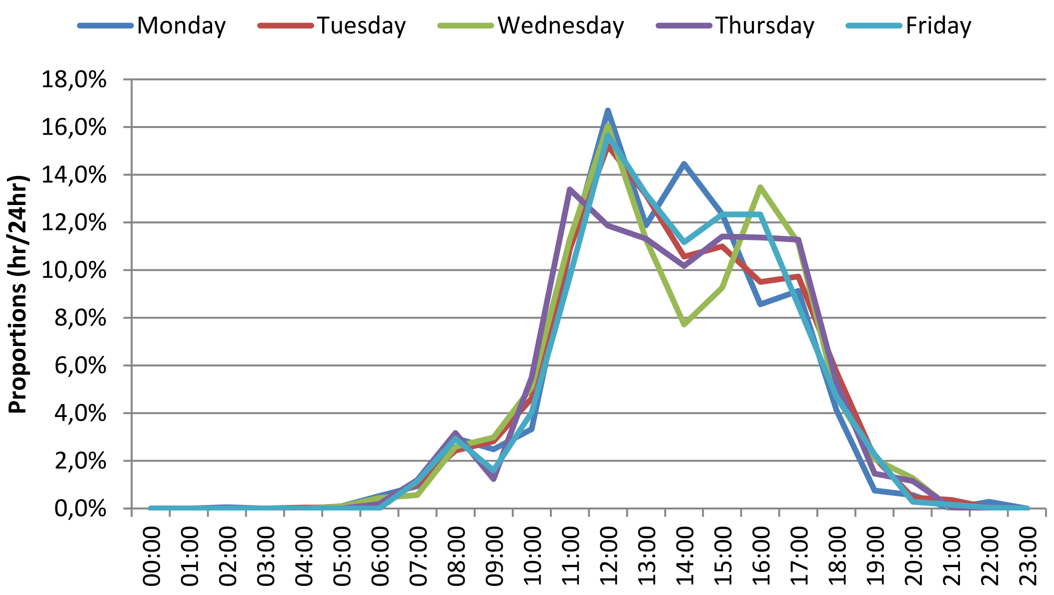


Figure 35. Weekdays volumes proportions for section 2 in Drottninggatan. All have a very similar trend and thus can be grouped together.

The fourth step consisted in plotting the grouped days' volume proportion patterns for the two sections in each street; see Figure 36 and Figure 37. It could be observed that all sections reflected a similar trend in their daily proportion patterns. This indicates that the daily proportion patterns apply to the whole area (land use).

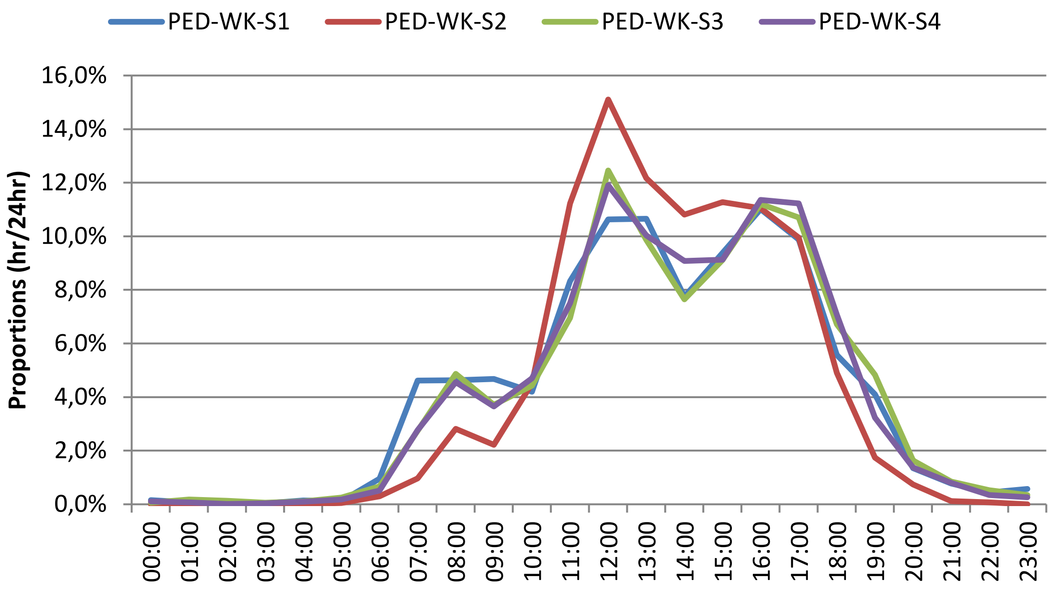


Figure 36. Grouped proportion patterns for weekdays (WK) of all sections (S) in Drottninggatan and Kyrkogatan.

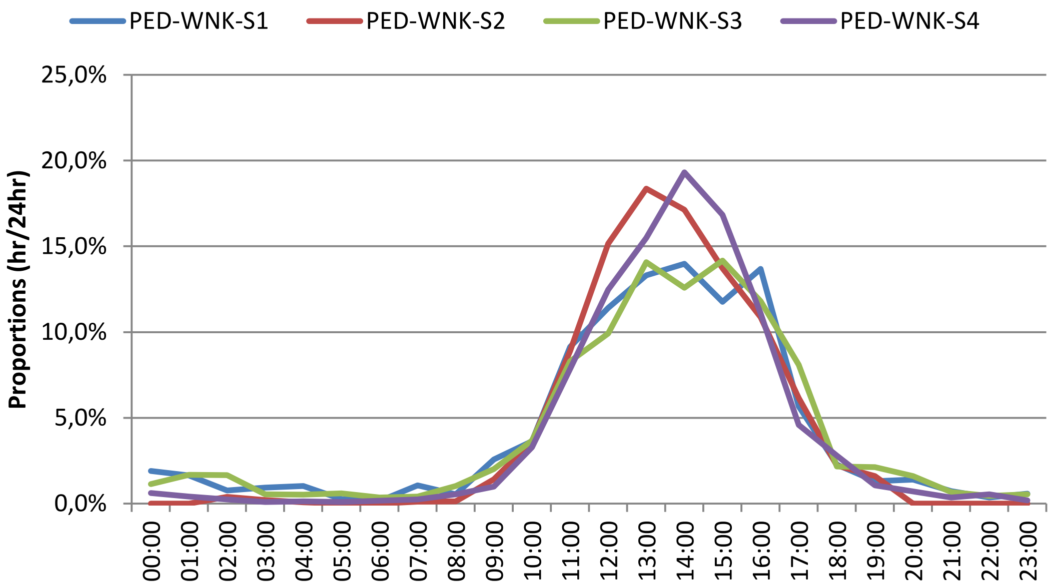


Figure 37. Grouped proportion patterns for weekend days (WNK) of all sections (S) in Drottninggatan and Kyrkogatan.

Furthermore, both streets reflected their peak hour volume at 12:00 on weekdays and at 14:00 for weekends with the exception of section 3 in Kyrkogatan, with a peak at 13:00. The latter could again be attributed to the small amount of data and the error of the Eco-counter and the pneumatic tubes. These peaks represented a range of 11-15% of the total daily volume on weekdays and 14-19% on weekend days. In addition, the main 12 hours of the day (from 7:00 to 19:00) accounted in average for a 93% of the total volume of the street on weekdays and 94% on weekend days. The rest of the day (night time) is in general of less importance for engineering studies, as affirmed by Robertson et al. (1994).

Since the grouped days' proportion patterns reflected similar trends at all sites, indicating a high correlation with the land use, a further grouping was performed. This was assessed by evaluating how similar were the volume proportions for each hour in each section. All presented some variation that could be attributed to the error in the Eco-counter, the pneumatic tubes and, to the intrinsic variations that could exist in each street (these latter assumed to be small). A single daily volume proportion pattern for weekdays and weekend days for all section was obtained.

The resulting daily volume proportion patterns that apply for both streets and, for weekdays and weekend days, are presented in Figure 38. It is important to notice at all time that average patterns help to provide good estimates and not exact values when used for expanding/adjusting tasks. The patterns could be refined even more with the collection of more data and thus increase their accuracy and reliability.

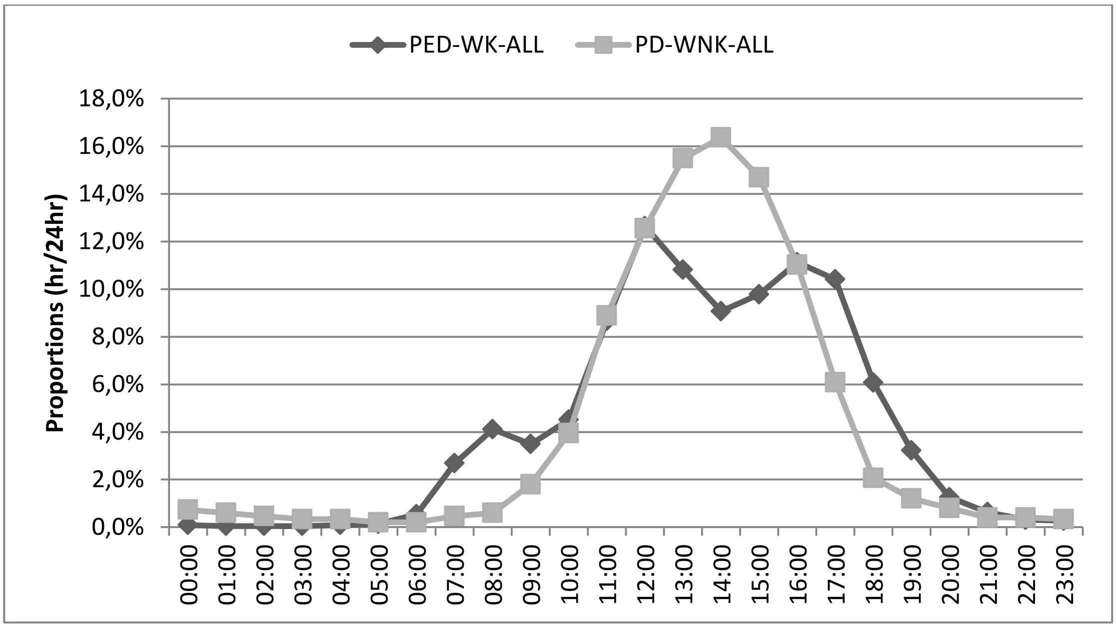


Figure 38. Averaged pedestrian volume proportion patterns for Drottninggatan and Kyrkogatan; the blue is from weekdays(WK) and the red from weekend days(WNK).

4.4 Data analysis

In order to perform different probabilistic and statistic studies it is important to recognize the type of data that is being handled. First, one important issue to identify is that pedestrian volumes belong to a discrete population. However, it was assumed the data was a continuous variable for the analysis below.

Another aspect considered was to know which type of distribution fitted the data. Therefore a normality test was carried on using the Anderson-Darling test, where the null hypothesis (H_0) stated that the population is normal, while the alternative hypothesis (H_1) stated that it is non-normal. The test results were evaluated using probability plots as those in Figure 39 and with the calculated p-value.

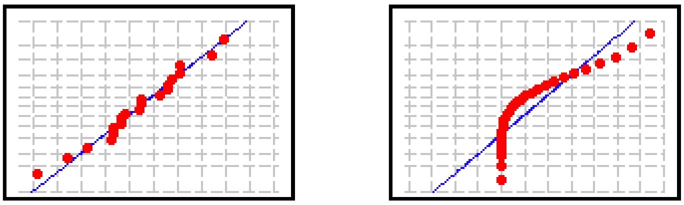


Figure 39. Illustrative figures representing behaviours of normal probability plots. To the left, the data form almost a straight line that represents a normal distribution. To the right, the data have a curved shape, being non-normal distributed (Minitab 16, 2010).

The manual sampled data was obtained mainly for weekdays as shown in Table 3 and Table 4. Furthermore the range of hours was from 12:00 to 18:00. The amount of data collected can be regarded as limited and reduced the ability to give more general results. However, it was decided to perform the statistics bearing this in mind.

For the test, an α-value of 0.01 was chosen for rejecting the null hypothesis (i.e. in the case of p-value being smaller). For all the 1 hour manual counts volumes (from both Drottninggatan and Kyrkogatan) the p-value resulted in a value of 0.209, this latter being higher than 0.01, which means that the null hypothesis was accepted and therefore the data considered as normally distributed. The resulting probability plot is shown in Figure 40.

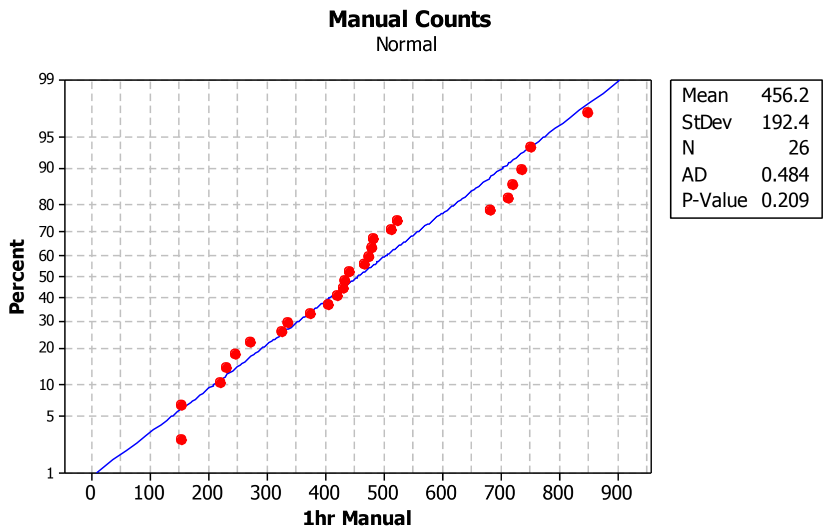


Figure 40. Probability plot for manual counts. The validity of the data being normal distributed is limited to weekdays and to the time range from 12.00 to 18.00 hours (26 samples).

The same test was performed to the data from the automatic counter within the same time period. The first step was to refine the data by removing the cars counted with the pneumatic tubes from the Eco-counter counts. In this case, a large amount of data was available in comparison to the manual sample (192 hours). Again the data resulted to be normally distributed with a p-value of 0.054, see Figure 41.

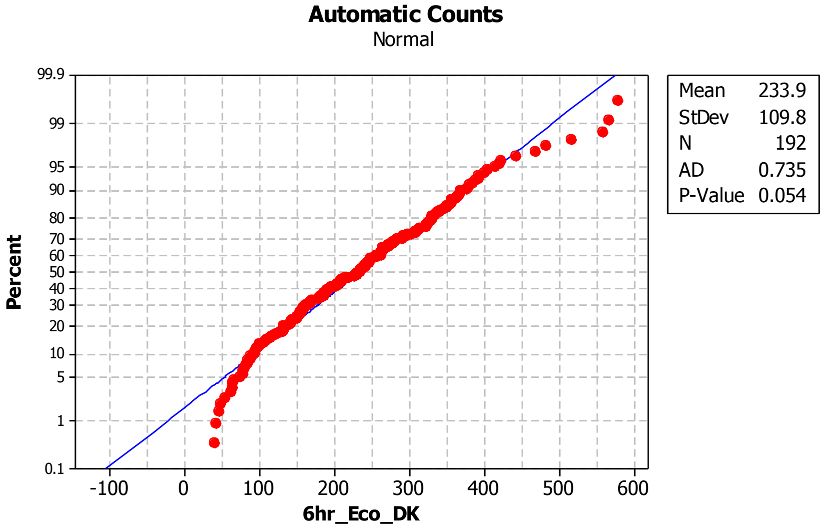


Figure 41. Probability plot for automatic counts. The data includes weekdays and weekends, ranged from 12.00 to 18.00 hours and includes Drottninggatan (D) and Kyrkogatan (K).

Further analysis of the data was performed, in this case two main scenarios were considered. The first was to evaluate the whole day sampled hours. Considering both streets and each of them individually, the result was a non-normal distribution with a p-value less than 0.005 in all cases. One of the probability plots is illustrated in Figure 42. Although the latter result, the data was adjusted by applying LOG_{10}, LN, and the square root, but there was no successful result and concluding that the data is not lognormal. The second scenario was to assess the main hours of activities in a day. For this, a range from 7.00 to 19.00 was chosen as the most active 12 hours during the day. Both streets together resulted in a non-normal distribution with a p-value below 0.005. However, when the streets were analyzed individually the result was different, with Drottninggatan being normally distributed, see Figure 43.

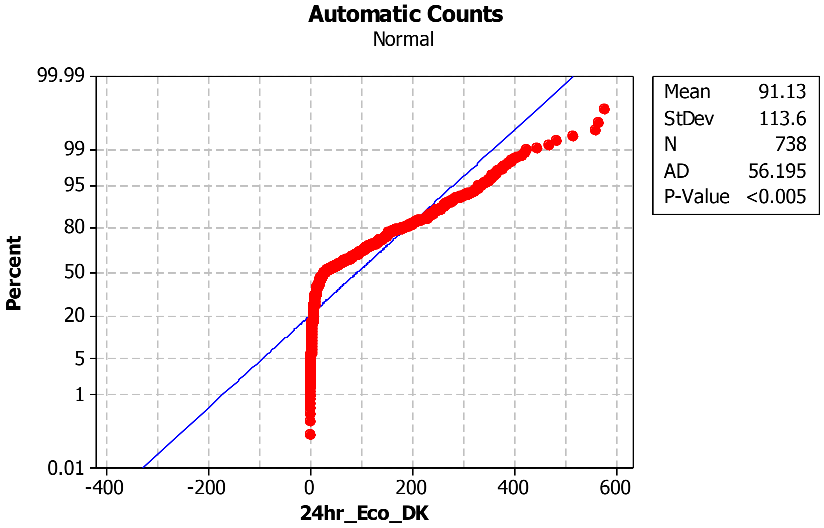


Figure 42. Probability plot for automatic counts. The data includes weekdays and weekends, account for the whole day and both streets.

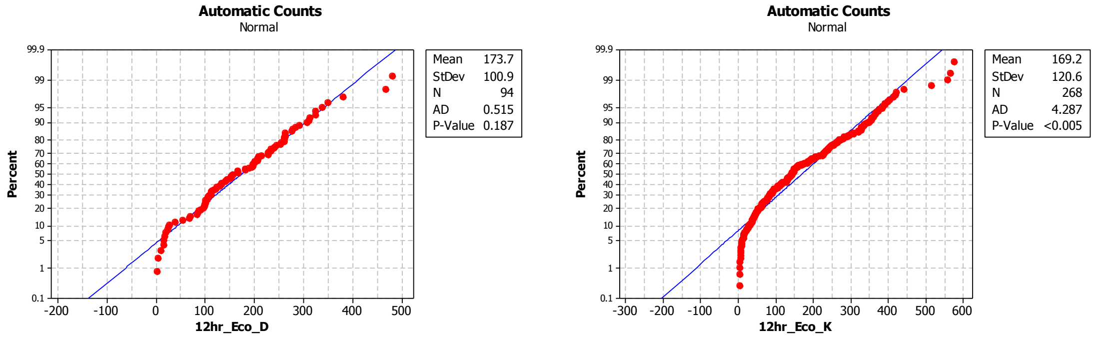


Figure 43. Probability plots for the automatic sampled data. To the left, Drottninggatan (D) has a p-value of 0.187 while to the right, Kyrkogatan (K) has less than 0.005.

As observed in Figure 42 and Figure 43, most of the deviation occurs when there is a significant amount of hours without recorded volume (e.g. no pedestrian walking). This means that the behaviour of the data is not the same during the whole day. This correlates in some way with previous findings in the work of David, et al. (1988). However, in the latter research they required to transform their data, resulting in a lognormal distribution for the main 12 hours of the day.

4.5 Model

In order to optimize and save resources when performing manual counts, a model was evaluated to find out when to perform this type of counts and for how long time. In this case the manual counts served to create several regression models based on various time intervals for the short counts. The goal was to determine how various time intervals covered the variability within one hour. In addition, another target was to assess when within the hour the sample should be taken (e.g. in the first 5 min).

The models were derived from 24 available 1 hour manual counts. These hours belonged to weekdays (from Monday to Friday), for the time range of 12:00 to 18:00, and for both Drottninggatan and Kyrkogatan. In this respect, the equations can only be applied for short counts within this time range, the stated locations and for the weekdays.

As said before in chapter 4.4, it is important to notice that the data does not come from a population of continuous data, instead it comes from a discrete one. Normal regression analysis requires the data to be continuous. However, it was assumed that the data was obtained from a continuous population. From this investigation several models were developed and are presented in Table 15. Furthermore, the data accounted to be normally distributed as proven in chapter 4.4.

Table 15. Equations for obtaining hourly volumes based on a short count interval.

Time Interval	Equation	S	R^2 (adjusted)	R^2 (predicted)
(F) 5 min	Y = 12.9 + 12.4 X	76.7	80.8%	78.6%

(M) 5 min	Y = 121 + 8.42 X	80.8	78.7%	67.2%
(L) 5 min	Y = 88.1 + 10.3 X	90.7	73.1%	69.5%
(F) 10 min	Y = 60.3 + 5.54 X	86.8	75.4%	72.2%
(M) 10 min	Y = 27.7 + 5.41 X	63.1	87.0%	84.1%
(L) 10 min	Y = 49.9 + 5.77 X	50.4	91.7%	90.7%
(F) 15 min	Y = 15.8 + 4.0 X	60.7	88.0%	86.2%
(M) 15 min	Y = 3.6 + 3.77 X	45.4	93.3%	92.2%
(L) 15 min	Y = 81.5 + 3.36 X	48.8	92.2%	91.2%
(F) 20 min	Y = 15.9 + 2.97 X	53.0	90.8%	88.8%
(M) 20 min	Y = 3.7 + 2.81 X	35.7	95.8%	95.3%
(L) 20 min	Y = 55.7 + 2.70 X	41.3	94.4%	93.9%
(F) 30 min	Y = 4.2 + 1.98 X	32.5	96.5%	96.0%
(M) 30 min	Y = 1.6 + 1.93 X	32.0	96.7%	96.0%
(L) 30 min	Y = 22.6 + 1.90 X	31.1	96.8%	96.4%
***(1) 15 min**	Y = 15.8 + 4.0 X	60.7	88.0%	86.2%
***(2) 15 min**	Y = 35.5 + 3.54 X	41.8	94.3%	93.3%
***(3) 15 min**	Y = -6.0 +3.93 X	48.8	92.2%	91.3%
***(4) 15 min**	Y = 81.5 + 3.36 X	48.8	92.2%	91.2%

- (F) First interval, (M) Middle interval and (L) Last interval in the hour.

- Y: Volume of the hour. X: Sampled volume in the specific time interval.

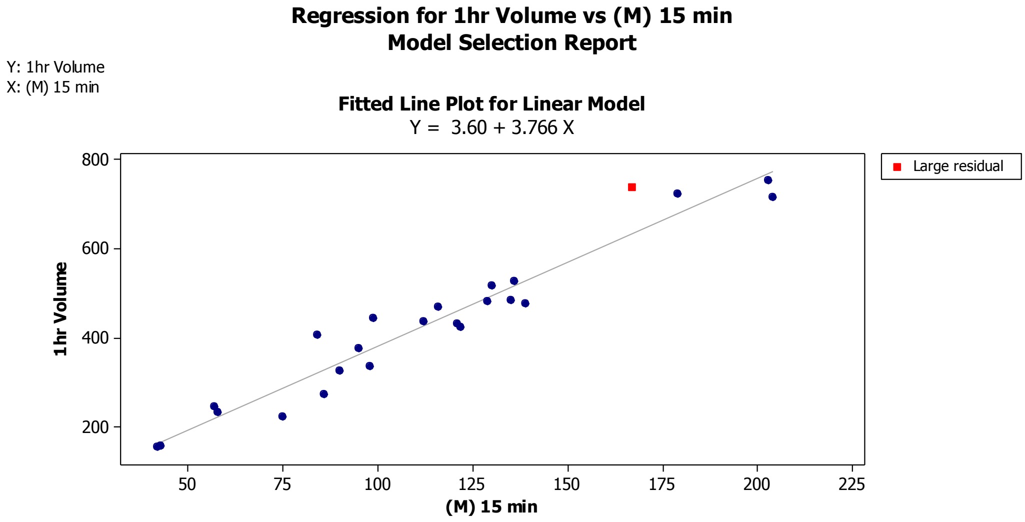
-All p-values where <0.05 being statistically significant and all Lack-of-Fit test >=0.1.

* 15 min intervals divided in the way that the automatic counter could do it.

For the 5 min time interval, it is not possible to select an exact middle position within the hour. Thus, two middle positions can be chosen, the range from 25-30 min or 30-35 min. The same happened with the 15 min time interval, where the middle positions of 20-35 min or 25-40 min could be picked. In both cases, the first middle positions were selected.

As observed, all the models belong to a linear approximation of the total volume of the hour based on a short sampling time. From the model it could be seen that less variability is accounted when performing counts with small time intervals, for example 5 or 10 minutes. In addition, with the increase of the time interval, more of the variability was accounted and a stable accuracy was reached within the different possible positions of the count within the hour. The best result for 15 and 20 minutes counts was for the middle position, as for 30 minutes the last position was the best, even though this accounted for a small difference less than 0.5% from the middle position.

As an example of the calculations performed and the results obtained, a regression model for 1 hour sampled manual counts versus 15 minutes time intervals is displayed, see Figure 44. The test shows that the model is statistically significant (p <0.05) and that it accounts for the variability in a 92.2%.



Statistics

	Selected Model	Alternative Models	
	Linear	**Quadratic**	**Cubic**
R-squared (adjusted)	93.26%	92.97%	92.95%
P-value, model	0.000*	0.000*	0.000*
P-value, linear term	0.000*	0.001*	0.974
P-value, quadratic term	-	0.740	0.370
P-value, cubic term	-	-	0.349
Residual standard deviation	45.423	46.367	46.458

* Statistically significant (p < 0.05)

Figure 44. Regression model for 1 hour sampled manual counts versus 15 minutes time intervals calculated with Minitab 16.

It is important to consider that the Eco-counter logs the data by intervals of 15 min as stated in chapter 3.3. In order to expand a short count with these data, the precise middle interval from 22.5 min to 37.5 min cannot be obtained directly from the device. Therefore, both the second or third 15 minutes interval within the hour can be chosen and still get good approximations, as shown in Table 15.

The accuracy of the expanded volume from short counts depends on how long was the time interval and at what position within the hour it is taken (Davis, et al., 1988). Works like that from Davis, et al. (1988) revealed that the longer the short count time is, the better the estimation of the expanded volume. In their work it is mentioned that "because small count intervals have more variation from one interval to the next, the potential for extracting a non-representative count for the time period being predicted is high". Additionally, the middle position is the most favourable within the time to be expanded. The variability phenomena are illustrated in Figure 45 and Figure 46.

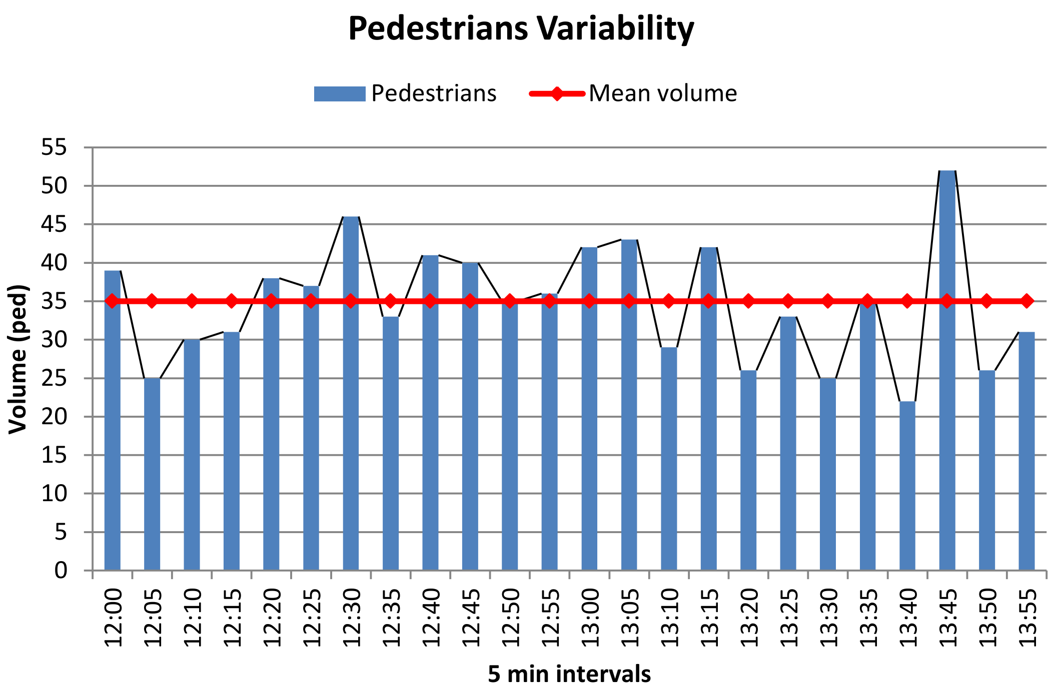


Figure 45. Variability of pedestrian volumes with 5 minutes time intervals; manual count in Drottninggatan 20-Aug-2010. The mean line serves as a reference to look out the changes in each step.

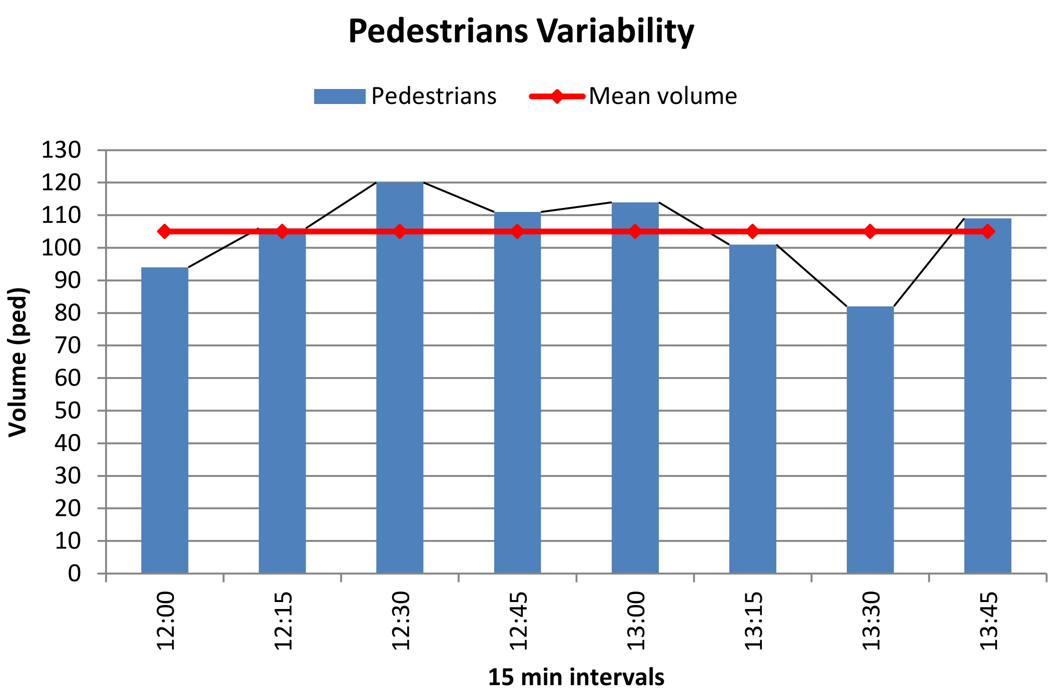


Figure 46. Variability of pedestrian volumes with 15 minutes time intervals; manual count in Drottninggatan 20-Aug-2010. The mean line serves as a reference to look out the changes in each step.

4.6 Example calculation

The following examples illustrate the calculation of the peak hour factor, volume of design, expansion factors and adjustment factors.

Consider the average of pedestrians walking on Tuesdays for section 2 in Drottninggatan (averaged Tuesdays for a two week study period time).

Average Tuesday in 15 minutes intervals (4 per hour):

Time	I1	I2	I3	I4
"12 AM"	0	0	0	0
"1 AM"	0	2	0	0
"2 AM"	0	0	0	1
"3 AM"	0	0	1	0
"4 AM"	0	0	1	0
"5 AM"	1	0	1	0
"6 AM"	0	1	6	3
"7 AM"	11	11	0	16
"8 AM"	9	13	24	30
"9 AM"	13	31	16	28
"10 AM"	31	40	43	29
"11 AM"	48	78	83	129
"12 PM"	110	125	116	120
"1 PM"	126	100	92	90
"2 PM"	93	81	65	89
"3 PM"	87	65	91	98
"4 PM"	58	66	89	82
"5 PM"	107	70	81	44
"6 PM"	81	34	30	34
"7 PM"	28	12	12	8
"8 PM"	8	1	4	1
"9 PM"	5	4	0	3
"10 PM"	2	2	0	0
"11 PM"	4	1	0	0

$i := 0..23$ $\quad x_{i,0} := 1$ $\quad$ Variables for calculations

$$V_{hour} := I1 + I2 + I3 + I4$$

$$V_{hour} = \begin{bmatrix} 0 \\ 2 \\ 1 \\ 1 \\ 1 \\ 2 \\ 10 \\ 38 \\ 76 \\ 88 \\ 143 \\ 338 \\ 471 \\ \vdots \end{bmatrix}$$

$$V_{day} := V_{hour} \cdot x = 3119$$

Volume for the whole day.

$$P_{hour} := max(V_{hour}) = 471$$ Peak volume

$$P_p := \frac{P_{hour}}{V_{day}} = 0.15$$ Peak volume proportion

$$t := \text{match}(P_{hour}, V_{hour}) \cdot [1] = 12$$ Peak hour

Peak 15 minutes within the peak hour:

$$P_{15} := max(I1_{t,0}, I2_{t,0}, I3_{t,0}, I4_{t,0}) = 125$$

$$PHF := \frac{P_{hour}}{4\,P_{15}} = 0.94$$

$$V_d := \frac{P_{hour}}{PHF} = 500$$ Design volume

Now, for example, lets assume that a short count was performed at 4:00 PM during the second 15 minutes intervals of the whole hour:

$I2_{16,0} = 66$ Second 15 minutes volume at 16:00

$V_{16} := I1_{16,0} + I2_{16,0} + I3_{16,0} + I4_{16,0} = 295$ Total volume at 16:00

$EMF_{I2\_16} := \frac{I2_{16,0}}{V_{16}} = 0.22$ Expasion minute factor for the second 15 minutes at 16:00

$EHF_{16} := \frac{V_{16}}{V_{day}} = 0.09$ Expasion hourly factor for 16:00 in the whole day

If the short count resulted in a volume of 77 pedestrians, then:

$V_{e16} := \frac{77}{EMF_{I2\_16}} = 344$ Expanded volume for 16:00

$V_e := \frac{V_{e16}}{EHF_{16}} = 3639$ Expanded volume for the whole day

The daily volume patterns can give the total expected volume for the day when the coverage count was performed. However, in several weeks, a month or a year the counted day will have volume variations (high and low volume seasons). For example, if the counting is performed on a day where an unusual activity was undergoing, an unexpected or biased result could be obtained unless this could be a special case and thus the result is right. But, if a general scenario is wanted and what is expected is an average volume within a time period (e.g. average volume for Mondays in month "x"), then adjustment factors must be applied, as stated in chapter 2.5.2. This is illustrated below:

Assume that the previous short count was made for the second Tuesday of a two week study period. The expanded volume will represent the second Tuesday, however for obtaining an average result for the Tuesdays of both weeks, the count need to be ajusted to account for the first Tuesday variability.

Tue_1	Tue_2	Tue_{avg}
0	0	0
0	2	1
0	0	0
0	1	1
0	2	1
0	3	2
0	19	10
2	59	31
69	81	75
86	88	87
167	118	143
349	325	337
468	473	471
481	332	407
339	315	327
380	300	340
312	276	294
324	277	301
201	153	177
62	69	66
5	23	14
12	10	11
0	2	1
0	0	0

$V_{Tue1} := Tue_1 \cdot x = 3257$ Volume for first Tuesday

$V_{Tue2} := Tue_2 \cdot x = 2928$ Volume for second Tuesday

$V_{Tue\_avg} := Tue_{avg} \cdot x = 3097$ Average volume for both Tuesdays

$$AF_{tue\_1} := \frac{V_{Tue\_avg}}{V_{Tue1}} = 0.95$$

$$AF_{tue\_2} := \frac{V_{Tue\_avg}}{V_{Tue2}} = 1.06$$

Adjustment factors for the 1 and 2 Tuesday.

$V_{aj} := V_e \cdot AF_{tue\_2} = 3849$ Ajusted volume

5 Summary and discussion

- Literature review

Part of the theory was obtained from motorized traffic knowledge. This does not mean that the methodology could not work because volume studies are handled in the same way independently from where they come from.

- Automatic Counters

The Eco-counter was only able to provide the data by direction. Therefore a direct comparison for individual sidewalks could not be performed. A general error was found for both sides, without having the possibility of assessing which side had the major influence on the results.

The Eco-counter counted everything, including cars, motorcycles, bicycles and pedestrians. This device could be deemed to be accurate since the data from the volumes of vehicles and "others" could balance the undercount of pedestrians. In this matter, the automatic counter could be used with certain restrictions and in specific conditions; for example, when it is not affected by cars or "others". In addition, to filter the data it is necessary to have additional devices such as pneumatic tubes, another type of automatic counters for bicycles or perform manual counts for the period that is needed to have the data; which in this case is preferable to rely just on the manual counts.

The raw data from the Eco-counter can give misleading results. If the Eco-counter data would not have been refined, the error could be much lower giving a first impression of high accuracy. Furthermore, the data from the pneumatic tubes used to refine the Eco-counter presented errors itself.

It was found that the resulting volume patterns from the Eco-counter could be biased by several factors. One factor is that errors from the device were noticed to be variable within certain range. For this investigation, it is not completely clear if the error is variable during the whole day or if it could turn to be constant with more samples. Furthermore, when refining the data, errors from the other devices and methods were merged to the one of the Eco-counter. These factors, along with the small intrinsic variation of each street, can result on an unexpected outcome.

There was not enough data (only two weeks per section) to assess properly the Eco-counter samples. With only two daily samples in every section, the judgment of which is the real value could be easily biased. It is important that at least 4 samples (1 month) are collected in order to preclude any unusual value that could have been affected by external factors.

- General Statistics

It was noticed that the majority of pedestrians were using the street instead of the sidewalks with arcades. A possible reason explaining this behaviour is that people preferred opened environments to walk rather than using a sidewalk that gave the impression of a big hallway with a far end, as shown in Figure 10. Furthermore, all the arcades in both streets did not have shops or centre of activities; conversely these were generally in the narrow sidewalk. Also, it is possible that the people chose a specific sidewalk (the narrowest one without arcades) because of their destination (related to origin-destination walking behaviour).

Properties, like gender, age and walking direction, are characteristic of the complete street and thus a classification scheme from any section and any sidewalk can be adopted. The preceding statement can be an advantage to be used in manual counts when the classification could be limited in some points due to high volumes (> 700 peds/hr/sidewalk). In this respect, if the street is the same and has the same characteristics (e.g. same land use, sidewalks at both sides, etc.), the side with the lower volume could be classified and the results applied to the other. However, one property that did not represent a problem to classify was the direction, thus being performed at all times.

The age interval for the adult's classification can be regarded as wide, from 14-60 years old. This was considered based on the judgement that people within this age interval have the same walking characteristic and abilities. Additionally, to add more age intervals would make the manual count more complex for the personnel, putting at risk the accuracy and reliability of it.

One of the most important factors affecting the volume of pedestrians in the area was the land use. Drottninggatan and Kyrkogatan are situated in a highly commercial area and both showed similar properties. Some differences in daily volumes were appreciated between different sections, perhaps because of the different activities available in each. Furthermore, the hourly volume proportions for all sections were close enough to be considered as equal.

- Volume patterns

The hourly volume proportions are independent of the total volume. They depend on how the volume is distributed along the day. Generally, one has to accept some percentage differences (e.g. ± 2% from intrinsic properties of the streets) in the hourly volume proportions between locations and days, in order to group their daily volume patterns. This is illustrated in Table 16 below. When percentage differences are set according to expert judgment or the proposed use of the data, one will be able or not to group certain days and locations into a single daily volume pattern.

Table 16. Example of how volume proportions are independent of volumes and how the average fit in all cases.

	Volume						**Volume Proportions**					
Time	Mon.	Tue.	Wed.	Thu.	Fri.	Avg.	Mon.	Tue.	Wed.	Thu.	Fri.	Avg.
12:00	67	74	77	54	90	72	19%	19%	18%	20%	17%	18%
13:00	54	59	64	41	77	59	15%	15%	15%	15%	15%	15%
14:00	48	53	58	35	71	53	13%	13%	14%	13%	14%	14%
15:00	45	50	55	32	68	50	13%	13%	13%	12%	13%	13%
16:00	56	62	66	43	79	61	16%	16%	15%	16%	15%	16%
17:00	48	53	58	35	71	53	13%	13%	14%	13%	14%	14%
18:00	39	43	49	26	62	44	11%	11%	11%	10%	12%	11%
Total	357	394	427	266	518	392						

Even though the data from the manual counts was logged in 5 min intervals, the data was grouped into 15 minutes to be able to compare it with the automatic counters. The researchers thought that it might be good to acquire the data the more detailed as possible to get more knowledge of the different time interval behaviours.

- Videos

Due to the limitation of the width recording capacity of the video camera and the characteristics of the street itself, i.e. parked cars, arcades and columns which restricted the view; only one sidewalk was considered to compare the count provided by the video and the manual count (in this case the one with the clearest view).

When performing the manual counts and analyzing the videos, some characteristic behaviour within the people walking were observed. For example, pedestrians had a high confidence about their walking priority; they believed that drivers respected their rights. Also, people tended to walk with variable speed (e.g. different walking purposes).

- Model

The equations used to evaluate the different time intervals for the manual counts are limited in time and space. General equations will require wide data collection plans, to account for different land uses and for the main 12 hours of the day.

- General

The samples taken were limited due to time restrictions and also the size of the study. Further studies are always recommended in order to get a good knowledge in this field. The conclusions were drawn based on this small amount of samples, meaning that they could be subjected to changes.

It is important to consider the economical aspects of the manual counts versus the automatic counts. One must think if it is proper to invest in new technologies that could provide unreliable data or use traditional methods such as the manual counts that provide data with higher quality.

6 Conclusions

Pedestrian volumes and their patterns were generated using the approaches for counting pedestrians presented here. The methodology needs to be assessed and improved since this is a pilot study made in two streets in the city of Gothenburg. In this respect, further studies and tests using this methodology are required with a broader data collection plan.

It was found that between 10 to 12 hours of the day is the main time for pedestrians' activities, e.g. ranging from 7:00-19:00. This statement confirms what was found in previous literatures.

The volume proportions between Drottninggatan and Kyrkogatan seem to couple according to the land use variable, both for weekdays and weekend days. The location for both streets considered as a commercial zone, reflect similar behaviour among the pedestrians. Additionally, it is concluded that a count can be performed anywhere in the street. The location can be selected based on how suitable the counters can be set.

The flow of people to each direction was independent from the volumes of people that walked in the area. In this respect, more people headed west to the main avenues such as Östra Hamngatan and Fredsgatan.

The size and characteristics of the sidewalk were key factors in the influence of people walking on the street. Narrow sidewalks (1.2-1.5 meters) without arcades accounted for most of the volume and people tended to walk on the street beside it. In the other hand, sidewalks with arcades (2-3 meters) attracted less pedestrians.

Manual counts are an accurate source for collecting data if performed with proper procedures and if the personal is committed to perform the task. A disadvantage of this approach is that they require man-hours which implies that this type of count cannot be performed for a continuous period of time such as the automatic counts.

At the beginning of each coverage count the personnel felt unfamiliar, not completely focused or used to the procedure. After the first 5 minutes it was comfortable enough to proceed properly since the personnel became more active and focused during the counting time. Also, detailed manual counts can become tedious for certain volumes. On average it was found that flows higher than 700 pedestrians/hr/sidewalk are complicated to classify.

The automatic count technology for pedestrians used in this study is good for generating patterns since it develops continuous counts, which allows collecting large amount of samples and generates more stable statistical data. However, in order to get good approximations of the patterns, the Eco-counter must be located in controlled/regulated environment. Moreover, the data filtering is hard to perform especially when the data requires to be refined by using other counters like pneumatic tubes. These technologies presented a high percentage of error.

Video counts are time-consuming when it comes to analyse them, but they provide highly accurate data since it can be examined in a repetitive manner. Mainly, the videos showed that the errors from the automatic counters are due to external factors.

Errors from the Eco-counter are not affected by the volume of pedestrians. Instead, they were due to other factors like the density of pedestrian walking through the counter, where people walking in groups were omitted. Another aspect was the objects that could block the counter for certain times of the day, e.g. a car, a bicycle, a person, etc.

The Eco-counter should not be located near stores or bus stop or any kind of source of pedestrians or where pedestrians can gather. This causes the counts to have a bias, reflected by successive peaks.

In general, it was found that pneumatic tubes are unstable and unreliable in urban areas due to cars driving at low speed and because of people altering the device (generally by curiosity). Consequently the data from it had errors that added to the errors from the Eco-counter when filtering the data, thus deviating the final result.

Regression models were used to determine an efficient short count interval in order to save money and resources when performing a manual count sampling. The models provided a good estimate of the volumes for the hour that could be used to reduce the amount of man-hours. In this matter, the manual counts should be performed at least for 15 minutes and for the middle position (e.g. 20–35, 25-40 min) within the hour being counted. The bigger the time interval counted, the closer to the reality are the results from the model.

7 Recommendations

It is recommended that when performing pedestrian counts, different approaches are considered at the same time. The automatic counters are good to use for obtaining long term data, but always together with an additional counting method like the manual counting. The latter helps to corroborate that the data is reliable/accurate and provides facts that can be used to calibrate/correct any error in the automatic devices.

The methodology consists on counting pedestrians using the tally sheet presented in this study, and to compare the data obtained with this approach with the one obtained with automatic and video counting technologies. As a recommendation, the short counts should be performed for at least 15 minutes and logged in 5 minutes intervals (the latter necessary if a detailed analysis of the data is required).

Manual counts are recommended to be performed in small studies that do not require long term data collection. Pre-training of the personnel is highly recommended for obtaining accurate and reliable manual counts data. If automatic counters are going to be used, it is always good to test their performance, for example, comparing them with manual counts or video counts.

Try different approaches when setting up the Eco-counter device. For example, a good approach could be to put the device in a 45 degrees angle to avoid the undercounting.

7.1 Future Research

- Perform surveys of non-motorized users, including Origin/Destination.
- Perform counts in intersections, putting emphasis on accounting for the change of walking direction between streets.
- Try new counting technologies, like video processing.
- Localization of counters in the public transportation.
- Create simulations of macro scenarios of the city. For example, using Vissim with the volumes and patterns obtained, to develop macro models of the volumes of people walking in the city.
- Count for long time periods to obtain monthly and seasonal variations.

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APPENDIX 1 – Volume proportions for each day and section

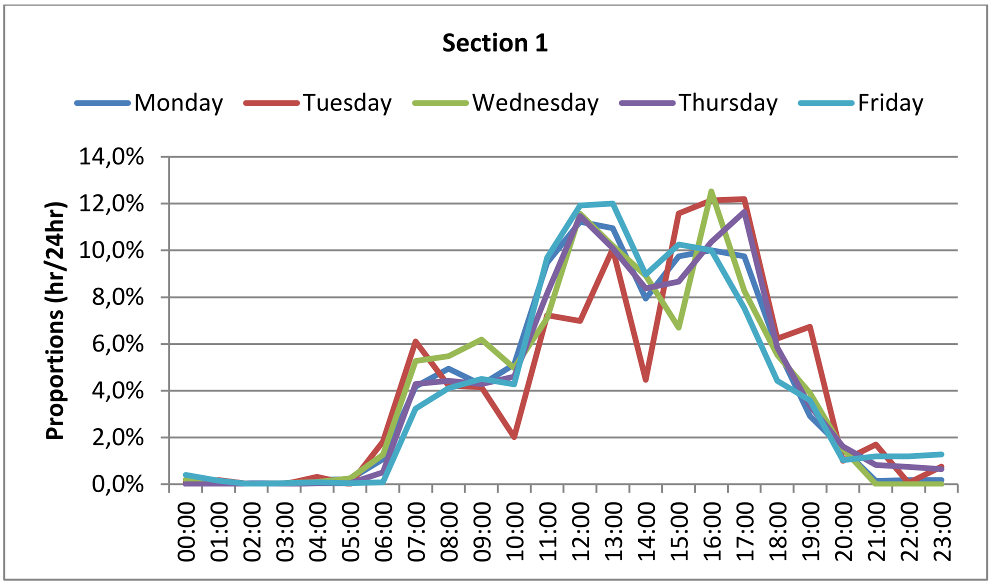

Figure 47. Section 1 in Drottninggatan.

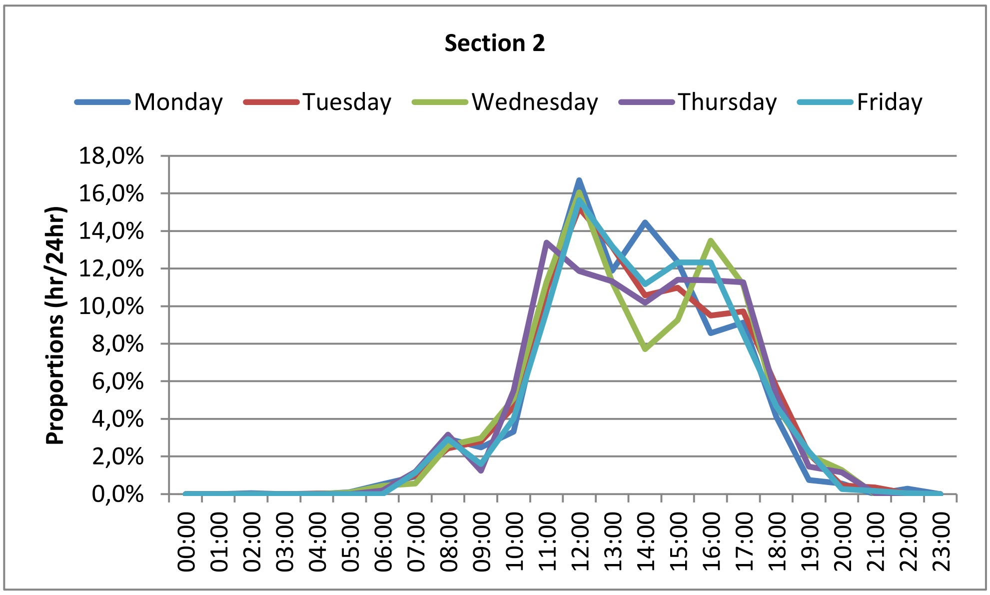

Figure 48. Section 2 in Drottninggatan.

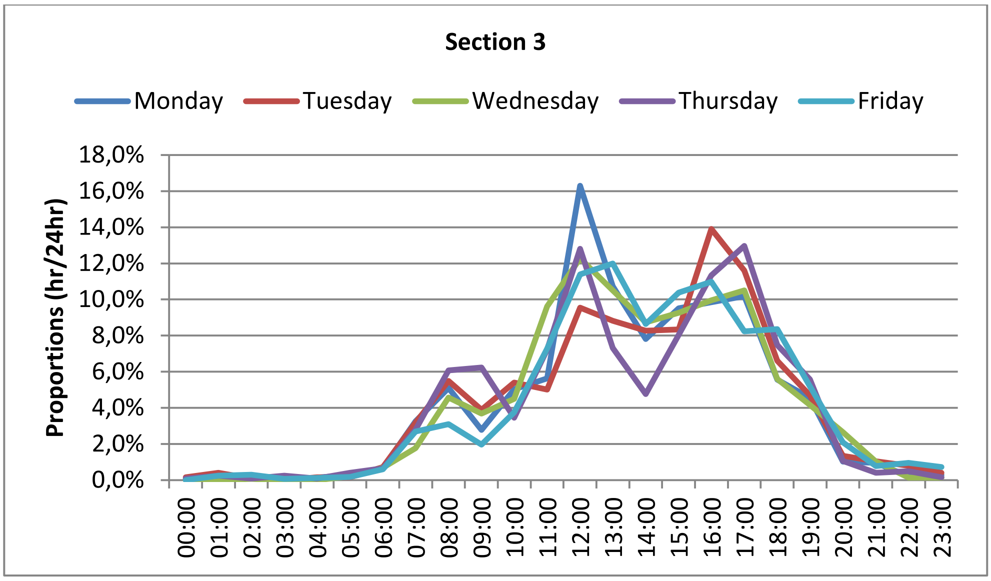

Figure 49. Section 3 in Kyrkogatan.

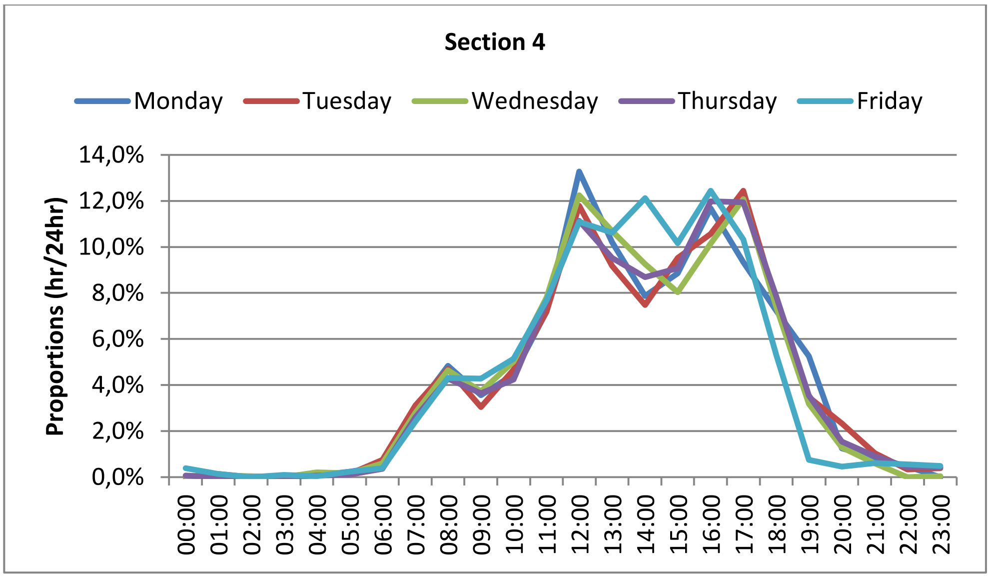

Figure 50. Section 4 in Kyrkogatan.

Appendix 2 – Volumes obtained with the manual counts

Notes:

- On the italicized red dates, the volumes were not classified for side A.
- Cars are counted for the street independently of each side.

Sections and Dates	12 PM			
	Car	**Female**	**Male**	**Other**
Drottninggatan-Östra H/Freds				
2010-08-20				
A		154	102	24
B		96	79	0
2010-08-27				
A		139	146	11
B	100	98	97	0
Drottninggatan-Freds/Östra L				
2010-09-02				
A	66		426	24
B		151	137	0
2010-09-06				
A	64		455	16
B		143	155	1
2010-09-07				
A	83		454	25
B		139	143	0
2010-09-13				
A	75		489	27
B		106	126	1
Kyrkogatan-Freds/Östra L				
2010-09-20				
A		55	69	1
B	66	87	62	6
2010-09-22				
A		80	65	13
B	60	32	56	0
Kyrkogatan-Östra H/Freds				
2010-09-29				
A	67	164	188	11
B		93	80	0
2010-10-04				
A	62	132	102	11
B		98	90	0

2010-10-08				
A	59	118	132	14
B		104	89	0

Sections and Dates	**1 PM**			
	Car	**Female**	**Male**	**Other**
Drottninggatan-Ostra H/Freds				
2010-08-20				
A		116	93	27
B		99	98	0
2010-08-27				
A		113	157	16
B	85	105	93	0
Kyrkogatan-Ostra H/Freds				
2010-10-02				
A	65	260	192	8
B		120	110	0

Sections and Dates	**2 PM**			
	Car	**Female**	**Male**	**Other**
Kyrkogatan-Ostra H/Freds				
2010-10-02				
A	57	336	241	15
B		160	113	0

Sections and Dates	**4 PM**			
	Car	**Female**	**Male**	**Other**
Drottninggatan-Ostra H/Freds				
2010-08-26				
A		118	67	31
B	50	82	59	1
Drottninggatan-Freds/Ostra L				
2010-09-06				
A	70		329	34
B		79	67	1
2010-09-07				
A	58		315	41

B		120	80	0
Kyrkogatan-Ostra H/Freds				
2010-09-27				
A	44	153	102	31
B		99	81	1
2010-10-05				
A	51	124	86	16
B		82	83	0

Sections and Dates	**5 PM**			
	Car	**Female**	**Male**	**Other**
Drottninggatan-Ostra H/Freds				
2010-08-24				
A		43	42	29
B		61	76	1
2010-08-26				
A		120	92	41
B	73	71	53	1
Drottninggatan-Freds/Ostra L				
2010-09-02				
A	56		266	35
B		91	76	0
Kyrkogatan-Freds/Ostra L				
2010-09-14				
A		38	34	1
B	63	52	30	17
2010-09-23				
A		105	54	18
B	67	66	21	1

Sections and Dates	**6 PM**			
	Car	**Female**	**Male**	**Other**
Drottninggatan-Ostra H/Freds				
2010-08-24				
A		39	40	16
B		40	37	0

APPENDIX 3 – Site setup