METHODS, TECHNIQUES AND INSTRUMENTS OF DATA COLLECTION IN EUROPEAN COUNTRIES

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ABSTRACT

Intelligent transport systems (ITS) are important instruments to cover the future traffic demand in European cities. There are different new approaches in the field of ITS especially regarding information systems using current or rather latest traffic data to inform road users about the current traffic situation and to enhance the traffic quality. But these ITS need verified data for effectiveness. Therefore accurately methods, techniques and instruments for data collecting are necessary.

In the first part of this thesis are briefly presented the variables that characterizes the flow conditions of traffic streams, as well as the components of a road system that may be a monitoring subject.

In the second part is described some measurement methods and a series of steps that need to be made first, from the definition of objectives to the presentation of the plan to collect the data.

In the third chapter, the most used instruments and techniques for obtaining traffic data in the European Union are described, being presented the types and main characteristics of the traffic sensors that are more often used. Some European organizations who are concerned about the transferability of collected data and methodologies are also introduced.

In the last part of this thesis, methodologies to collect data are described and applied.

KEYWORDS:

-DATA COLLECTION

-INTELLIGENT TRANSPORT SYSTEMS

-TRAFFIC MANAGEMENT

-TRAFFIC SENSOR

ZUSAMMENFASSUNG

Intelligente Verkehrssysteme (ITS) sind wichtige Instrumente, um die zukünftige Verkehrsnachfrage zu decken. Auf dem Gebiet des ITS, insbesondere die Verkehrsinformationen betreffend, wurden verschiedene neue Ansätze entwickelt, um die Verkehrsteilnehmer über die derzeitige und zukünftige Verkehrslage zu informieren und die Verkehrsqualität zu erhöhen. Hierbei wird auf Daten zur aktuellen Verkehrslage zurückgegriffen. Diese Systeme müssen auf verifizierten Daten basieren. Präzise Methoden, Techniken und Instrumente zur Datenaufnahme sind hierfür notwendig.

Im ersten Teil der Arbeit werden kurz sowohl die Variablen dargestellt, die den Verkehrsfluss beschreiben als auch die verschiedenen Teile des Verkehrssystems benannt, für die ein Monitoring durchgeführt werden kann.

Im zweiten Teil werden einige Messmethoden vorgestellt. Desweiteren wird beschrieben, welche Schritte zur Vorbereitung einer Datenaufnahme notwendig sind, von der Definition der Zielstellung bis zur detaillierten Erarbeitung der Datenaufnahme.

Der dritte Teil der Arbeit umfasst die gebräuchlichsten Instrumente und Methoden zur Datenaufnahme der aktuellen Verkehrslage in der Europäischen Union. Die gebräuchlichsten Messinstrumente sowie deren Eigenschaften werden beschrieben. Ebenso werden wichtige europäische Organisationen, die sich mit der Übertragbarkeit der Daten beschäftigen, vorgestellt.

Im vierten Teil der Arbeit werden Methoden zur Datenaufnahme beschrieben und angewendet.

KEYWORDS:

-DATENAUFNAHME

-INTELLIGENTE VERKEHRSSYSTEME

-VERKEHRSMANAGEMENT

-MESSMETHODEN

RESUMO

Sistemas de transporte inteligentes (ITS) são instrumentos importantes para cobrir a futura procura do tráfego em cidades europeias. Existem diferentes e novas abordagens no campo dos STI, especialmente em relação a sistemas de informação que usam dados recentes ou atuais para informar os condutores da situação atual do tráfego, e para melhorar a sua qualidade. Não obstante, esses STI necessitam de dados credíveis para funcionarem corretamente. Portanto, métodos, técnicas e instrumentos mais eficazes são necessários.

Na primeira parte desta tese são brevemente apresentadas as variáveis que caracterizam as condições de escoamento de fluxos de tráfego, bem como os componentes de um sistema viário que possa ser objeto de monitoramento.

Na segunda parte é descrita alguns métodos de recolha de dados e uma série de passos que necessitam ser efetuados em primeiro lugar, desde a definição do objetivo à apresentação de um plano para recolher os dados.

No terceiro capítulo, são descritos os instrumentos e técnicas mais usadas na União Europeia, sendo apresentados os tipos e características de sensores de tráfego usados com mais frequência. Também são descritas algumas organizações Europeias que se ocupam com a transferência de dados recolhidos e metodologias.

Na última parte desta tese, metodologias para recolher dados são descritas e apresentadas.

PALAVRAS CHAVE:

-RECOLHA DE DADOS

-SISTEMAS INTELIGENTES DE TRANSPORTE

-PLANEAMENTO DE TRÁFEGO

-SENSOR DE TRÁFEGO

RESUME

Les systèmes de transport intelligents (ITS) sont des instruments importants pour répondre aux futurs besoins du trafic dans les villes européennes. Il existe de nouvelles approches dans le domaine des STI, notamment au niveau des systèmes d'information utilisant des données récentes ou actuelles pour informer, en temps réel, les conducteurs de la situation du trafic et pour améliorer la qualité de celui-ci. Toutefois, ces STI ont besoin de données crédibles pour fonctionner correctement. Des méthodes, des techniques et des instruments plus efficaces sont donc nécessaires.

La première partie de ce mémoire présente brièvement les variables qui caractérisent les conditions d'écoulement du trafic ainsi que les composantes d'un réseau routier pouvant faire l'objet d'un contrôle.

La deuxième partie est consacrée à la description de méthodes de recueil de données, à la définition de l'objectif et à la présentation du plan suivi pour recueillir les données.

La troisième partie décrit les instruments et les techniques les plus fréquemment utilisés dans l'Union européennes et présente les types et les caractéristiques des capteurs de trafic les plus courants. Il y est aussi question d'organisations européennes qui s'occupent des méthodologies et du transfert des données recueillies.

La dernière partie de ce mémoire présente et décrit des méthodologies de recueil de données.

MOTS CLES:

RECUEIL DE DONNEES

SYSTEMES DE TRANSPORT INTELLIGENTS

GESTION DU TRAFIC ROUTIER

CAPTEUR DE TRAFIC

INDEX

List of Abbreviations

A	Propagation speed of sound in air at the time of measurement
A_0	Propagation speed of sound in air at 0 º (A_0=331.4 m/s)
B	Ambient temperature at measuring moment
d	Distance between two consecutive sensors
D	Distance between the transmitter-receiver and the vehicle
EU	European Union
FCD	Floating Car Data
F_d	Frequency Doppler-Fizeau
GPS	Global Positioning System
ITS	Intelligent Transport Systems
k	Concentration
K	Correlation coefficient that depends on the geometry of the spire
l	Length of the concentration zone
L	Average length of vehicles (Chapter 1) or
	Length of the road segment (Chapter 2) or
	Length of the vehicle (Chapter 3)
L_d	Length of the detection zone
m	Average number vehicles present in Δx
n	Number of vehicles travelling the road segment or
	Number of input branches (Sub chapter 2.3)
n_a	Number of vehicles that passes by the trial car
n_f	Number of vehicles that overtakes the trial car
n_s	Number of vehicles overtaken by the trial car
n_w	Difference in progress between the trial car and the vehicles in the traffic stream
N	Number of spires
OCIT	Open Communication Interface for Road Traffic Control Systems
P	Perimeter of the spire
q	Traffic flow
q_{ij}	Traffic flow from *i* to *j*
Q_i	Total traffic flow from *i*

Q'_j	Total traffic flow going to *j*
R	Resistance
t_1	Instant the vehicle enters the zone of action of the first sensor
t_2	Instant the vehicle enters the zone of action of the second sensor
t_a	"Returning" travel time
t_i	Presence time over the sensor
t_w	"Going" travel time
T	Observation Period (Chapter 1 and 3) or
	Average travel time (Chapter 2)
TMC	Traffic Message Channel
u_i	Instantaneous velocity of the vehicle
u_s	Average velocity in space
u_t	Average velocity in time
ΔP	Pressure variation
Δt	Time between emission and reception
Δt_i	Time spent by each vehicle to travel Δx
Δx	Distance travelled by the vehicle
α	Angle between the emitted wave beam and the vehicle speed
λ	Wavelength
ϕ	Occupation rate

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1
INTRODUCTION

1.1. Objectives and Organization

The development of projects for the construction of new roads and their subsequent maintenance, the progressive increase of traffic volumes associated with the mobility of citizens especially in the big cities requires a careful preparation of traffic studies.

These traffic studies helps to improve the organization, optimization and the redesign of existing road structures, the promotion of public transport systems, road safety and the management, control and monitoring of traffic, minimizing environmental impact. Thus, the studies in question are assumed to be of great importance with regard to quality of life of citizens and the development of their social environment.

Traffic studies easily include the characterization of traffic streams made of vehicles moving in a certain period of time in a direction along a route. In the first chapter are briefly presented the microscopic and macroscopic variables that characterizes the flow conditions of traffic streams, as well as the components of a road system that may be a monitoring subject. In a microscopic characterization, vehicles are considered separately. In turn, the macroscopic characterization considers the movement of a group of vehicles which constitutes the traffic stream.

In cities of moderate size, the presence of the pedestrian component, public transportation and bicycle is usual. However, these components are not subjected to an extensive study in this work, even knowing that some of the data collection instruments are quite useful, for example, in the counting of pedestrians and bicycles. It is also important to notice that in this work only the individual traffic will be completely discussed.

In the second chapter of this work is explained the general plan prior to data collection, as well as the methods to measure macroscopic variables. Planning data collection and the methods to use is a very important phase in traffic studies. It is when the type of instruments or/and the number of operators and their tasks are determined.

The constant technological advance occurred either in the measurement equipment, either during data processing, has facilitated traffic studies. Allowing a permanent collection, these devices are especially important for data acquisition in real time that can serve as support for Intelligent Transport Systems of traffic control. They are also used when it is not feasible to make a manual collection of the data necessary to the study, for example in the achievement of high traffic volumes. Chapter three describes manual and automatic procedures to collect traffic data, and presents the main types and characteristics of sensors commonly used in Portugal, Germany, as well as in the most of European coutries .

In chapter four, methodologies using two types of sensors to analyse collected data are presented.

1.2. TRAFFIC DATA

1.2.1. VOLUME

The traffic volume quantifies the number of vehicles passing a particular section of the road during a given period that may last a year, months, weeks, days, minutes, etc.

This parameter can be obtained easily, since it only requires the counting of vehicles passing through the section under study. Therefore it is often used to characterize the flow conditions of the flowing traffic.

The traffic volume is one of the most important data on the flowing traffic and it will be on the recorded traffic volumes that will fall the most attention in this work, in terms of methods and instruments used in its determination.

1.2.1.1. Traffic flow

The traffic flow corresponds to the distribution of vehicles per time, being defined by the number of vehicles passing a section during a certain period of time, normally expressed in vehicles per hour (vehicles / h).

When determining the flow, the period of observation is usually one hour. Therefore it means the traffic volume that would flow in one hour if the rate of passage of vehicles were kept constant throughout that time.

1.2.1.2. Traffic Composition

The traffic flows are normally heterogeneous, comprising vehicles of very different characteristics. This may mean that the same value of traffic volume may correspond to traffic flows with different behaviours. So, when traffic data is collected it is possible and even desirable to register the vehicles by aggregating them into classes of similar characteristics previously selected and defined. This aggregation can be done in two major classes, light vehicles and heavy vehicles. The use of automated counting equipments allows a better characterization of the traffic composition, carrying out the collection of the following measurements at the same time:

- Length;
- Distance between axes;
- Time;
- Weight.

Knowing the diversity of traffic characteristics, it is important to have a single unit of volume measurement to be obtained through the concept of equivalence coefficient, which allows the transformation of the real volume into another volume constituted only by light vehicles. This coefficient represents the number of cars that, under the same conditions, produces the same effect as a vehicle of a certain class.

The classification of vehicles is very important, allowing, for example, the evaluation of the noise level or pavement degradation through knowledge of the percentage of heavy vehicles.

1.2.2. Concentration

The concentration is measured by the number of vehicles per unit length at a given instant. Thus, the concentration describes the distribution of vehicles in space, reflecting the freedom of maneuver and fluidity that are associated with the proximity between vehicles.

In general the concentration is expressed as vehicles per kilometre (vehicles / km), or as a percentage of the total length of road occupied by vehicles.

This variable is difficult to measure by direct observation because it implies that these are carried out in a fixed time over space, which means the use of aerial photographs or video images. Therefore it is usual to calculate it using the occupation rate.

1.2.3. Occupation Rate

In the control and traffic management, it is increasing the use of devices usually placed on the pavement allowing the measurement of presence time, which is defined as the time in which a particular detection zone is occupied by the presence of a vehicle.

The occupation rate corresponds to the ratio between the sum of the times of presence and duration of the observation period, expressed as a percentage. In other words, is the percentage of time the sensor is activated by the passage of successive vehicles.

The occupation rate ϕ can be related directly with the concentration k through the relation:

$$\phi = (L + l).k \qquad (1.1)$$

with

L - average length of vehicles

l - length of the detection zone

This relation becomes quite useful since it is relatively easy to measure ϕ. This allows a more frequent use of k, overcoming the difficulties that result from its direct measurement.

1.2.4. Velocity

There are two different concepts of average velocity in traffic streams, commonly known as average velocity in time and average velocity in space. The average velocity in time u_t is represented by the arithmetic mean of the instantaneous velocities of vehicles passing a section for a certain period of time, and may be obtained by:

$$u_t = \frac{1}{n}\sum u_i \qquad (1.2)$$

with

u_i - instantaneous vehicle velocity

n - number of vehicles travelling in the road segment

On the other hand, the average velocity in space u_s corresponds to the arithmetic mean of the instantaneous velocities of the vehicles, ie, the speeds of vehicles in a fixed instant, which exist in a given space. Knowing that it is easier to get the instantaneous speed of vehicles crossing a section, instead of measuring it at some instant along the segment, it is convenient to express the average velocity in space for that situation.

Therefore, it is demonstrated that if u_i is the speed of vehicles that cross the section over a certain time, the value of the average velocity in space u_s is given by this relation:

$$u_s = \frac{n}{\sum \frac{1}{u_i}} \tag{1.3}$$

The average velocity in space u_s will be more sensitive to the presence of slow vehicles in the traffic stream, reflecting the time that vehicles occupy a particular road segment.

1.2.5. Time Between Vehicles

The time between vehicles is the time, recorded in a fixed location, that elapses between the instants of passage of successive homologous points of the vehicles. It is generally used as a reference point, the bumper or the front wheel of the vehicle.

The time between vehicles reflects its proximity, being useful in studies of road safety, in the distinction between vehicles that circulate freely and vehicles under congested situations, in the regulation of traffic lights, in studies of capacity in unsignalized intersections, etc. [1]

1.3. Environmental data

When managing environmental information, the most important goal is to increase road safety through a dynamic response to the current traffic and environmental conditions. Therefore, the collection of environmental data and the creation of situational control proposals (warnings, speed limits) are important to increase road safety. The plausibility of these climate related circuits is the basis for the application of advertisements for the road users.

Environmental data collection consists in the measurement of several environmental factors that may influence the performance of drivers. For example, wetness, visibility, wind, temperature, slipperiness and humidity in the road surface affects road safety. In one hand it reduces the adhesion between the vehicle and the road, increasing the braking distance and reducing the braking forces in curves. On the other hand the visibility and sensitivity of a driver is altered. These negative influences are taken into account when reducing the speed limit through electronic message signs, as shown in figure 1.1. In addition, the decreased capacity of a wet road can also be useful in terms of traffic stabilization by applying restrictions in flow velocity.

The components of the measuring equipment must be installed according to the characteristics of the road, also taking into account meteorological and topographical features.

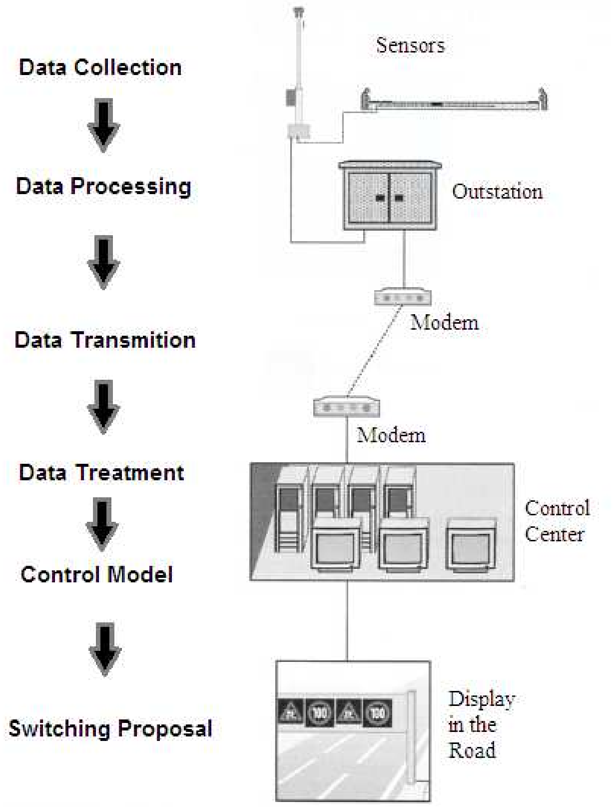

Figure 1.1 – Basic system of the environmental data collection

1.4. BICYCLES

Today, using a bicycle generally involves travelling in short and medium distances, mostly in an urban environment. In developed countries such as Denmark, Germany and Netherlands, some policies that encourage cycling have been proposed and implemented for several reasons including: improved public health, individual health and employers profits, a reduction in traffic congestion and air pollution, improvements in road traffic safety, improved quality of life, improved mobility and social inclusiveness.

The manner in which the public roads network is designed, built and managed can have a significant effect on the utility and safety of cycling as a form of transport. The cycling network may be able to provide the users with direct and convenient routes minimizing unnecessary delay and effort in reaching their destinations.

The collection of traffic data on bicycles helps to improve the planning and management of urban centers. Because of bicycle strong dependence on weather conditions, several and repeated surveys over long periods of time are necessary.

The design peculiarities of bicycles often lead to difficulties in their automatic detection and their distinction from other moving objects in the road area:

- Narrow width, when circulating side by side with other vehicles or when a group of cyclists is moving together;
- Low weight, when using sensors based on pressure;

- Little or no metal content, important for magnetic sensors as well as with the use of induction loops;
- Few reflective surfaces.

For streets without bicycle facilities, cyclists can also drive mixed in traffic, together with cars and/or pedestrians. Even the fast-moving skaters can be recognized as a cyclist by normal detection instruments.

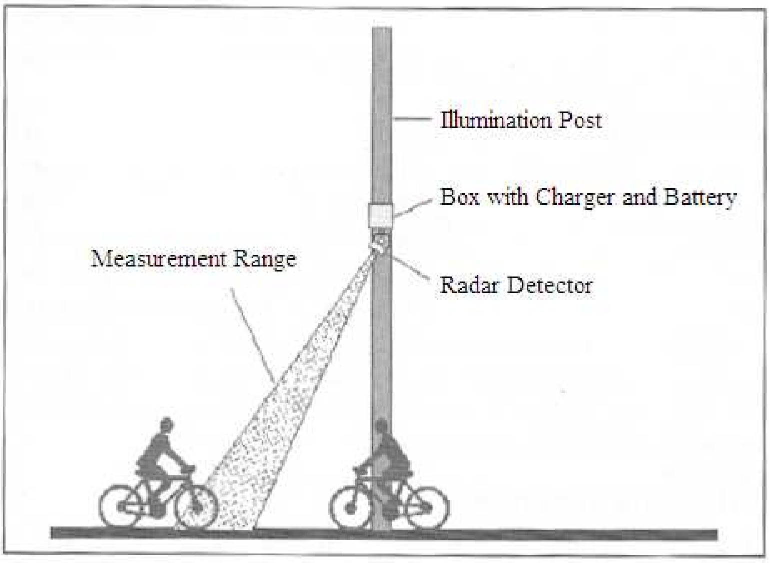

Figure 1.2 – Operating principle of a counting station

Furthermore, the same street element (roadway, bicycle path or sidewalk) is often driven in both directions.

The automatic sensors often cover only a portion of road space or even only one lane. A complete automatic collection of all cyclists in the entire road space is most of the times difficult or not possible and requires a special selection of measuring sites and locations.

1.5. PEDESTRIANS

On any trip there is always a pedestrian component, which may take place at the beginning, middle or end of the trip. Therefore, journeys by foot, especially the short distance one, constitute a very significant part of total travel, making it necessary to provide a series of infrastructures that allow pedestrians to carry out these travels quickly and safely. Such infrastructures are called a pedestrian network.

The pedestrian network, in addition to ensure the circulation of pedestrians, must also assure the existence of a minimum living space that allows the performance of a whole series of social and leisure activities that do not necessarily involve travel.

Recently, with the increased concerns about the sustainability and environmental problems created by growth of motorized traffic, the pedestrian, coordinated with the public transport, has to be taken into account as a real alternative to use of automobiles, particularly on short journeys. However, from all road users, the pedestrians are the most vulnerable because they do not have any kind of external protection, leading to more severe consequences whenever there is a collision with vehicles.

The correct preparation of any component of the pedestrian system requires knowledge and understanding of the key characteristics and capabilities of human beings. For example, the size of the human body determines what is the minimum height and width necessary for the free movement of people and influences the capacity of the various components of the pedestrian (sidewalks, crossings, ramps, stairs, etc). The fact that people try to avoid the physical contact between them determines the space required for each person in waiting areas or in areas with high pedestrian occupation rate.

The knowledge of other characteristics of pedestrians such as the speed of movement and extension of pedestrian paths help in resolving certain situations, such as the determination of the cleaning time to give to pedestrians in crosswalks with traffic lights, or the determination of the number of bus stops and their locations.

The automatic data collection methods that will be described further in this work cannot be used for pedestrians. Therefore, the counting of pedestrian are carried out mostly manually using record sheets or hand-counting devices, or even a trimmed video with a supplement manual evaluation. Nevertheless, some data can be collected automatically when data from public transports systems are available.

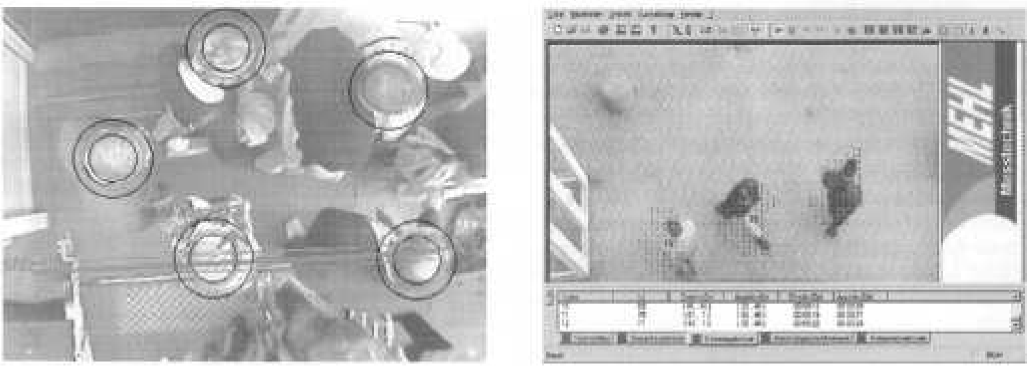

Figure 1.3 – Detecting people with trimmed video [3]

When planning the counting of pedestrians manually, the evaluation of the weather conditions is very important since the behaviour and the number of pedestrians can change substantially in the presence of wet and/or cold.

In order to obtain plausible results with the same weather conditions, the data should be collected in several points at the same time or over several days. However it takes time to plan and organize, and involves higher costs when compared to the trimmed video.

1.6. PUBLIC TRANSPORTATION

Ensuring accessibility is the ultimate goal of transport policies. Economic growth, expansion of urban areas and social issues related to the change in family structure are the main reasons for the growing use of public transportation, particularly in recent years.

The intensive use of individual transport, often beyond what would be rationally admissible, has well known causes and consequences. It is true that the car is almost unbeatable in flexibility, continuous availability, privacy, commodity and comfort that makes it the most used type of transport.

However, the effects from the increasing use of private cars such as the increased congestion, road accidents, pollution, noise and fuel consumption, led to a decreased quality of life and loss of economic competitiveness in certain areas.

Figure 1.4 – The use of space by cars and public transportation in a demonstration in Münster (Source: Press-Office City of Münster, Germany)

The option of trying to follow the growing transportation demand with an increased supplying in terms of construction of road space has been abandoned, not only because of the heavy investment it requires, but also social and environmental causes. It is urgent to take measures to ensure the sustainability of the transport system, and the public transportation has an important role to play here.

It is recognized that there are advantages of public transportation for the individual transport, particularly regarding to the efficiency of land occupation, which can carry more people using less space, and thus reducing congestion, but also in energy and environmental areas.

The characterization of the service demands of public transportation is based on a collection of information designed to investigate the conditions under which the transportation demands of the population is satisfied. This information includes not only the temporal and spatial coverage of the network, but also the transport operators and stock used, information systems and tariffs practiced.

A very important aspect to note is the conditions under which the supply of transport is provided to users, in particular the regularity and punctuality of vehicles, often hampered by the presence of other traffic. Minimizing the negative impact associated with this problem is the ongoing monitoring of the transport network, being nowadays possible by the remarkable progress achieved in recent years in the field of information technology and telecommunications. The fact that it is known where the vehicle is will allow the control center to perform an integrated real-time management of the system, supervising the progression of vehicles along the route, and take the necessary measures in order to adjust the needs of passengers. The supervision of vehicles also contributes effectively to the safety of staff and passengers. On the other hand the monitoring of vehicles allows the update of information that the user receives.

When managing any public transportation system is essential to obtain data whose analysis would support the decision-making and in this case it may include: physical characterization of the lines (geometry, signage, equipment at bus stops, etc.), size and vehicle performance, operating conditions, times and period of operation, volume of passengers, passengers entering and leaving at bus stops, fares and ticketing system, security, etc.

Obtaining these data requires systematic and periodic counting and surveys, which requires a compromise between its cost and the credibility of the information required. One solution is to organize over longer intervals the campaigns of data collections that require the mobilization of more resources, which will be complemented by smaller surveys carried out at shorter intervals.

Data on travel time and velocities may be obtained by observers travelling inside the vehicle recording the time of passage, as well as delays and their causes, or by on-board equipment which in the most advanced cases, automatic vehicle location systems are used.

Also the ticketing system can give useful information about the travel patterns of the public transport users, which can be supplemented with surveys specifically designed not only to know the origin and destination of travel, but also to know the quality of service offered.

2
MEASUREMENT METHODS

2.1. PLANNING DATA COLLECTION

The increased traffic and the demand of citizens in improving the quality of life has created a growing need to conduct traffic studies in many different areas such as transport planning, the project of transport infrastructure, management and traffic control, transport public, road safety, circulation plans, environmental impact, etc.. The objectives of the studies may range from the calibration and validation of models, to monitoring and evaluating the impact of measures.

In all these studies it is essential to have the maximum information possible obtained at the cost of an appropriate data collection. This task has become easier with the recent technological advances in computer and communications equipment, which will lead to more reliable measurement, while processing and data management are made simpler.

The existence of more and better resources does not replace the need for a collection of traffic data requiring significant mobilization of resources, which justifies a careful preparation in their organization in order to obtain useful information at the lowest cost possible. This plan should contain a set of steps that are described in the following sub chapters.

2.1.1. DEFINING GOALS

A clear definition of the objectives to be achieved is a prerequisite for successful data collection and constitutes the initial phase of the process that will determine the further work.

There are, as noted initially, a variety of types of traffic studies for which it is necessary to conduct campaigns to collect data, ranging from the calibration and validation of models to monitoring and enforcement of management measures and traffic control, which fit the objectives that should be permanently present in the planning of the work to collect data.

2.1.2. THE AVAILABILITY OF EXISTING DATA

One of the first steps is to have knowledge of the existing information, in order to avoid data duplication and the waste of human and material resources.

The definition of the missing variables, or variables that need to be updated, affects the rest of the planning of data collection.

2.1.3. Defining the variables to measure

Once defined the objectives and having knowledge of the existing data, the next step will be to characterize properly the variables to be measured with, including the accuracy which should be done.

It's supposed to select the smallest number of variables in order to minimize costs and to have a volume of information compatible with the deadlines and available resources to analyze.

2.1.4. Available resources

The availability of time, human and material resources are important factors to take into account when planning the data collection.

The solution lies in finding the balance between the consumption of resources and the gain of information.

2.1.5. The selection of methods, techniques and measuring equipment

Depending on the chosen variable, there are usually several alternatives to make the measurement, since the methods can be simple and direct as manual methods or the automated methods that require the use of specific equipment.

Each alternative has its advantages and disadvantages, having the need for a proper evaluation to find the best solution. Note that, sometimes, the adoption of a certain method allows the achievement of extra information with a reduced additional cost.

In the following chapter it will be presented the techniques and equipments to collect traffic data, the ones that are used in most European countries.

2.1.6. Sample definition

On the impossibility of knowing the information about all users, it is necessary to obtain samples that represent the real situation.

However there is the need to balance between the cost of obtaining more information and accuracy, and the cost of missing information.

2.1.7. Programming the data collection

The data collection program comprises a set of tasks ranging from the preparation of the campaign to collect data, to the processing and analysis of the data. In general, this plan includes the following phases:

- Visiting the site;
- Testing the equipment;
- Recruiting staff;
- Training staff;
- Installation of the equipment;
- First test;
- Collection campaign;

- Data processing;
- Removal of equipment;
- Processing and data analysis;
- Reporting the results. [4]

2.2. Methods to Measure Flow, Velocity and Concentration

To measure vehicle speeds it may be used direct methods in which the best known is through a device based on Doppler effect (radar pistol). Indirect methods relies on the time a vehicle takes to travel a predetermined road segment. In this case, the measurement of the time can be done manually or electronically using generally the same kind of counting equipment, in pairs and spaced a fixed distance, or even through video images using software recently developed based on image analysis.

The precision of the velocity value is the main difficulty of indirect methods, since it will be necessary to measure the passage of time with great precision, especially for vehicles travelling faster.

Methods based on satellite positioning systems have been recently used to determine the speed of the cars, which requires them to have the measuring equipment, for example GPS device, inserted in the vehicle itself. The accuracy achieved is sufficient in most applications. However there are some difficulties, particularly in urban areas due to possible reflections of the signal transmitted by satellite or shadow areas that prevent the signal reception.

Generally there are three methods to measure macroscopic variables of traffic streams:

- Measurement at a fixed location over time;
- Measurement in an fixed instant throughout the space;
- Mobile observer method.

A description of each method and, in particular, how achieve the values of the variables in each case, are presented below.

2.2.1. Measurement in a fixed location over time

In the Figure 2.1 is represented in a space-time diagram of trajectories of the vehicle in a traffic stream.

Considering a distance Δx and the observation period T. Δt_i is the time spent by each vehicle i to travel Δx. The traffic flow q is calculated by:

$$q = \frac{n}{T} \tag{2.1}$$

being n the number of vehicles passing in Δx during the time T.

The concentration k during the time T, can be achieved by the ratio between the average number of vehicles m present on Δx, and the length Δx. That is:

$$k = \frac{m}{\Delta x} \tag{2.2}$$

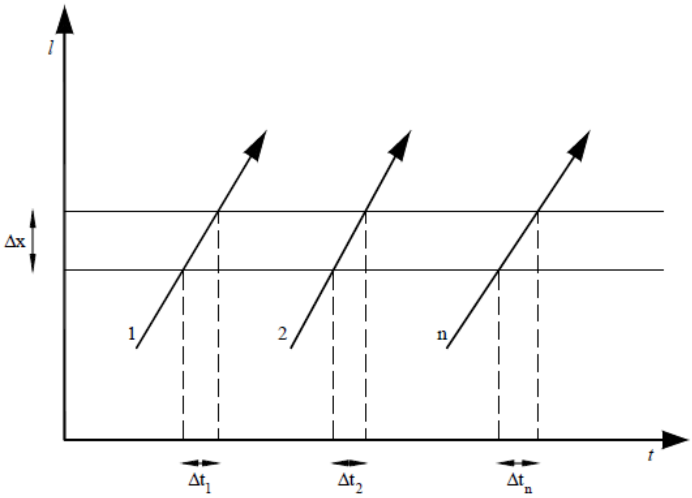

Figure 2.1 – Observations at a fixed location over time

Or, assuming that the average number of vehicles in Δx corresponds to the occupation rate, it comes:

$$k = \frac{\sum t_i}{T} * \frac{1}{\Delta x} \tag{2.3}$$

Finally resulting in:

$$k = \frac{\sum \frac{1}{u_i}}{T} \tag{2.4}$$

with

u_i – velocity of the vehicle *i*

T – observation period

In order to determine the average velocity in space is necessary to use the fundamental relation provided by,

$$u_s = \frac{q}{k} \tag{2.5}$$

As a result of the sum of equations (2.1) and (2.4):

$$u_s = \frac{n}{T} * \frac{T}{\sum \frac{1}{u_i}} \tag{2.6}$$

From which it comes back to the presented result where the average velocity in space is the harmonic mean of the individual velocities, that is:

$$u_s = \frac{n}{\sum \frac{1}{u_i}} \tag{2.7}$$

Finally, the average velocity in time is calculated by:

$$u_t = \frac{\sum u_i}{n} \qquad (2.8)$$

2.2.2. MEASUREMENT IN AN FIXED INSTANT THROUGHOUT THE SPACE

Considering the length *L* of the segment of road where *n* vehicles are present in the interval *Δt*. The concentration *k* is given by:

$$k = \frac{n}{L} \qquad (2.9)$$

The average velocity in space is calculated by:

$$u_s = \frac{\sum u_i}{n} \qquad (2.10)$$

where

$$u_i = \frac{\Delta x_i}{\Delta t} \qquad (2.11)$$

To calculate the traffic flow *q*, it is possible to do a similar transformation to what was done in the previous case when determining the concentration:

$$q = \frac{n}{T} = \frac{n * u_s}{L} \qquad (2.12)$$

Knowing that:

$$u_s = \frac{\sum u_i}{n} \qquad (2.13)$$

it comes:

$$q = \frac{\sum u_i}{L} \qquad (2.14)$$

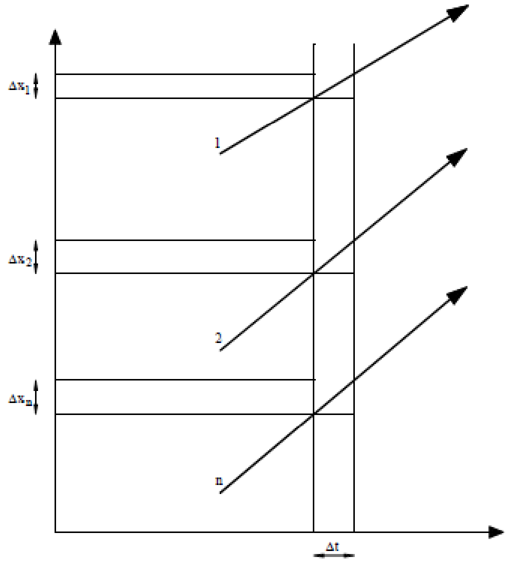

Figure 2.2 – Measurement in a fixed time over space

2.2.3. MOBILE OBSERVER METHOD

In the mobile observer method (also known as Floating car method), the measurements are taken from a trial car that runs along a road segment along with the traffic stream. It is a method often used, being possible to obtain a valuable set of information in a quick and simple way, involving reduced material and human resources.

Specially designed for two-way roads, the method of the mobile observer consists in going through the road segment in both traffic directions, recording the following values:

- Data collected in the direction of the traffic movement:
    - n_s - number of vehicles overtaken by the trial car;
    - n_f – number of vehicles that overtakes the trial car;
    - t_w – “going” travel time.
- Data collected in the opposite direction of the traffic movement:
    - n_a - number of vehicles that passes by the trial car;
    - t_a – “returning” travel time.

Assuming that the number of vehicles passing the road segment *n* remains constant during the time used to run it in both directions ($t_w + t_a$), its value is given by:

$$n = n_f - n_s + n_a \tag{2.15}$$

If doing:

$$n_w = n_f - n_s \tag{2.16}$$

it comes:

$$n = n_w + n_a \tag{2.17}$$

The value n_w reflects the difference in progress between the trial car and the vehicles in the traffic stream, having a positive value if the vehicle moves slower and negative otherwise.

The flow q of the traffic stream is given by:

$$q = \frac{n_a + n_w}{t_a + t_w} \tag{2.18}$$

Changing the equation (2.15) it comes:

$$t_w - \frac{n_w}{q} = \frac{n_a}{q} - t_a = T \tag{2.19}$$

Each member of the expression (2.16) represents the average travel time T of the traffic stream, where n_w / q is the correction to be applied to the time spent by the trial car. This correction takes into account the speed difference between this vehicle and average velocity the traffic stream.

Thus, the average velocity in space is given by:

$$u_s = \frac{L}{T} \tag{2.20}$$

where L is the length of the road segment.

In turn, the concentration can be obtained using the fundamental equation, dividing the flow q by the average velocity in space u_s.

There is the need to perform a series of round trips, between 6 and 12, depending on the variability of flow conditions that are found, determining the average values for each variable recorded to reach the final values of the macroscopic variables q, u_s and k.

It is very important the selection of the road segments because this method requires a certain homogeneity regarding physical and traffic characteristics. In other words, the road segment must end if there is, for example, a variation in the number of lanes of the road or a intersection that marks a distinct traffic conditions before and after it.

As already noted before, this method is especially suitable for two-way roads since roads in one-way is obviously not possible to make the travel in the opposite direction. This difficulty can be overcome, allowing the application of the method in one-way road, doing two sets of runs in the direction of the movement at speeds significantly different, obtaining two values of t_w and n_w, which will allow the calculation of the flow q and the average travel time T from solving the following equations:

$$T = t_{w1} - \frac{n_{w1}}{q} \tag{2.21}$$

$$T = t_{w2} - \frac{n_{w2}}{q} \tag{2.22}$$

As described above, it should be made several runs in order to obtain more reliable results. [4][5]

2.3. Origin-Destination Matrix

When studying intersections, it is essential to know the directional distribution of the traffic, that is, the traffic flows for all of the possible moves in the form of a matrix, usually referred as matrix Origin-Destination (The Matrix O/D).

There are several methods that can be used for the measurement of volumes, from the manual counts to automatic counts, being these last ones specially recommended if it is not required to follow the trajectory of vehicles. In these cases, the most widely used method in Europe is the number plate recognition system, where observers record the vehicle plates that are later combined through specific programs for automatic calculation, identifying pairs of equal plates, matching each pair to a travel made between a specific origin and destination.

In the plate recording method it is usually measured the time, in intervals of 5 minutes. In order to know the number of observers and their tasks, below is presented a methodology for its determination, considering the minimum value of observers to obtain a full matrix O/D.

Considering an intersection with n input branches. q_{ij} is the flow of the traffic stream that goes from i to j, and Q_i and Q'_j the total flows originating and terminating in the branches i and j. So:

$$Q_i = \sum_j q_{ij} \qquad i = 1,2,\dots, n \qquad (2.23)$$

$$Q'_j = \sum_i q_{ij} \qquad j = 1,2,\dots, n \qquad (2.24)$$

The total number of traffic streams (variables) is:

$$n^2 + 2n$$

where n^2 corresponds to the total of q_{ij} and 2n to Q_i and Q'_j.

Between these variables there are $2n$ connecting equations, independently from the type indicated in (2.20) and (2.21).Therefore, there is an indeterminate system of $2n$ equations with $(n^2 + 2n)$ variables. In its resolution is necessary to know n^2 independent variables.

Knowing that the sum of the total traffic flows in i is equal to the sum of the total traffic flows in j, the number of independent external flows is (2n-1). Because they are easiest to measure is normal to start first by them, reducing the problem by knowing which independent interior flows are necessary to measure:

$$n^2 - (2n - 1) = n^2 - 2n + 1 = (n-1)(n-1) \qquad (2.25)$$

On the other hand, assuming that, as happens in some cases, movements are not possible the turnaround inside the intersection ($q_{ii} = 0$), the problem becomes:

- nº of traffic streams: $n(n-1) + 2.n$
- nº of equations: 2.n
- nº of variables to measure: $n(n-1)$
- nº of exterior traffic flows: 2.n – 1
- nº of inner traffic flows: $n^2 - 3.n + 1$

Therefore it can be applied the following rules in the organization of the process and measurement:

- When turnaround movements are allowed:
    - Measurement of (2.n - 1) external flows;
    - Measurement of (n - 1) inner flows in (n - 1) branches.
- When turnaround movements are not allowed:
    - Measurement of (2n - 1) external flows;
    - Measurement of (n - 2) inner flows in (n - 2) branches;
    - Measurement of (n - 3) inner flows in only one of the other two branches.

It should be noted that, in any case, what matters is to know the total number of variables to measure. Its distribution by internal and external flows depends on the particular characteristics of the area under study, equipment and/or number of observers available. [4]

3

TECHNIQUES AND INSTRUMENTS TO COUNT VEHICLES

3.1. OVERVIEW

The selection of the counting techniques depends on several factors such as human resources and materials available, the local characteristics, the required accuracy for the final results, the amount of data to be collected and the duration of the observation period.

3.2. OBSERVATION PERIOD

Depending on the needs, the parameters to measure and the degree of representativeness or precision required, the measurements at a counting post can be temporary (a few hours or weeks) or permanent.

The permanent collection of data will allow the creation of statistical databases, as well as traffic management in real time. The collections will allow the temporary execution of studies necessary to the dimensioning of infrastructure, traffic management and the placement of road equipment.

This distinction determines the choice of the counting technique to use. In the case of temporary measurements, it can be used manual counting or automatic counters, with sensors easily removable. For the case of continuous measurement is usual to use automatic sensors, usually inserted in the pavement and not removable.

For a statistical treatment of data, the day and the hour are the time units most often used. Thus, the time it takes to collect data may vary from one week for temporary posts to one year for permanent posts. For traffic management it is essential the knowledge of the traffic levels in real time, being in these cases the traffic flow usually calculated for intervals of 3 to 6 minutes. In turn, for the analysis of capacity and service levels should be considered the 15 minutes peak of the rush hour.

Therefore, the period of observation and collection of traffic data can be decomposed and aggregated at different time intervals, depending on the objectives of the study to be made. [6]

3.3. MANUAL COUNTING

In this case the counting of vehicles are made by observers directly on site. Previously, the tasks that the observers have to perform were clearly and previously communicated.

This is a simple technique that does not require the use of any measuring equipment and has the important advantage of the human capacity of observation that, when necessary, can make a difference in cases when is needed to know the trajectory of directional movements of vehicles in intersections.

In the case that the traffic volumes or observation period are high, this technique is no longer advisable, since the effort required exceeds the human limitations, or the number of observers can be unaffordable.

The use of observers requires an initial learning phase, with the realization of a pilot study to test the feasibility of the technique and make, if necessary, appropriate corrections. It is also necessary to provide control mechanisms to minimize possible mistakes.

It should be provided conditions of amenity and safety to the observers to prevent their fatigue or loss of concentration. It is generally recommended that the counts are made only in 80% of each aggregation period (4 in 5 minutes or 12 in 15 minutes) multiplying the values recorded by 1.25 to obtain the final values.

The observers record the data in specially designed forms for this purpose and may have mechanical equipment (pressing a button) or electronic (keyboard, touch screen with the silhouette of the vehicle) that facilitates the collection of traffic data and even the further processing in the case that the electronic recorded data can be easily transferable to any data analysis software. [4]

3.4. AUTOMATIC COUNTING

Automatic counting requires the installation of automatic measuring equipment on the study site, which may require the interruption of the traffic circulation and are especially recommended for long periods of observation, to justify the cost of acquisition, installation and maintenance.

In general, the accuracy achieved with the automatic counters is good and is easy to read the collected data through software. However it is not possible to use only one type of automatic equipment when there is the demand to measure certain traffic variables that needs to follow the path of vehicles.

These systems are based on the detection of vehicles according to several types of technologies that will be described in the following sub chapter.

3.5. TRAFFIC SENSORS

3.5.1. PNEUMATIC ROAD TUBE

The pneumatic tube is the oldest traffic sensor used in Europe. With the technological advances, there has been a tendency for substitution by inductive loops. However, they are still widely used because of their reliability regarding temporary counting.

This sensor is presented in the form of a rubber tube, attached to the pavement surface using appropriated spikes. Held perpendicular to the longitudinal axis of the road, the tube is squeezed by the front wheels of the vehicle, generating inside a variation of pressure. This variation pressure is propagated to the extremities of the tube and in particular to the end, connected to an element, sensitive to air pressure, triggering an electrical contact. It is then possible to count the number of axis that pass over the sensor, accumulating impulses in a counter.

The tubes are normally black, presenting the following key features:

- Rupture when stretching: 700%;

- Temperature resistance: -40 º to +90 º C;
- Abrasion resistance: excellent;
- Residual deformation by compression: 20%

There are two possible sections, circular or semi-circular, as illustrated in the next figure.

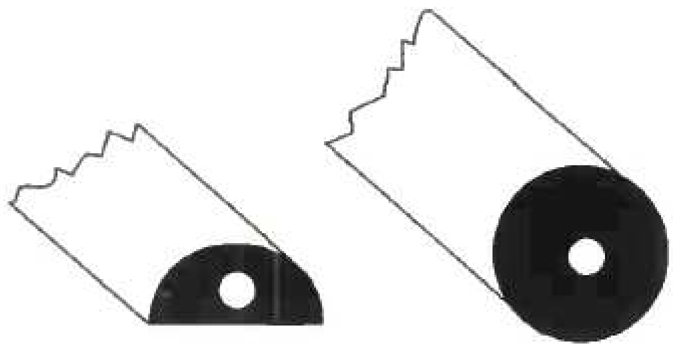

Figure 3.1 – Pneumatic road tubes sections most widely used [7]

The semicircular tubes are more expensive but have advantages when compared with circular tubes. The pressure is better divided with the passage of vehicles, since his profile is less likely to squeeze. They are more resistant, with smaller displacements, providing greater safety for pedestrians and lower noise.

The pneumatic tubes have a relatively short lifetime, which varies from days to several months, depending on the quality of rubber, traffic and/or vandalism.

The implementation of pneumatic tubes does not require big construction works, being its relatively quick and easy installation. In most cases it can be carried out without interruption of traffic circulation.

The tube should be placed across the road traffic and secured to the pavement surface through studs and clamps, nailed or bolted. Figure 3.2 shows the type of material used.

Figure 3.2 – Example of material used when fixating tubes, and its final presentation [3][7]

In its placement it should be chosen segments of road where the speed of circulation is stable, since its implementation in braking or acceleration areas may lead to premature wear. The passage of vehicles on the sensors generates noise, so their installation in residential areas should be avoided.

Such sensors require regular maintenance to prevent the development of holes or cuts that interfere with its proper functioning. Depending on the quality and the status of the pavement, the pipe will tend to sink in the surface layer of the bituminous pavement during hot weather. In this case, there is the need to reinstall it before it sinks more than half of its diameter.

The pneumatic tubes can perform traffic counts and therefore the traffic flow measurement using a tube for each direction of traffic movement. When only one pneumatic tube is used, only the axes are counted. The passage of an axis on the tube transmits a signal and identifies the active zone subject to squeezing.

In the case of two tubes placed at a distance from each other (usually 1 to 2 meters), and with the use of an appropriate detector, it is possible to make the following measurements per traffic direction:

- Traffic flow;
- Velocity.

The classification of vehicles is carried out mainly using to the velocity difference between consecutive axles, considering that axes with identical speeds belong to the same vehicle. It should be noted that in situations where the vehicles are going together with the same speed, this parameter is not sufficient to correct the individualization of the vehicles and can lead to lower traffic volumes to the real. Figure 3.3 presents an example of how to calculate the speed in the case of having two pneumatic tubes installed at a distance *d* between them.

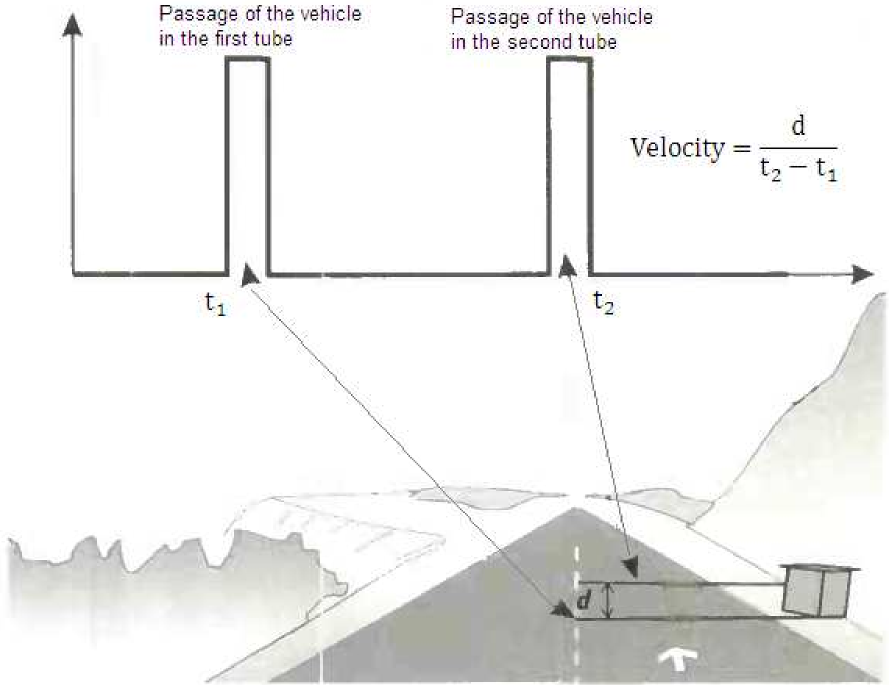

Figure 3.3 – Calculating the velocity using two pneumatic tubes

The pneumatic tube works well for temporary measurements, which may last a few days or weeks especially in low intense traffic lanes.

In addition to the applications already mentioned such as obtaining traffic flows and speeds, this sensor can also be used in service stations or systems to open barriers in car parks, acting as warning systems.

His alert function is also important in cases of particular interest in detecting the passage of vehicles such as railroad crossings, or the detection of vehicles in loopholes. The signal given by the passage of vehicles will trigger a process of recording and data processing.

With the emergence of other types of sensors such as inductive loops or piezo-electric sensor, the pneumatic tube is practically into disuse in the case of permanent counts. The disadvantage of being noisy should be taken into account when applied to urban centers.

3.5.2. Inductive Loop

Inductive loops, also known as electromagnetic sensors, are the devices for measuring the traffic parameters most used in European countries.

This sensor consists in an induction whorl installed in the cover of the pavement, with insulated wires made of copper and installed in spiral, sensitive to the presence of the metal mass of the vehicle in its magnetic field.

The electromagnetic sensor are mainly characterized by its resistance R, expressed in olm (Ω) and by its inductance I, expressed in microhenry (μH). The inductance depends, directly or indirectly, on its perimeter, its width, the effective radius of the cross section of the wire, the number of spirals and can be estimated by the following empirical formula:

$$I = K\,P\,N^2 \qquad (3.1)$$

with

K - correlation coefficient that depends on the geometry of the spire, between 1.1 and 1.6;

P - perimeter in meters;

N - number of spirals.

Once the loop is deployed in the pavement, its inductance will be stable since the surface of the pavement is, normally, constant. The passage of the metal mass of a vehicle on the loop will cause a changing in the magnetic field. This variation is reflected into a voltage variation, related to the kind of vehicle and its time of passage.

The connection of the spire to the edge of the detector is achieved, in most cases, placing the detector in an oscillating circuit. The detector submits the spire to an electric oscillation creating an electromagnetic field, which will be modified with the passage of a vehicle. These changes are detected, amplified, calibrated, adjusted and transformed into an electrical signal "0 or 1", representing the presence of the vehicle. This variation is translated to tension peaks whose length is related to the length of the vehicle and its time of passage. This principle of this operation is schematized in the figure 3.4.

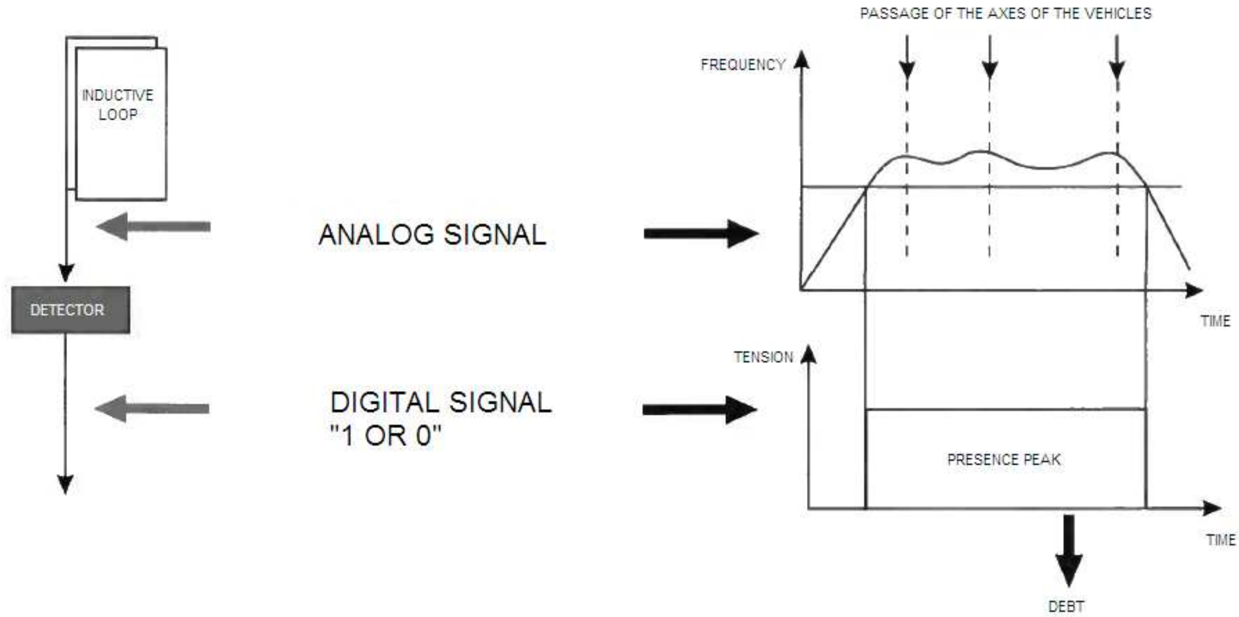

Figure 3.4 – Functioning of an inductive loop

The service life of the inductive loops is, in most cases, equal to the pavement, since they are largely immune to weather conditions and is difficult to be vandalized.

The use of removable inductive loops placed on the floor for temporary measurements have a very variable duration, a few months to 1 or 2 years depending on the quality of the pavement and the aggressiveness of the considered traffic.

The induction loop may be prefabricated or manufactured on site, being the number of loops usually between 3 to 5.

In general, these sensors are installed on the surface of the pavement through narrow cuts, with a depth ranging between 50 and 70 mm and with a width between 10 and 15 mm. After the opening is clean and dry, a layer of sand with a height of 10 mm is deposited at the bottom. The loop itself is connected to the detector by a shielded cable comprising two twisted conductors also deposited into the opening.

An inductive loop allows the measurement of the basic parameter of the presence of a vehicle, defined by the effect caused by a vehicle in the sensor field of action. The detection of presence will allow the counting for all vehicles.

The presence time t_i is the interval of time between the instant of penetration of the vehicle's front in the zone of action and the instant the rear of the vehicle leaves the area of action of the sensor.

Taking into account the distances defined in Figure 3.5, the presence time t_i can be deduced by the expression 3.2.

$$t_i = \frac{L_d + L}{u_i} \tag{3.2}$$

with

u_i – velocity of the detected vehicle;

L – length of the vehicle;

L_d – length of the detection zone.

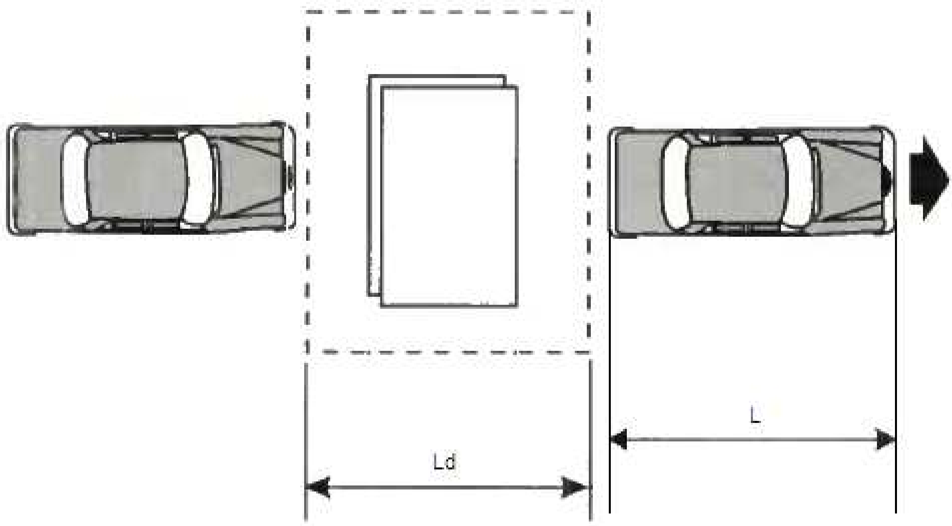

Figure 3.5 – Distances necessary to calculate the presence time of a vehicle [7]

With the implementation of a single loop per lane, it will be possible to obtain the traffic flow and the occupation rate ϕ defined by:

$$\phi = \frac{\sum t_i}{T} \tag{3.3}$$

with

ti – presence of the vehicles over the induction loop;

T – duration of the observation period.

The use of an induction loop also allows the detection of stationary vehicles, being useful, for example, in the case of intersections with traffic lights.

Through the deployment of two loops per lane, with a distance *d*, it becomes possible to calculate the instantaneous velocity of the vehicle u_i, given by equation 3.4.

$$u_i = \frac{d}{t_2 - t_1} \tag{3.4}$$

t_1 and t_2 represent the instants the front of the vehicle enters the zone of action of each sensor.

With this configuration of spires is possible to obtain classified counts by the length of the vehicle, after measuring the time of presence and velocity.

In the case of bicycles, their detection is not always possible. The lack of metal mass and their circulation in the same lane as other vehicles are the main causes. However, it is possible using a spiral implanted on a special track for this type of vehicle.

The inductive loop allows the counting of the number of axes belonging to the same vehicle, as illustrated in figure 3.6. Together with the calculation of distance between axes, this device allows a traffic classification into several categories.

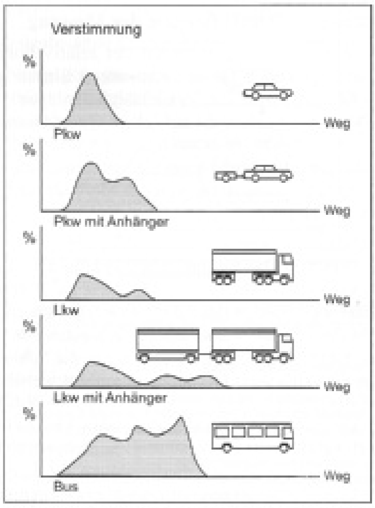

Figure 3.6 – Curves of different types of vehicles [3]

In urban areas, inductive loops are widely used to detect the presence or passage of vehicles, with the aim of regulating the operation of traffic lights.

3.5.3. PIEZO-ELECTRIC SENSOR

This sensor appeared in the late 80's and currently has many applications. The preparation of this sensor took a few years, currently regarded as being a reliable product. However it has limited application in specific cases where there is a need to know the value of rolling loads.

The piezo-electric sensor has two components, connected by an hermetic mechanical and electrical systems:

- Sensitive piezoelectric cable, which generates the electrical signal;
- Extension cable, which transmits the signal to an electronic equipment for data processing.

These sensors measure the electrical polarization degree each time the wheel of a vehicle passes over them. When some materials are requested mechanically, it appears on its surface an electric charge proportional to the requested force. This is the piezoelectric principle, used in the development of these sensors. Quartz and some ceramics naturally possess these properties.

Once the cable is subjected to a pressure variation ΔP, is the material that is electrically charged. The tension that occurs in the extremities will be a linear function of pressure variation.

In the figure 3.7 is displayed the constitution of this sensor.

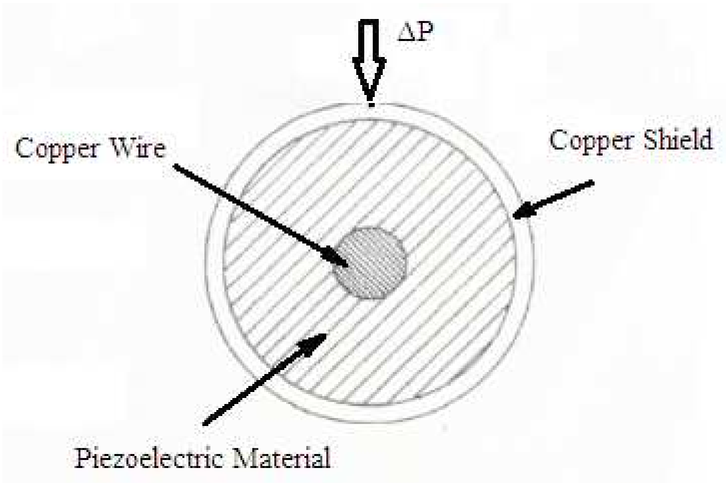

Figure 3.7 – Constitution of a piezo-electric sensor

The detectors associated with these sensors have the function to handle the signal, correct it according to the speed and enable the application of algorithms for automatic verification. Due to the combined effects of dynamic pressure tire-pavement and the contact surface of the tire, the electrical signal derived from the piezoceramic cable need a particular analysis for the measurement of loads.

Whatever may be the piezoceramic cable characteristics, the quality of measurements of the loads is directly related to the mechanical connection between the materials constituting the floor and the cable itself. Therefore the site should present all the characteristics of the good exchange of useful tensions (vertical) and the elimination of undesirable tensions (horizontal).

To maintain a good performance is necessary a regular verification, for example 6 in 6 months, that can be obtained through the use of an calibrated “impact” device, or an standard truck whose axle loads are known.

For long duration measurements there is some detectors that automatically proceed to his auto-verification using articulated heavy vehicles or light vehicles as the standard vehicle. The use of auto verification based on light vehicles allows more accurate measurements on lanes with small volumes of heavy vehicles, such as the left lanes on highways.

The lifetime of these sensors depends on the quality of the pavement where it is installed, but under normal conditions can be more than 5 years.

The sensor should not be installed on the pavement without protection. If the sensor is deformed, its qualities can be changed. In order to ensure its mechanical resistance, to ease the transportation and installation, the sensor is usually packaged in a resin bar. For the implementation of this cable is necessary the intervention of specialized operators and the cutting off the traffic for about 3 hours. It will also be necessary to make a cut in the pavement with 6 cm wide and 6 cm depth, as shown in Figure 3.8.

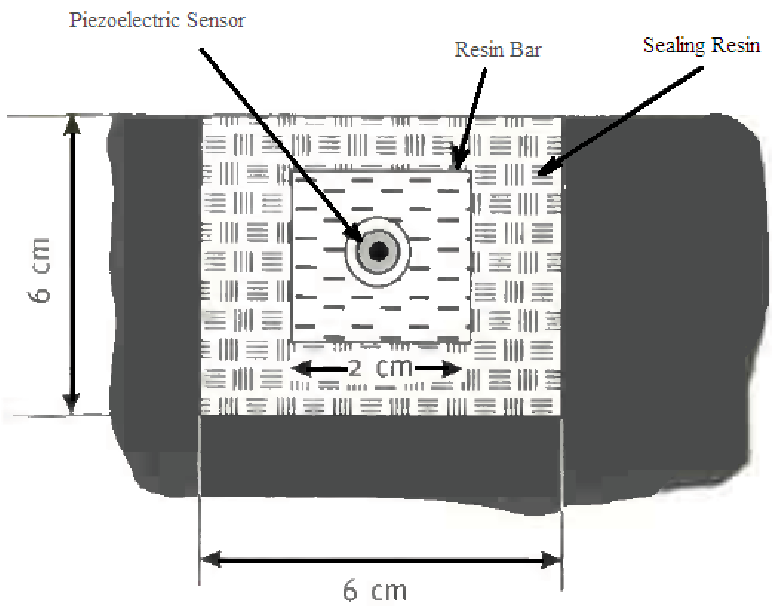

Figure 3.8 – Cross section of a piezoelectric sensor installed on the road

The sensor, before being coated by the resin, must be checked. To do this, a pressure is applied gradually over its circuit of 25 by 25 cm, to the entire length. Depending on the results, the sensor should be classified as:

- **Class 1**: for weighing in motion, the dispersion of the measured value with the real value should be less than 10%;
- **Class 2**: Intended for the classification of vehicles, the dispersion should be less than 20%. These sensors should only be used for measuring traffic flow and velocities.

Whatever the type of application, the pavement should be in good condition, since the quality of the measurements depends on the uniformity of the pavement. The piezoelectric cable can be used for the detection of axles of vehicles and for measuring the force of impact of the vehicle axles on the pavement.

The combined use of two cables (for measurement of velocity) or his use with other sensors, especially inductive loops, allows the calculation of the total weight of the vehicle, the wheelbases and classification of vehicles by category.

This sensor is also used in statistical collections of rolling loads, counting, detection and classification of vehicles. Its development was the main factor in the practical application of the system *Surveillance Automatique du Trafic Lour* (SATL) in France. [6] [8]

In Portugal, the piezo-electric sensor is used together with inductive loops in the National System of Automatic Traffic Control.

3.5.4. Radar

The radar, originally developed for military purposes, was quickly inserted into the road system, due to the quantity and quality of information that is able to receive. Widely used initially, its importance has declined with the use of inductive loops.

The operating principle of the radar is based on Doppler-Fizeau effect. It operates in a frequency band, ranging from 10 to 25Ghz.

The radar diffuses its energy through an antenna, generally parabolic type, aimed with a few degrees of openness. After reflection of the wave emitted on moving vehicles in the area of action, the backscattered wave returns to the same antenna with a frequency gap, higher or lower depending on the direction of travel and proportional to vehicle speed. The pace, the difference between the frequencies of emission and reflection, is called the frequency Doppler-Fizeau. This frequency F_d is proportional to vehicle speed and the cosine of the angle between the velocity vector and the emitted wave beam, as defined in the expression 3.5 and figure 3.9.

$$F_d = \frac{2u_i.\cos\alpha}{\lambda} \tag{3.5}$$

with:

u_i – Vehicle velocity (m/s);

λ – wavelength (m);

α - angle between the emitted wave beam and the vehicle speed (degrees).

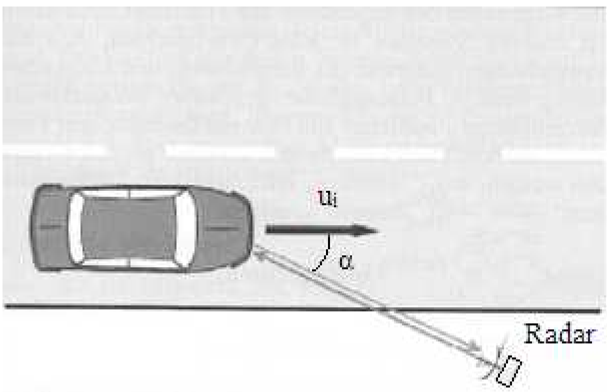

Figure 3.9 – Doppler frequency

The combination with electronic devices leads to take into account the vehicles travelling towards the radar, vehicles moving away from the radar or all vehicles whatever is the direction of movement.

The radar can contain, in the same box, an antenna for transmission and reception, the emission source, an electronic system to process the Doppler signal, and sometimes the power source.

The radar should be subject to regular maintenance in order to ensure their proper orientation and restore the microwave sources, which degrade over time.

The best choice for the mounting location the radar depends on the parameters to be measured and the possible obstacles that may lie on the antenna field of view. Fixed and permanent radars should be placed on its own post or on a structure in the area (building, bridge), directed to the area to observe. When setting the radar it should be taken into account the orientation and direction to the vehicle, since the Doppler frequency varies with the cosine of the angle α. The radar should be fixed to a tripod, in the case of temporary measurements, velocity measurements or use by police forces. In all cases it should always be stable to do not vibrate with the wind or passing vehicles.

Basically, the information obtained from the radar are:

- Presence or absence of a vehicle in the detection zone;
- Direction of movement (moving away or approaching);
- Velocity;
- Types of vehicles (heavy or light) from analysis of the return of the Doppler signal;
- Occupation rate.

There are two types of use, temporary measurements and continuous measurement. In the case of temporary measurements, the radar is mainly used in the measurement of speed, allowing its control, for example, in studies before and after by the police (manual models used primarily as repressive measures, with the possible integration of a photographic camera).

In Europe there are different models of radars that allow its use in static structures or applied to vehicles.

In the case of continuous measurement and taking into account the quality of the information of the signal, the radar can also be used to collect data such as traffic flow, speed, occupation rate and direction of movement. However, the count of vehicles is almost impossible in case of traffic jam.

The radar is privileged in applications such as detecting traffic at intersections managed by traffic lights, or the detection of certain vehicles (police, fire, public transport, etc.) in order to ensure their priority.

This last system works with a transmitter in the priority vehicle and a reception device usually placed on the top of a traffic light, as observed in Figure 3.10.

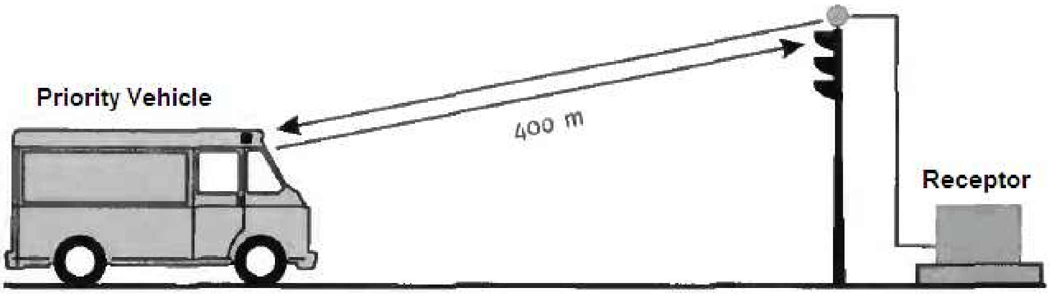

Figure 3.10 – Detection of priority vehicles with radar

3.5.5. VIDEO

The development of video sensors for traffic analysis is a relatively recent technique, intended for automatic detection of incidents and the development of traffic studies. Despite the technological diversity of cameras, video sensors require models specifically adapted to the concerned applications.

Essentially, a video system follows the scheme in Figure 3.11.

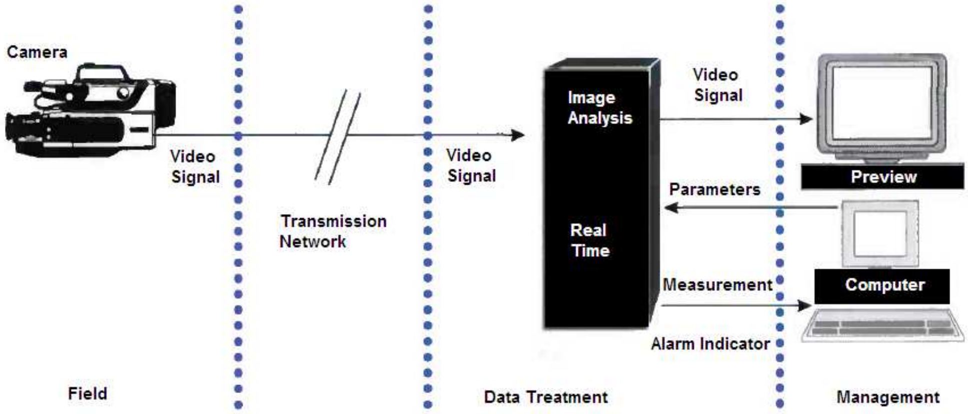

Figure 3.11 – General structure for the functioning of a video system

For traffic measurement, the video camera can be completed with specific devices marked in the road in order to increase the accuracy of the measurements. The performance of the video sensor is affected by the weather. Therefore, the device should be placed in a protective box.

Parallel to the collection of video images, image analyzers contain algorithms for image processing, specific for the desired application. For any application, the analyzers work in real time, day and night. For the night-time operation, it may be necessary to add lighting to the site (infrared type).

The placement on the video device basically depends on the scenario to observe, the restrictions relating to the image processing and environmental constraints.

The camera is usually placed on a pole or a proper integrated support site (for example, road signs or bridges). The chosen focus and site for deployment defines the field of view where will be made the measurements. As an example, the schematic figures of 3.12 and 3.13 describe deployments of automatic applications adapted to incident detection and traffic measurement, respectively.

Whatever the type of image analysis is, video sensors can provide important information on the site observed, such as traffic status, existence of incidents and weather conditions. However, it is necessary the presence of an operator for the treatment of such information.

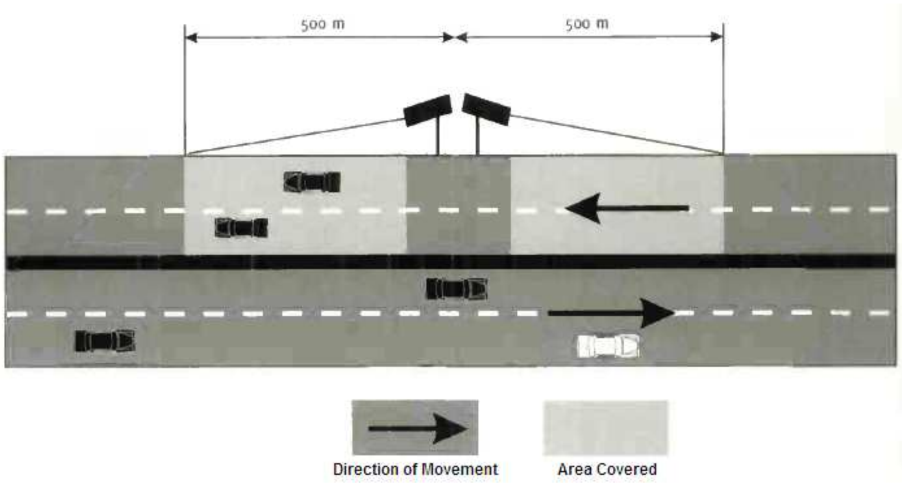

Figure 3.12 – Implementation of a video system to detect incidents [7]

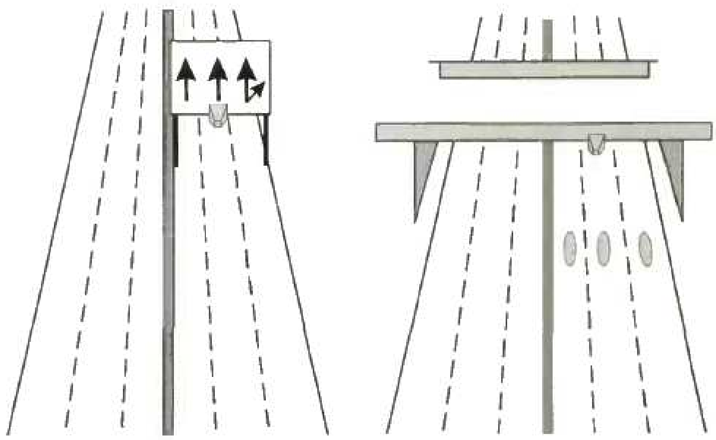

Figure 3.13 – Implementation of a video system for traffic measurements (portico and bridge) [7]

The principle of the analyzers for automatic incident detection is based on the detection of a vehicle stopping in a traffic lane or on an emergency escape. This stop, which means an incident in traffic flow, activates an alarm in real time.

The performance achieved currently (annual average value) of the analyzers for automatic detection of accidents is:

- Incident detection rate: 90% (day and night);
- False alarm rate: 5 to 13%;
- Incident detection time: 15 seconds, average. [6]

Video systems for measurement of traffic allow the collection of the following data:

- Count of vehicles;
- Classification in light and heavy vehicles;
- Average velocity;
- Occupation rate.

The performance achieved by these analyzers, regarding to the measurement of the flow, will be:

- Error < 10%, if the observed site has no specific markings on the pavement;
- Error < 3%, if the observed site has specific markings on the pavement; [6]

The next two figures shows how important is the existence of marks on the pavement in order to increase accuracy of the measurements. In Figure 3.14. the projected shadow from the vehicle in the right lane has a negative effect on the detection of the vehicle on the left.

Figure 3.14 – Video system without marks in the pavement [7]

In turn, the Figure 3.15 shows that the vehicle on the right hides the mark the ground, which facilitates his detection. The projected shadow does not hide the mark on the left lane.

The application of video sensors, along with the image analysis, is used mainly in control and road maintenance. Currently these sensors are mainly used in highways, high speed urban roads and tunnels.

The use of image analysis for automatic detection of incidents seems to be a strong possibility for future years due to the increasing robustness of the algorithms for image processing, and the increasing demand from road concession operators.

Figure 3.15 – Video system with marks in the pavement [7]

3.5.6. MAGNETIC SENSOR

This sensor became known in 1991, considered as a possible replacement for the inductive loops.

The magnetic sensor analyzes the variation of the earth's magnetic field caused by the passage of vehicles. One of its peculiarities is the small size, having some models a format similar to a credit card.

It can be placed in the center of the road or on the verge. There are two ways to perform measurements of a temporary nature.

The first refers to the attachment to the middle of the traffic lane of a plate, constituted by a material resistant to the passage of vehicles, through four screws or studs. According to the manufacturers, the plate can have only the sensor function or have a group of functions: sensor, detector, and memory. In the first case, the information from the sensor is transmitted by radio telemetry to a counting mark installed up to a distance of 20 meters.

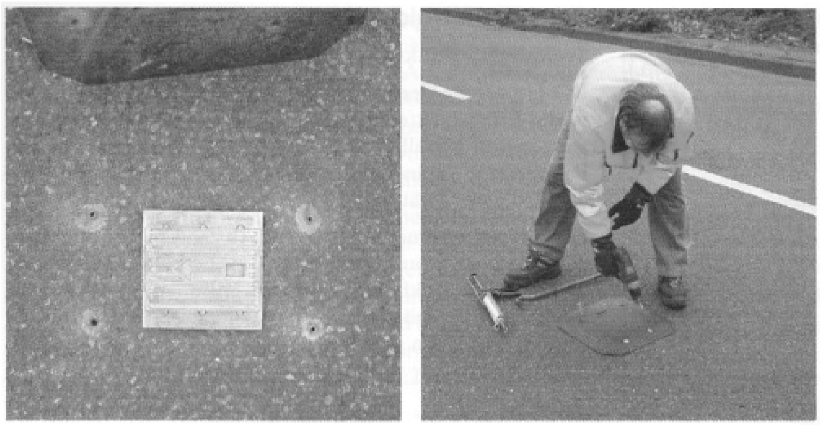

Figure 3.16 – Application of a magnetic sensor [3]

In the second case, the operator cannot control the sensor. To read the data it will be necessary to dismantle the plate from the floor. In both cases, the power is integrated on the board without any physical connection to the side of the road.

With regard to measurements with a permanent nature, the magnetic sensor is presented in the form of a cylinder, with diameter and height that can vary, intended to be implanted vertically on the pavement surface, usually in the middle of the traffic lane.

For its implementation will be necessary to carry out a hole for mounting the sensor and a ditch for the cable.

This sensor provides information about the passage and the presence of vehicles, allowing the measurement of the flow of vehicles when used in only one traffic lane.

The use with an appropriate detector will allow measurement of the length of vehicles and consequent classification, also allowing the measurement of the speed when used in pairs.

The magnetic sensor is mostly intended to temporary measurements. The magnetic sensor can be installed on any floor, regardless of the quality of the surface layer. It also presents a good electromagnetic immunity.

3.5.7. Optical fiber sensor

Recent research shows that the optical fiber can be used as a sensor of traffic and particularly for weighing vehicles in motion. Usually have a length of 55 cm, formed by two metal plates and a fiber optical cable between them. The concept of this sensor is based on the birefringence induced on the fiber cable when it receives a charge.

The light beam, emitted by a laser diode, is injected into the fiber through a polarization separator. Birefractivity under the influence of the optical field decomposes into two orthogonal components. The passage of a charge on the sensor leads to a gap between these two components.

The load supported by the sensor becomes a succession of maximum and minimum, called polarimetric fringe, corresponding to detected optical intensities. The counting of the fringes will determine the variation of birefringence associated with the weight of a wheel. The profile of the vehicle will be characterized by a number of fringes that depends on the weight, the passage time and the tire pressure.

With this sensor, it will be used an electro-optical converter that will ensure the generation of a light beam towards the sensor through a fiber optic transmission, which can reach a few kilometers. Through a polarization separator, reflected beam is detected.

In the experimental stage, the optical fiber is placed between two metal strips, as described in Figure 3.17, and immersed in the bottom of a U-profile armed polymer, with the help of an elastomeric resin. This set is placed on the pavement, in an appropriate slot for this purpose.

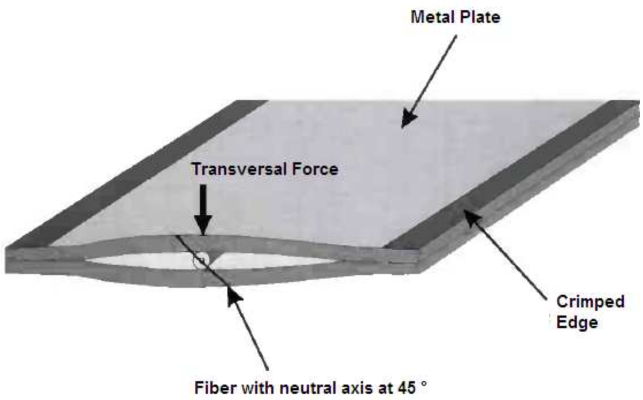

Figure 3.17 – Detail of the optical fiber sensor

The optical signal may provide a large amount of information, extracted with the help of a numeric processor. Thus, it is possible to make detections, traffic counts and measurements of the following parameters:

- Weight, per wheel and axle, of the vehicle in motion;
- Vehicle velocity;
- Distance from the wheel per axis;
- Wheelbase.

The various measurements allow the possible use of this sensor in the classification of vehicles, the dynamic weighing of axles, the detection of anomalies (tire pressure or suspension of the vehicle) and measurement of temperature variations of the pavement. It is presented in Figure 3.18 the response to the effect caused by the tire pressure.

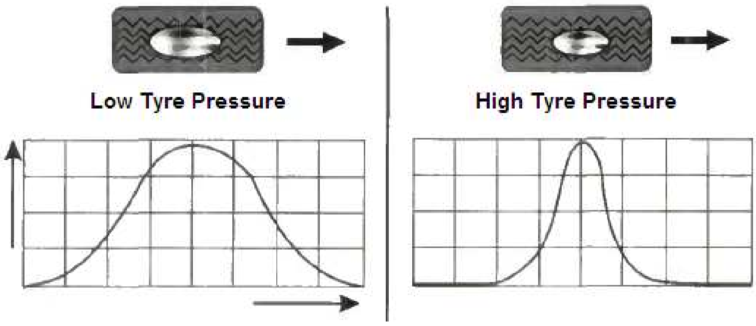

Figure 3.18 – Influence of the weight of the tires, for the same vehicle weight

3.5.8. Ultrasound sensor

This non-intrusive sensor is presented as an alternative to the inductive loops. The ultrasonic sensor consists in a directed antenna that emits ultrasonic sound waves of around 50 KHz. In the absence of obstacles, the detection radius corresponds to a disk whose diameter depends on the direction and antenna height.

With the passage of a vehicle, the reflected wave will be captured by the receiver after a certain time, depending on the propagation velocity of waves in the air. With the exploitation of this principle, the sensor will send a signal for the count of vehicles and allow the calculation of occupation rate.

The measurement of time between emission and reception, Δt, allows the measurement of the distance D between the transmitter-receiver of ultrasound and the vehicle, as shown in Figure 3.19. From this distance will be possible to classify the vehicles.

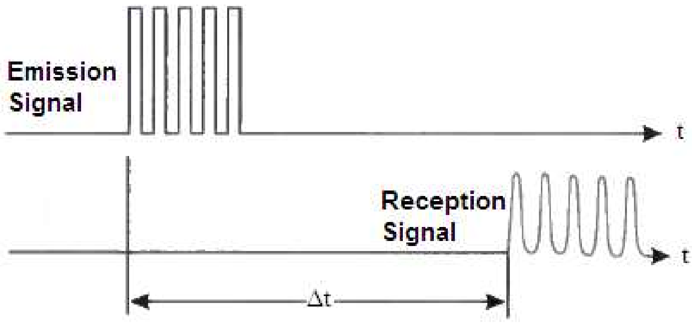

Figure 3.19 – Time between emission and reception signals

The distance between the sensor and the vehicles can be calculated by the following formulas:

$$2.D = \Delta t.A \tag{3.6}$$

with

$$A = A_0\sqrt{\frac{B}{243}} \tag{3.7}$$

A - Propagation speed of sound in air at the time of measurement;

A_0 - Propagation speed of sound in air at 0 º (A_0=331.4 m/s);

B - Ambient temperature at measuring moment.

This type of sensor can be assembled horizontally from the side of the road, or vertically on a post or a portico at the bottom, as shown in Figure 3.20. In the case of horizontal installation, it becomes possible to count the vehicles operating on different routes. Vertical installation of this sensor will allow the further differentiation of categories of vehicles.

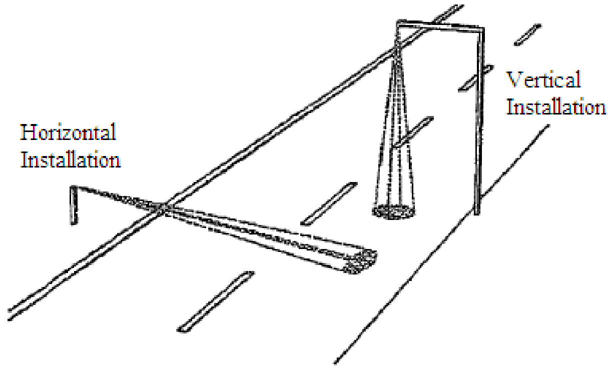

Figure 3.20 – Different ways to place an ultrasound sensor

The ultrasonic sensors have small size, and can be installed permanently or used as portable units, both on the side as the upper lanes of traffic. These equipment is considered to be reliable, durable and require little maintenance.

The ultrasonic sensor has a range of about 10 to 12 meters, allowing, in particular, the traffic flow measurement and distinction of classes. The vehicle classification can be made using the vertical sight, by measuring the height or horizontal sight, using two sensors.

It can also be used to obtain the occupation rate. The analysis of the Doppler effect, or the use of two sensors (spaced a certain distance known, for example 5 meters) allows the measurement of speed.

This type of sensor is used in massive scale in Japan, especially on motorways, as it is easy to maintain and their placement does not require construction works. In Europe these sensors are not permanently installed, being used for temporary measurements: mobile stations to measure the traffic flow or stations to measure heights.

3.5.9. Infrared sensor

Commercialized under many forms, the infrared sensor is widely used for industrial applications and in different ITS. Infrared sensors can be classified into two major families, passive infrared and active infrared, both used for traffic purposes.

The passive infrared works by detecting the heat emitted by an object, an animal or human body and is commonly used in lighting controls, opening doors or entrance control security.

The primary use of this type of sensor is to detect the presence of vehicles or pedestrians, reaching 100 meters range, as shown in Figure 3.21. This detection can be operated especially in urban areas, with the traffic lights to detect, for example, the presence of pedestrians on a crosswalk or approaching vehicles.

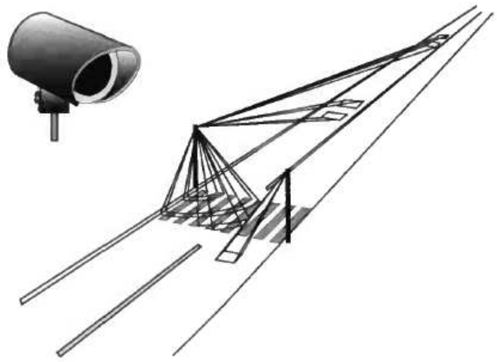

Figure 3.21 – Example of a passive infrared sensor [7]

The active infrared work by the principle of emission / reception of an infrared ray (wavelength from 0.9 to 1 µm).

The emitter is usually composed of a light-emitting diode that emits a light ray very thin. It can also be laser, with the advantage of emitting a visible ray, which will allow easier alignments.

Depending on the mode of reflection of the ray, the whole emitter / receiver can be used in three different ways:

- **Barrier mode**: the transmitter and receiver, placed face to face, allow the detection of the vehicle in motion by cutting the infrared ray, as shown in Figure 3.22a. Its range may exceed 200 meters.
- **Reflection mode**: the transmitter and receiver are placed in the same box and the ray is reflected by a surface consisting of a prismatic reflector or glass micro-spheres, as shown in Figure 3.22b. Its range can be more than 30m.
- **Proximity mode**: similarly to the previous mode, the transmitter and receiver are placed in the same box, however, is the mobile vehicle that ensures the reflection, as shown in Figure 3.22c. The placement is simpler than previous methods but features some disadvantages such as the difficulty in detecting dark colored vehicles. Its range is limited to about 3m.

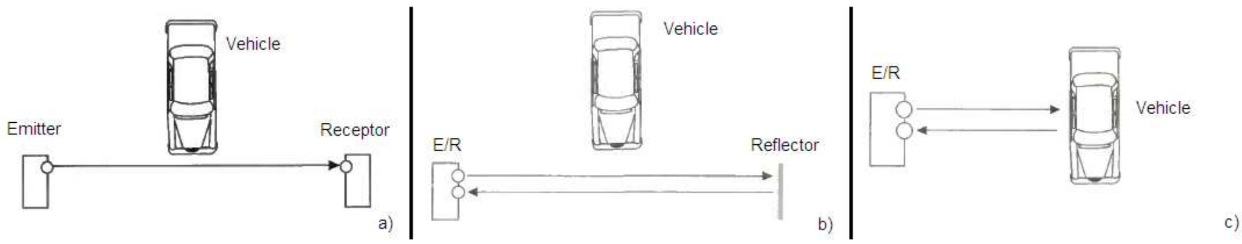

Figure 3.22 – Examples of active infrared sensor modes

This type of sensor allows measurements of flow, velocity, and with two cells, the length of the vehicle. For the count of vehicles will only be used barrier and reflection modes.

The infrared technology is widely used in car navigation system in Europe such as in identifying vehicles travelling over the speed limit.

3.5.10. ACOUSTIC SENSOR

This type of sensor is still not yet widespread in European countries. It's a new traffic monitoring system, compact and lightweight, non-intrusive on the road, based on the detection of acoustic signals produced by vehicle engines. It consists in a set of microphones to convert the received acoustic signal into analogue signals.

It can be mounted on existing structures such as street light posts, road signs or bridges. Therefore it is not necessary to interrupt the traffic to be installed. It allows the measurement of the traffic flow, the occupation rate and average velocity for each monitored zone and for a certain period of time.

It is a sensor that does not emit any signal, so it requires little power to operate. Thus, the battery associated with this system is kept charged by a small solar panel, avoiding the use of electric power by cables.

3.5.11. QUARTZ SENSOR

The functioning of this sensor is based on the principle that the elements of quartz modify their electrical properties depending on the applied load. The quartz crystals inserted between two aluminium profiles, ensure the transmission of vertical loads. These sensors should be enclosed in the pavement, like the piezo-electric sensors.

The sensor of quartz crystals, still under development, is mainly intended for the weighing in motion. Due to its small length (modules from 0.75 to 1.00 meters), it is necessary to combine several modules and add received loads to evaluate the weight of the axles of vehicles.

This type of sensor has been developed by the company Golden River Ltd. (United Kingdom), in order to consider its use in traffic management and traffic planning.

3.5.12. LASER SENSOR

The sensor systems based on laser rays, are mainly used in detection and classification of vehicles and operations of repression.

The operation of this equipment is based on relations time / distance. In general, it is the emission of two laser rays, with the speed and length of a vehicle calculated considering the time between the interruption of two beams and the time period during which this happens. This data is stored in memory and also considers the time and collection date. At the end of the data collection, it will be imported and analyzed using appropriate and specific computerized tools (supplied by the manufacturer).

For the application of this equipment on roads with many traffic lanes in each direction, it should be taken into account the possible loss of information. In fact, considering more than one traffic lane, if it passes several vehicles simultaneously in front of the sensor, only one will be registered.

The laser sensors can be placed on the roadside fixed on street light posts in the case of data collection during long periods of time. In the case of short-term counts it can be used a tripod.

The speed and accuracy of laser systems make it suitable for its application in cases in which vehicles must be properly identified. The laser detection is often combined with video detection, especially in the case of speed control.

3.5.13. Microwave sensor

The microwave sensors are small systems, lightweight and easy to install. It is a cheaper alternative to detect vehicle presence when compared to inductive loops.

Its size, low cost and low energy consumption makes them ideal for detection of moving vehicles at intersections with traffic lights and roads in temporary construction.

The detection of a vehicle is made with the spread of low-level microwave energy along the section of a road. With the approach of the vehicle, part of the microwave energy is stopped and reflected back to the sender allowing to deduce the speed and direction of movement of the vehicle.

In the installation of microwave sensors should take into account their potential tendency to suffer interference. Today there are many applications for microwave technology, therefore is crucial to ensure that no installation is subject to interference. [3][6][7]

3.6. Networking

3.6.1. The aim of networking

The main concern of networking is to make an interaction and cross the information of the various systems of traffic detection and traffic control in a data processing room.

It should be also avoided that measures taken in a certain area, influence the effectiveness in other control posts.

An essential prerequisite for an interaction of different traffic detection posts and integrated traffic control systems in a coordinated strategy is the development and mutual understanding of the traffic situation and the status of all relevant systems.

3.6.2. Networking in the planning process

The data exchange process is preceded by his integration in the planning process. Both in large metropolitan areas or small and medium sized cities, it is required a networking system representing a complete planning process and the implementation of traffic management strategies.

To avoid unnecessary effort when exchanging data, operators should be familiar with networking requirements in the design of the strategies to be implemented. On the other hand, operators should take into account the development of existing networks. In appendix, through figure A.1, the importance of networking in traffic management can be observed.

3.6.3. Basic forms of networking

There are different basic shapes of telematic systems for data exchange:

- Local networking as a direct connection of multiple systems (Figure A.2);
- Connection of multiple systems on a common center (monocentric networking, Figure A.3);
- Integration of systems at different centers, which are linked together (polycentric networking, Figure A.4).

By combining these basic shapes, other shapes can be formed (mixed forms, Figure A.5). The networking shape that best fits in different cases depends on conceptual-functional, technical-physical and organizational-institutional factors. [9]

3.6.4. Networking in Europe

It is known that traffic data can be used for different purposes. The collected information about traffic is necessary for transportation planning and quality management in the context of a Europe without borders.

Therefore, it is of great importance to share this information in an organized and standardized way.

There are several technologies, legal instruments and organizations in Europe involved in the sharing of traffic information, and some of the most important will be introduced below.

- **DATEX II**: is a standard developed for information exchange between traffic management centres in Europe. With the aim to support sustainable mobility in Europe, the European Commission has been supporting the development of information exchange mainly between the actors of the road traffic management domain for a number of years. In the road sector, the DATEX standard was developed for information exchange between traffic management centres, traffic information centres and service providers and constitutes the reference for applications that have been developed in the last 10 years. DATEX was originally designed and developed as a traffic and travel data exchange mechanism by a European task force set up to standardise the interface between traffic control and information centres. With the new generation DATEX II it has become the reference for all applications requiring access to dynamic traffic and travel related information in Europe. [10]
- **ITS Action Plan and Directive**: This Directive is an important instrument for the coordinated implementation of ITS in Europe. It aims to establish interoperable and seamless ITS services while leaving Member States the freedom to decide which systems to invest in. Under this Directive the European Commission has to adopt within the next seven years specifications (i.e. functional, technical, organisational or services provisions) to address the compatibility, interoperability and continuity of ITS solutions across the EU. The first priorities will be traffic and travel information, the eCall emergency system and intelligent truck parking. The Commission already took a major step towards the deployment and use of ITS in road transport (and interfaces to the other transport modes) on 16 December 2008 by adopting an Action Plan. The Action Plan suggested a number of targeted measures and included the proposal for this Directive. The goal is to create the momentum necessary to speed up market penetration of rather mature ITS applications and services in Europe. [11]
- **Traffic Message Channel**: TMC is a technology for delivering traffic and travel information to drivers. Each traffic incident is binary-encoded and sent as a TMC message. Each message consists of an event code and a location code in addition to expected incident duration, affected extent and other details. The message is coded according to the Alert C standard. It contains a list of up to 2048 event phrases which can be translated by a TMC receiver into the language of the user. In Europe, location code tables are maintained on a national level, assigning numerical codes to locations (typically major junctions) on the road network. Sources of traffic information typically include police, traffic control centers, camera systems, traffic speed detectors, floating car data, winter driving reports and roadwork reports.

- **ERTICO**: is the network of Intelligent Transport Systems and Services stakeholders in Europe. It connects public authorities, industry players, infrastructure operators, users, national ITS associations and other organisations together. ERTICO plays a leading role in advancing the TMC standards, opening frameworks for telematics services, making future preventive safety systems and the progress in the technical framework for interoperable tolling in Europe. [12]
- **Open Communication Interface for Road Traffic Control Systems**: With the intention of standardising interfaces for systems of the road traffic engineering, the companies Dambach, Siemens, Signalbau Huber, Stoye and Stührenberg founded this working group. OCIT interfaces are the basis of an open architecture. They concentrate on standardised connections between distributed central and decentralized components, like subsystems, tools and field devices. With the use of internet technology they enable traffic management systems and system-far networks, which cover field devices and central devices. [13]

4

COLLECTING DATA

4.1. INTRODUCTION

In the assessment of road facilities, it is essential to the maximize the available information, which is achieved through an appropriate data collection. In particular, the study of intersections becomes necessary the knowledge of the directional traffic volumes. In the collection of these, it should be defined the places and counting type to be carried in order to obtain reliable and precise data with the least possible cost.

Even if it is able the automatic registration of the number of vehicles passing in a section, normally is not possible to get the number of vehicles which perform a specific turning movement. In most intersections, the counting of directional traffic volumes is performed manually through observers properly instructed to the effect. The values for total volumes of input and output sections can be easily obtained using the automatic counters.

In this chapter, it will be presented the analysis of collected data by two different ways: floating car and inductive loop (in a intersection with traffic lights). These data were provided by the Supervisor Mrs. Isabel Viehmann. As the amount of data provided is huge, the entire set of data will not be presented in this work.

4.2. FLOATING CAR DATA

As described in Chapter 2.2.3, the measurements in this method are taken from a trial car that runs along a road segment along with the traffic stream. In this particular case, the trial car collected data on the velocity and capture angle every 2 seconds.

It can be observed in the following table that was made a sequence of 23 tests, between the 6h52 and 15h05 on the day 04/09/2009. Note that the observation period of each test varies between 1 and 30 minutes, being No 4 the test which collected the largest number of data (879).

Test nº	Starting	Finish	Observation period	Amount of data	Last data
1	6:52	7:02	0:10	310	322
2	7:41	7:43	0:02	67	389
3	8:29	8:51	0:22	637	1026
4	9:00	9:30	0:30	879	1906
5	9:37	9:38	0:01	41	1947
6	9:44	9:46	0:02	63	2010
7	9:46	9:48	0:02	53	2063
8	9:53	9:55	0:02	52	2115
9	9:57	10:08	0:11	330	2445
10	10:10	10:16	0:06	153	2598
11	10:18	10:29	0:11	308	2906
12	10:30	10:35	0:05	155	3061
13	10:36	10:43	0:07	198	3259
14	10:46	10:48	0:02	61	3320
15	10:52	11:09	0:17	496	3816
16	11:12	11:22	0:10	288	4104
17	12:41	12:42	0:01	54	4158
18	12:46	13:03	0:17	501	4659
19	13:04	13:14	0:10	280	4939
20	14:01	14:12	0:11	305	5244
21	14:18	14:31	0:13	357	5601
22	14:34	14:53	0:19	555	6156
23	15:04	15:05	0:01	30	6186
		Total:	3:32	6173	

Table 4.1 – Amount of data from FCD

There were thirteen data that were not considered because the sensor was turned off. In other words, the status of the sensor was 0. To inform the operator of the last results in each test, the sensor changes the status from 1 to 201 (table 4.2).

The first test differs from others because the trial car did not perform any movement, being the speed zero all over the 10 minutes.

TIMESTAMP	SIM_ID	STATUS	SPEED	ANGLE	X	Y
22-04-09 8:34	17430118903	1	87	92	123,179	5,141,475
22-04-09 9:00	17430118903	0	0	0	0	0
22-04-09 12:42	17430118903	201	0	0	1,241,428	513,457

Table 4.2 – Examples of raw data from FCD

It is also possible to observe through the graphics in attachments (from A.6 to A.27) that the maximum speed value of 87km / h was reached during the 3rd test.

The fact that the trial car is often stopped can be explained in the case of traffic jams or if it was a vehicle that had to deliver goods.

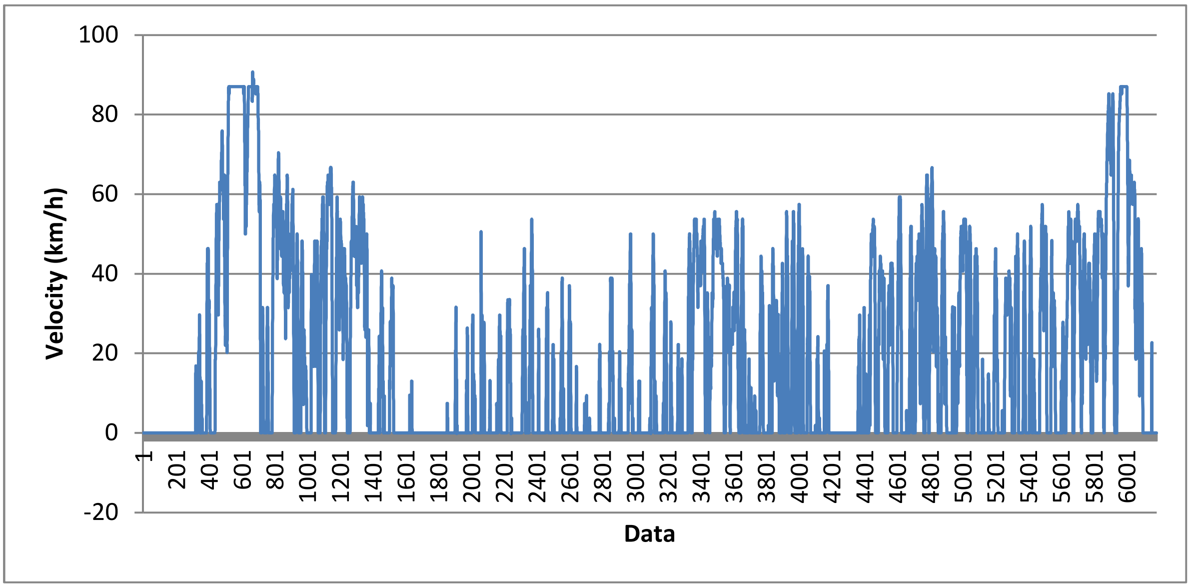

Figure 4.1 – Velocity variation of the trial car from 6h52 to 15h05

Through the variation of velocity during the observation period, it can be seen that the trial car had 3 long periods that wasn't collecting data.

4.3. Data from inductive loop

As explained earlier, the inductive loop is a device to measure traffic parameters most used in European countries. It consists in an induction whorl installed in the cover of the pavement, with insulated wires made of copper and installed in spiral, sensitive to the presence of the metal mass of the vehicle in its magnetic field.

The output data from this sensor consists in day, hour, detector identification, status, flow (vehicles per hour), velocity (Km/h) and occupation rate as shown in table 4.3. During the observation period which lasts from 02/03/2009 to 29/09/2009 (approximately 6 months), the maximum values for the traffic flow, velocity and occupation rate were 1500 veh/h, 49 km/h and 86% respectively.

DAY	TIME	TIMESTAMP	DETECTOR ID	Status	Q VEH	V VEH	OCC
09-04-09	10:22	09-04-09 10:22	K1154_D11_IS15	1	1500	36	27
11-04-09	21:48	11-04-09 21:48	K1154_D11_IS15	1	560	49	8
27-05-09	7:18	27-05-09 7:18	K1154_D11_IS15	1	160	1	86

Table 4.3 – Examples of raw data provided from the inductive loop

Analyzing the monthly average values present in Table 4.4, it is possible to conclude that a high occupation rate does not mean that traffic flow must be also high. However, the vehicle average velocity remains constant.

	Traffic Flow vehicles/h	Velocity km/h	Occupantion rate %
March	420.07	36.51	7.94%
April	433.69	36.42	8.30%
May	411.87	35.77	8.59%
June	426.61	36.72	7.84%
July	400.58	37.83	6.78%
August	451.54	36.30	8.32%
September	449.42	36.32	8.53%

Table 4.4 – Monthly average values for traffic flow, velocity and occupation rate

If the traffic flow is low and the velocity is high, the occupation rate can be almost zero, as the occupancy rate depends on both.

5
FINAL CONCLUSION

The traffic volume is one of the main parameters that characterize the traffic flows. As the traffic consists in vehicles in movement along a path, it is necessary to report their presence or passage. In this study have been described various techniques used in the automatic collection of data, considering observations in a fixed location over time. If the observations are made in a fixed instant throughout the space, it would need another type of techniques such as aerial photography or video (applied differently in this study).

Recent technological developments, in both the automatic collection equipment as computer applications associated, has facilitated in most cases the task of data collection in European countries. However, when it is intended to follow the path of the vehicle, in particular to knowledge of the volume of the directional movements at intersections, it is inevitable the use of human resources. In fact, these are difficult to replace since has not yet been found a process which allows to obtain automatically, and in an effective way, the directional movements and consequently the Origin-Destination Matrix.

Despite of having better means, the collection of traffic data still requires a mobilization of resources, which justifies the development of methodologies to minimize these resources. In particular, where the technology has not yet exceeded the human capacities, it is necessary to find methods to optimize the resources involved, allowing to minimize costs.

In this work was also featured the different techniques and instruments to collect data used in Europe. It is concluded that the transferability of these is very high, being the used instruments to collect data almost the same in the most European countries, and there are several organizations and directives, some sponsored by the European Union, to promote the appropriate exchange of data between the various traffic control centers.

In the last part of this work was performed an analysis of the collected data provided by Supervisor Mrs. Viehmann. It was exemplified the type of data the two sensors can collect, as well as its subsequent processing. Note that the total amount of data is not available in this work, since it is an enormous quantity of information.

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[13] http://www.ocit.org/, 31/01/2012

7
APPENDIX

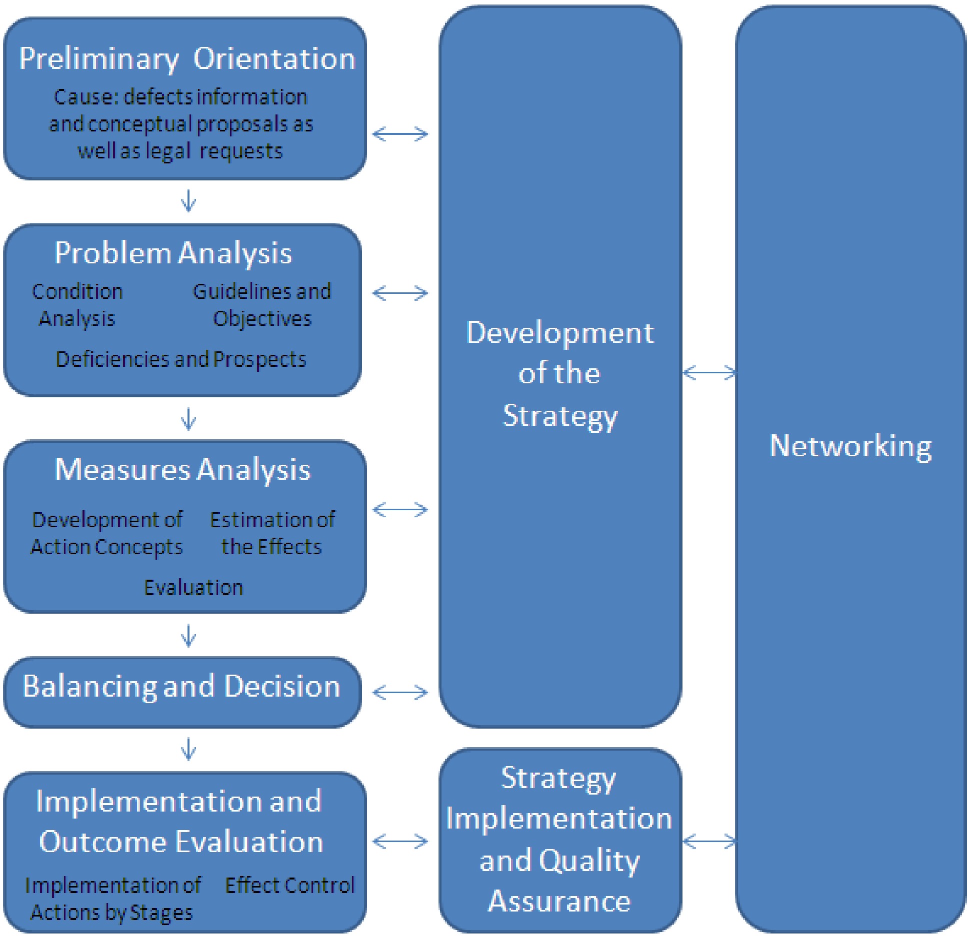

Figure A.1 – Networking in the traffic planning and traffic management

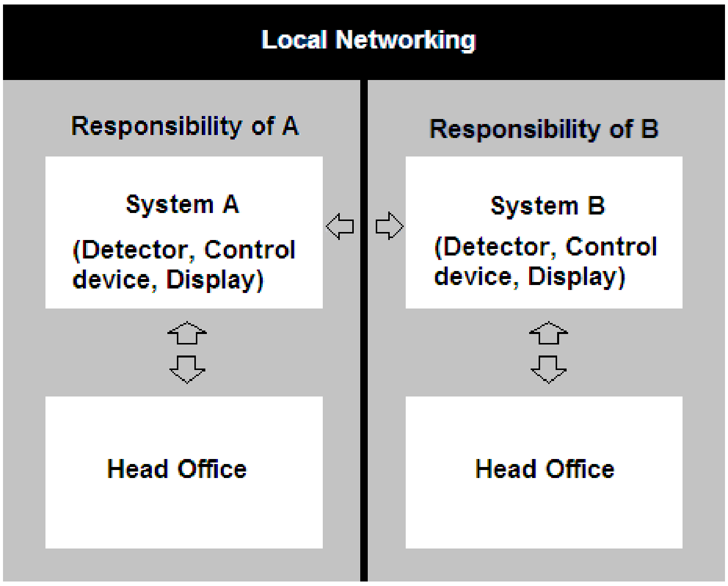

Figure A.2 – Local Networking

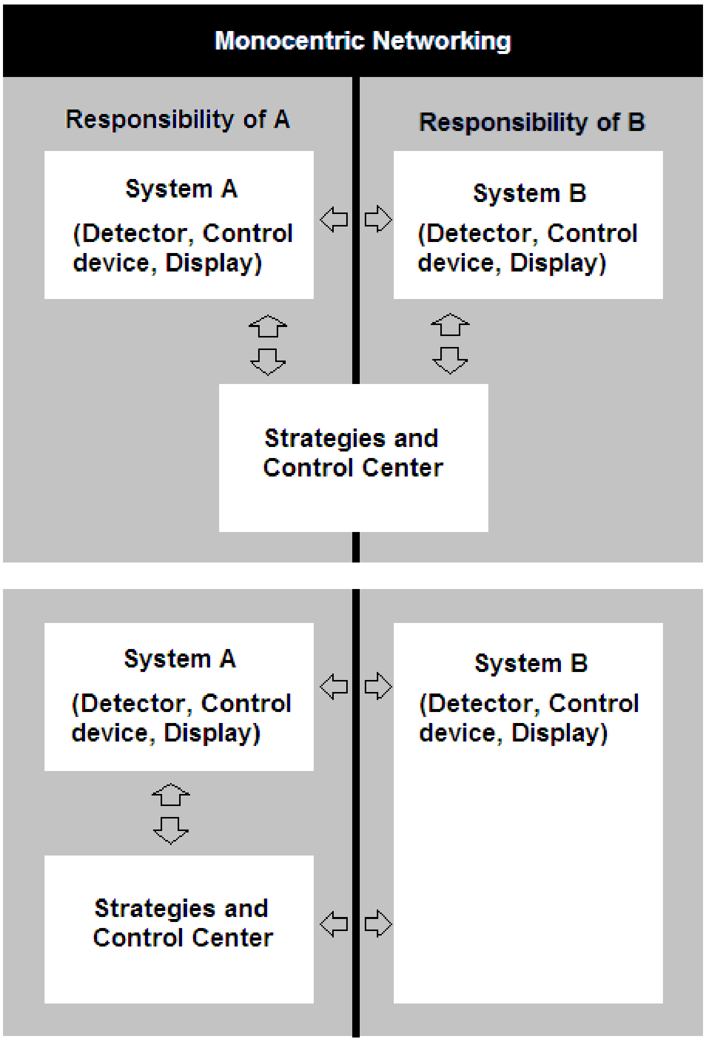

Figure A.3 – Monocentric Networking

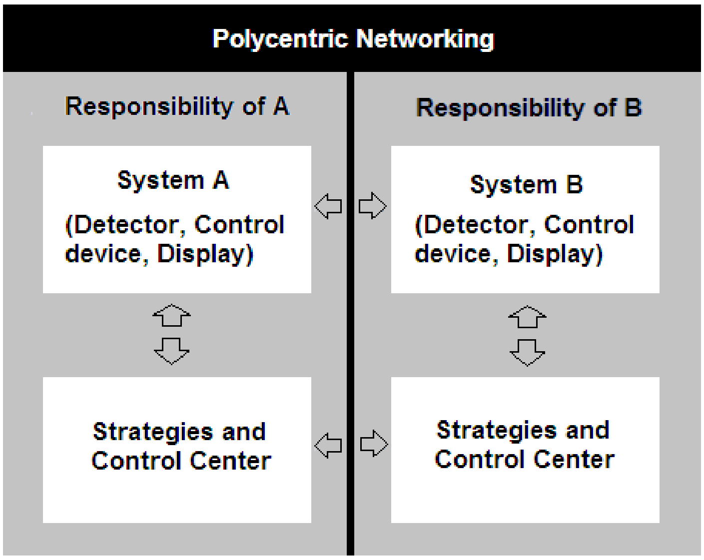

Figure A.4 – Polycentric Networking

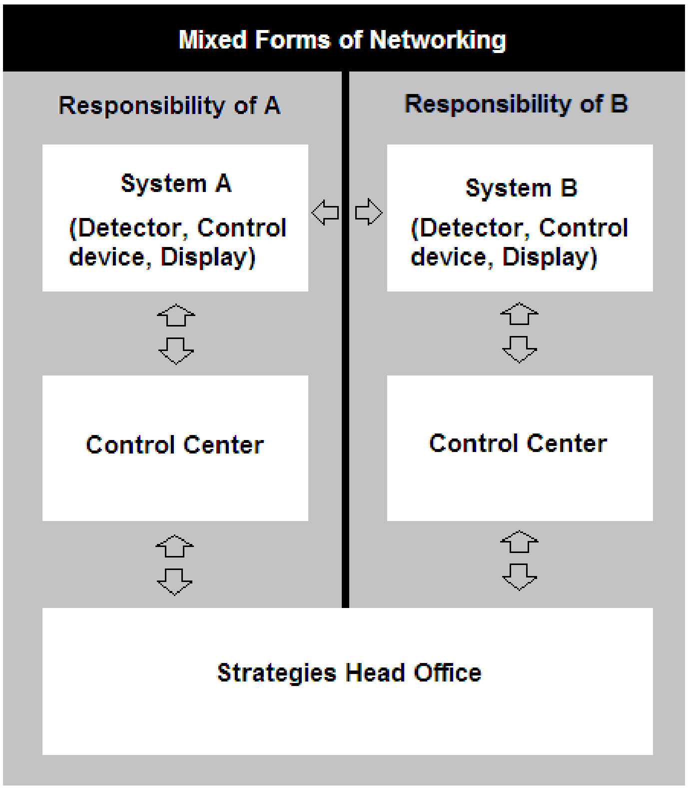

Figure A.5 – Mixed forms of networking

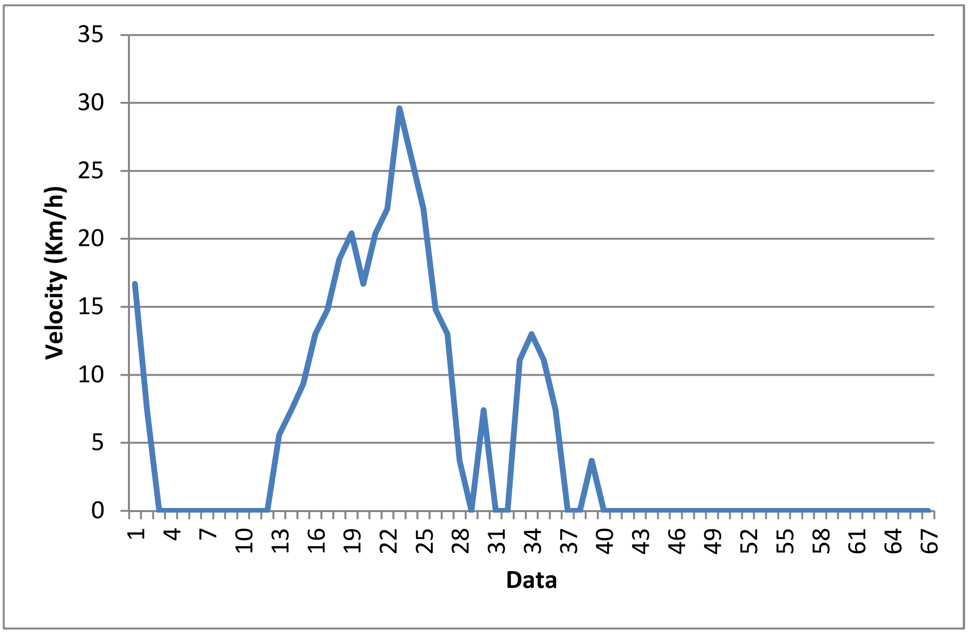

Figure A.6 – Graphic of the test 2, between 7h41 and 7h43 (FCD)

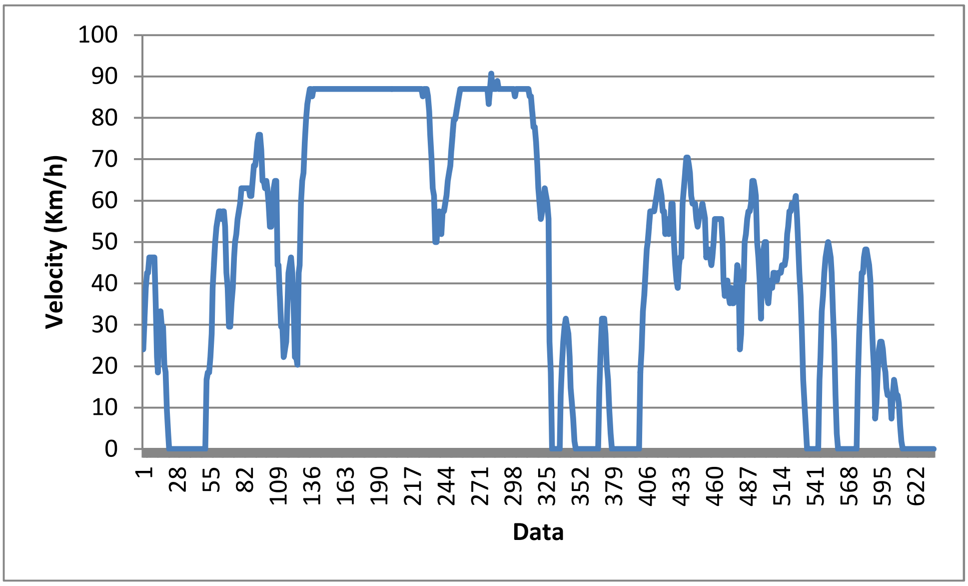

Figure A.7 – Graphic of the test 3, between 8h29 and 8h51 (FCD)

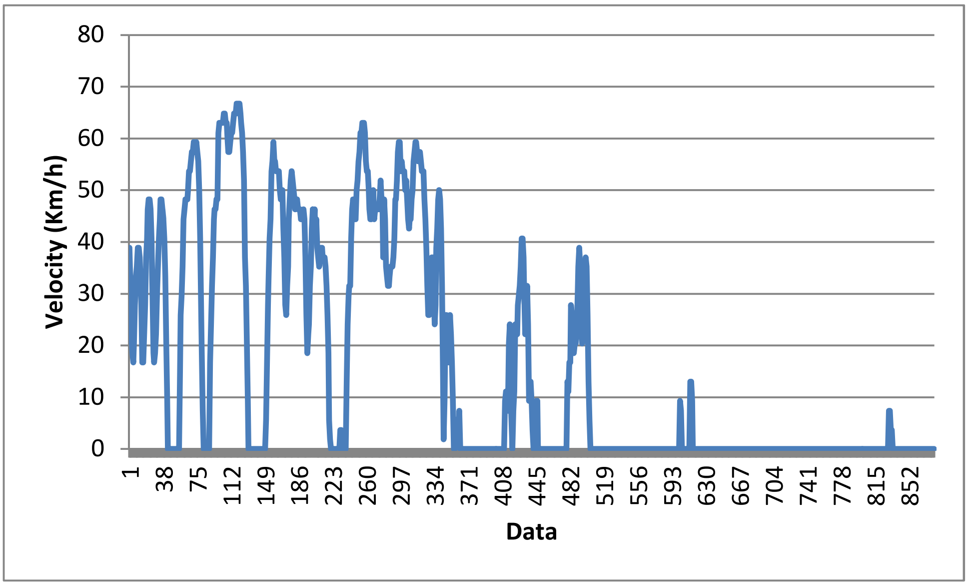

Figure A.8 – Graphic of the test 4, between 9h00 and 9h30 (FCD)

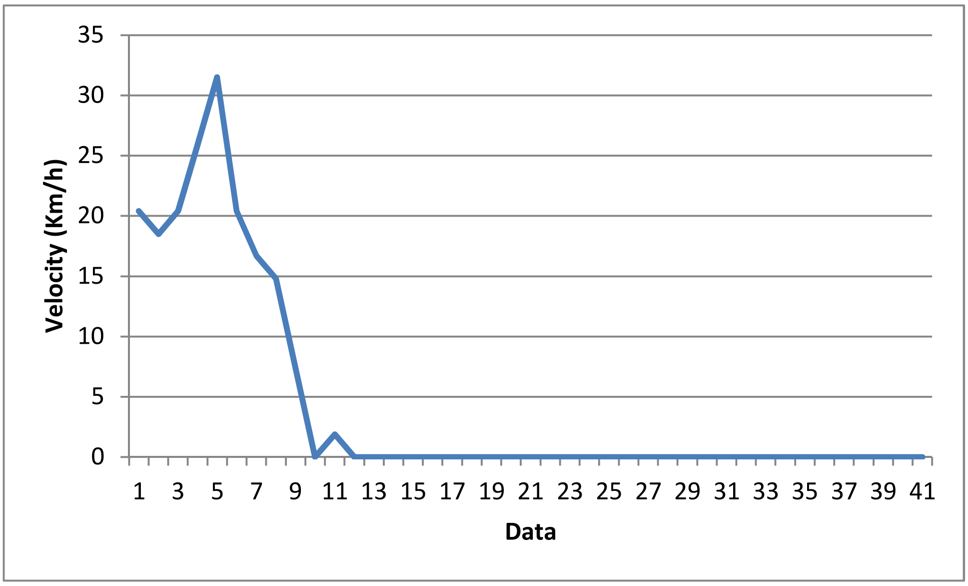

Figure A.9 – Graphic of the test 5, between 9h37 and 9h38 (FCD)

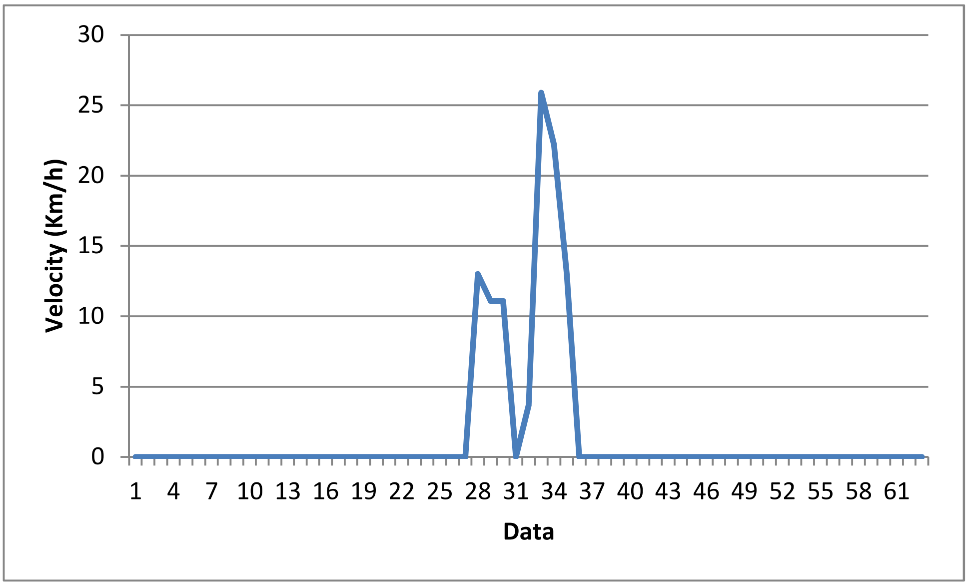

Figure A.10 – Graphic of the test 6, between 9h44 and 9h46 (FCD)

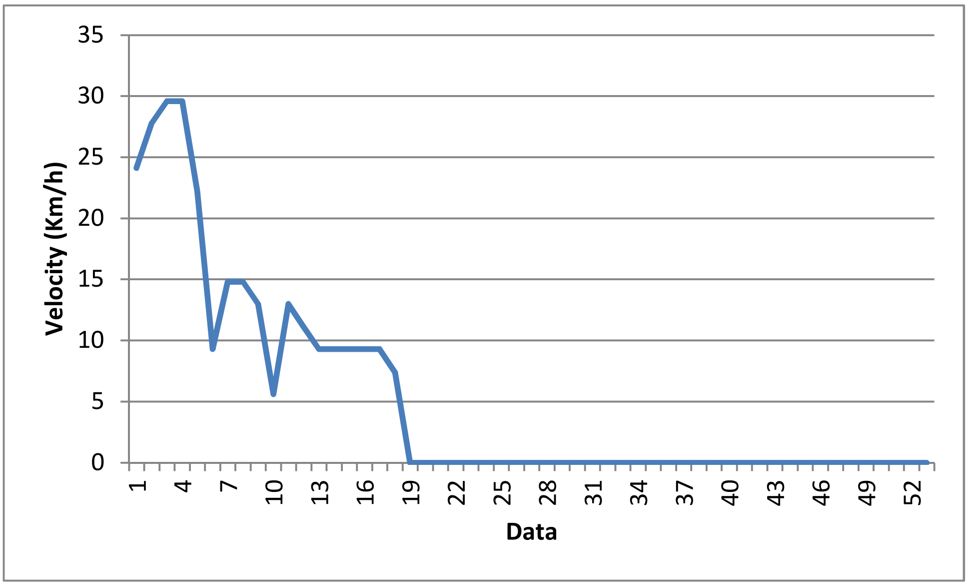

Figure A.11 – Graphic of the test 7, between 9h46 and 9h48 (FCD)

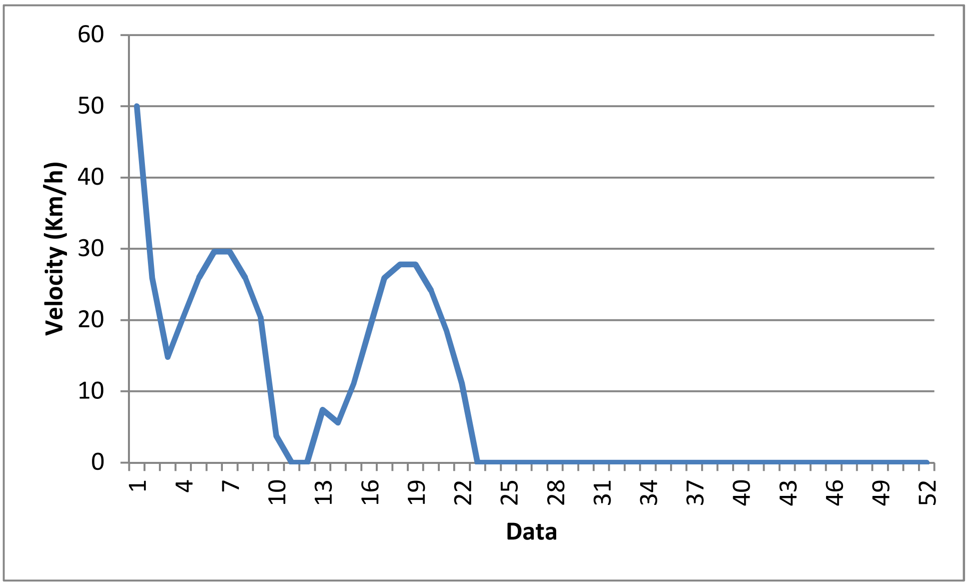

Figure A.12 – Graphic of the test 8, between 9h53 and 9h55 (FCD)

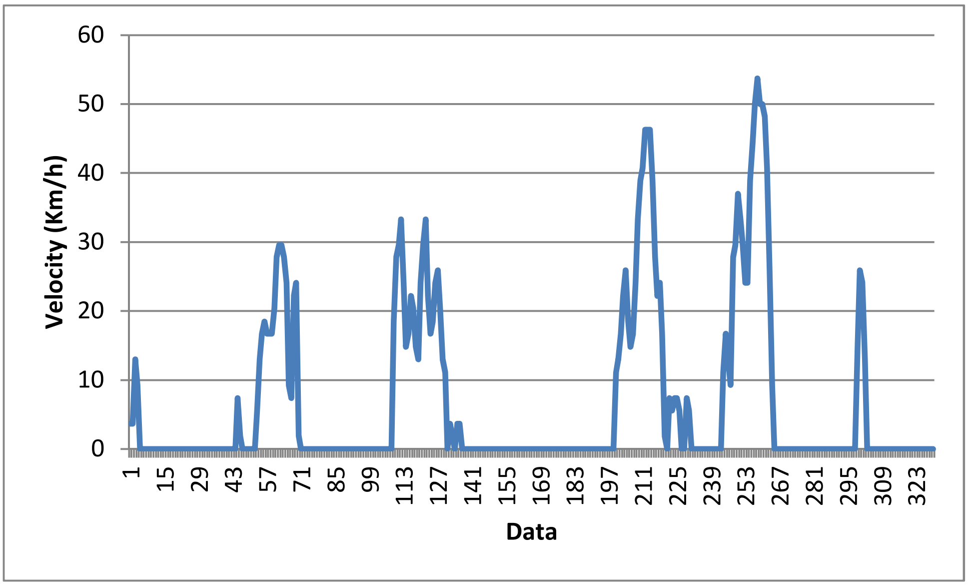

Figure A.13 – Graphic of the test 9, between 9h57 and 10h08 (FCD)

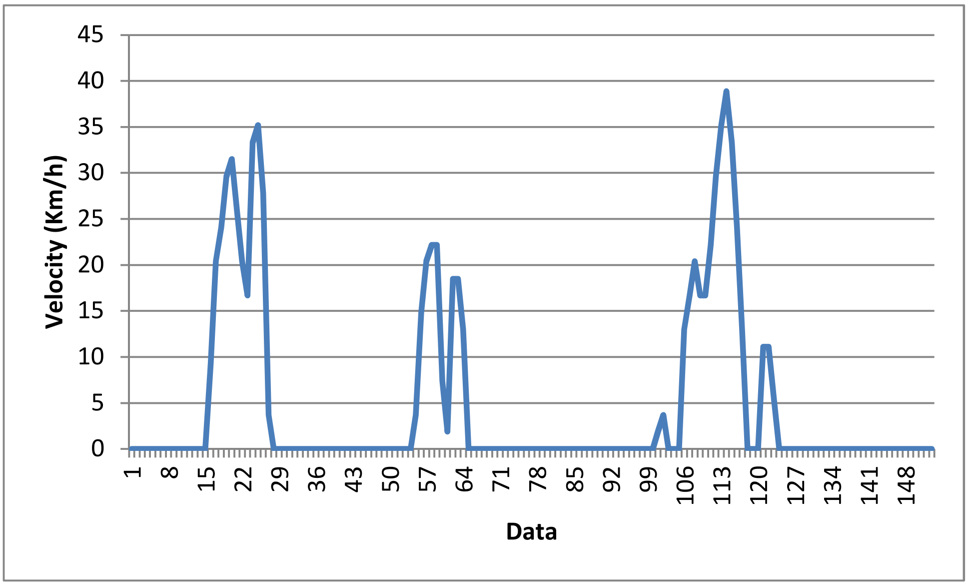

Figure A.14 – Graphic of the test 10, between 10h10 and 10h16 (FCD)

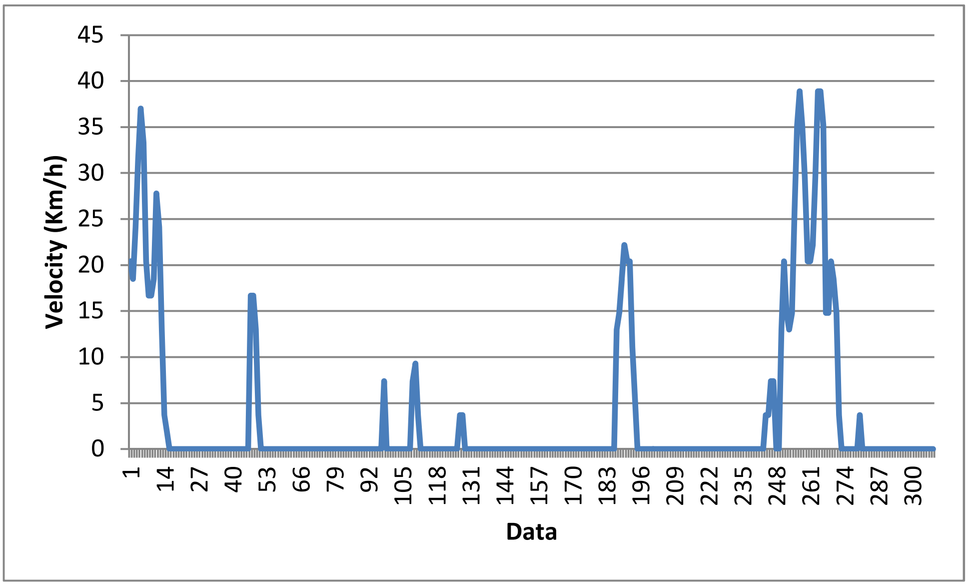

Figure A.15 – Graphic of the test 11, between 10h18 and 10h29 (FCD)

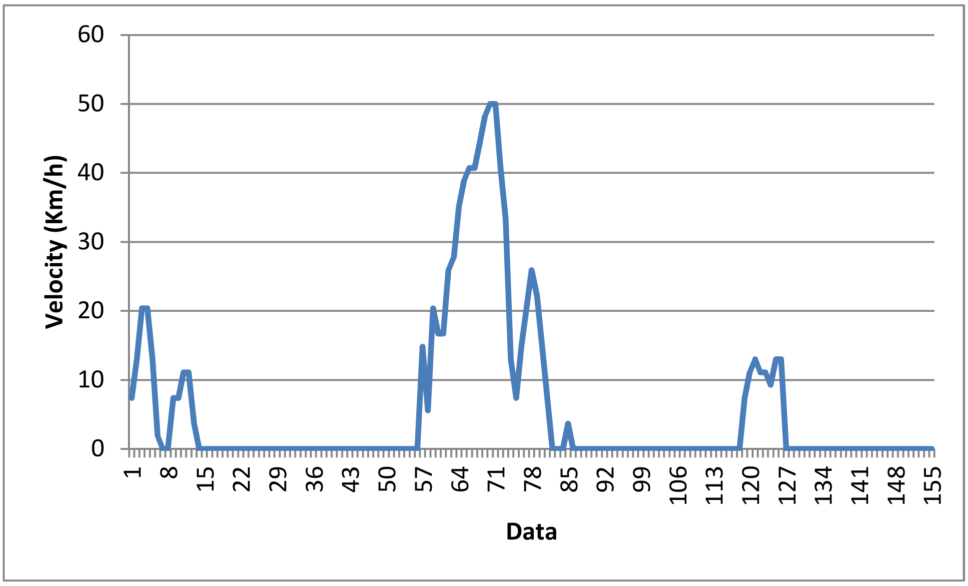

Figure A.16 – Graphic of the test 12, between 10h30 and 10h35 (FCD)

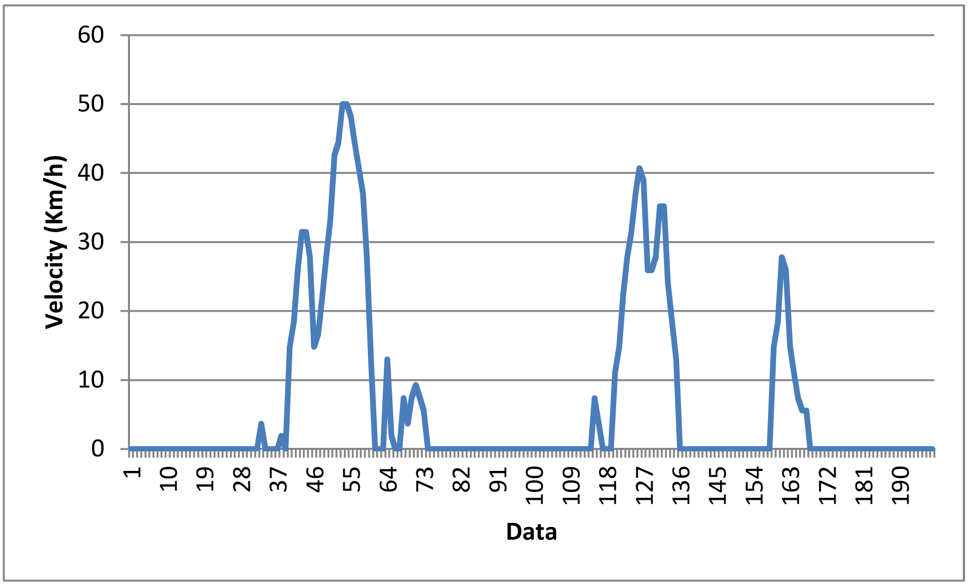

Figure A.17 – Graphic of the test 13, between 10h36 and 10h43 (FCD)

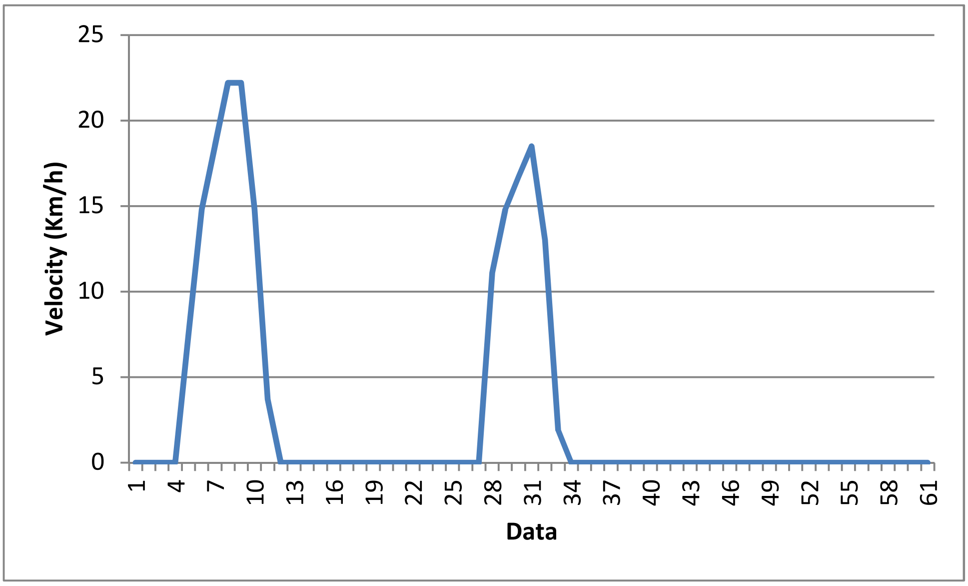

Figure A.18 – Graphic of the test 14, between 10h46 and 10h48 (FCD)

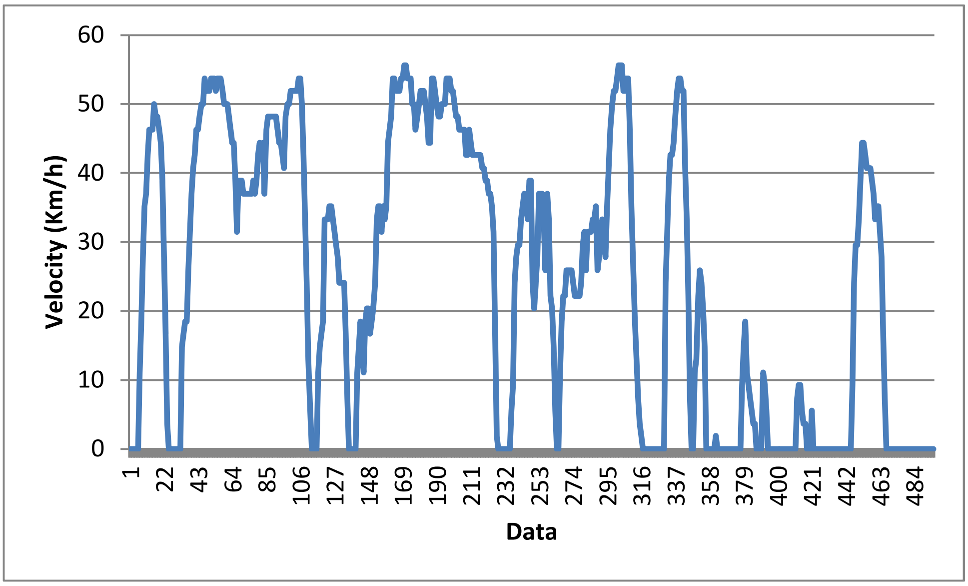

Figure A.19 – Graphic of the test 15, between 10h52 and 11h09 (FCD)

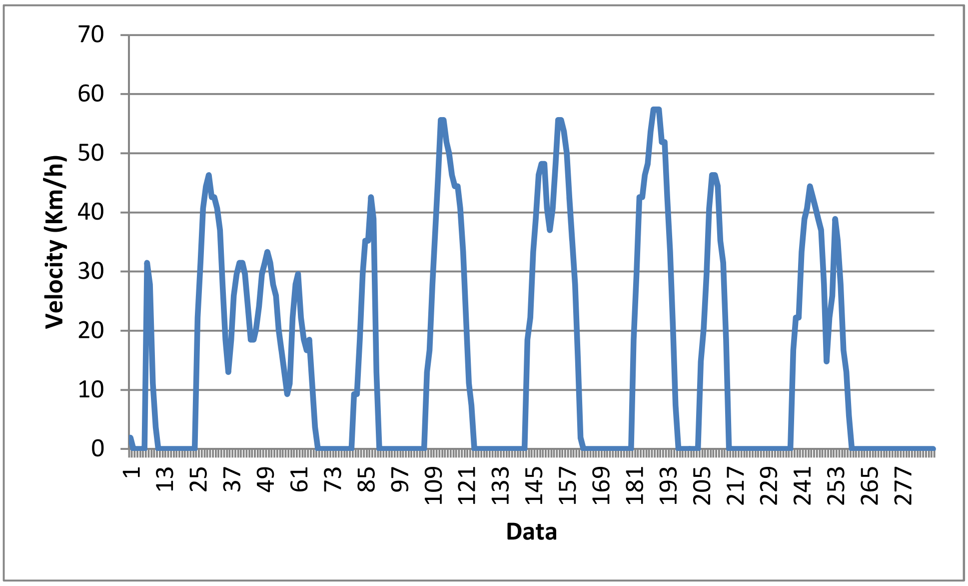

Figure A.20 – Graphic of the test 16, between 11h12 and 11h22 (FCD)

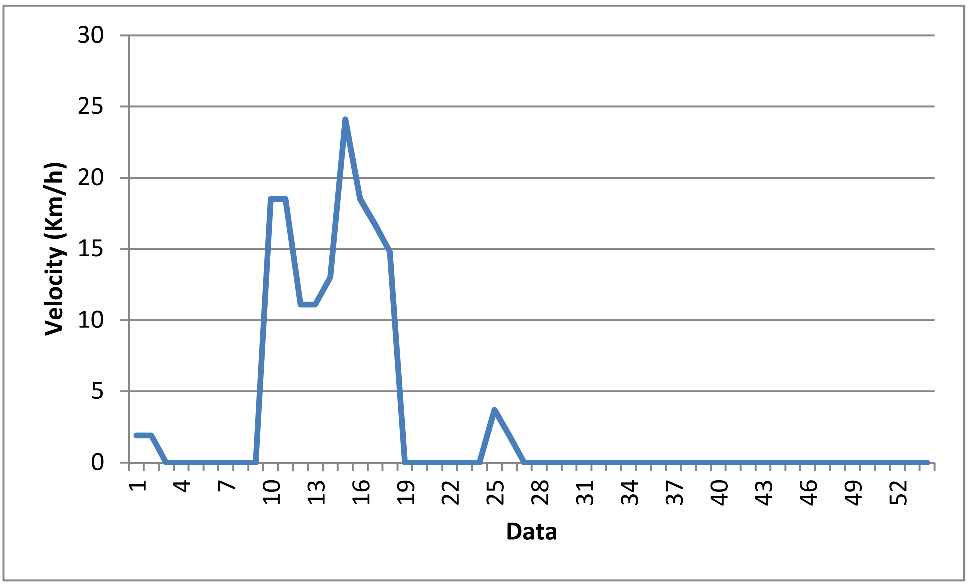

Figure A.21 – Graphic of the test 17, between 12h41 and 12h42 (FCD)

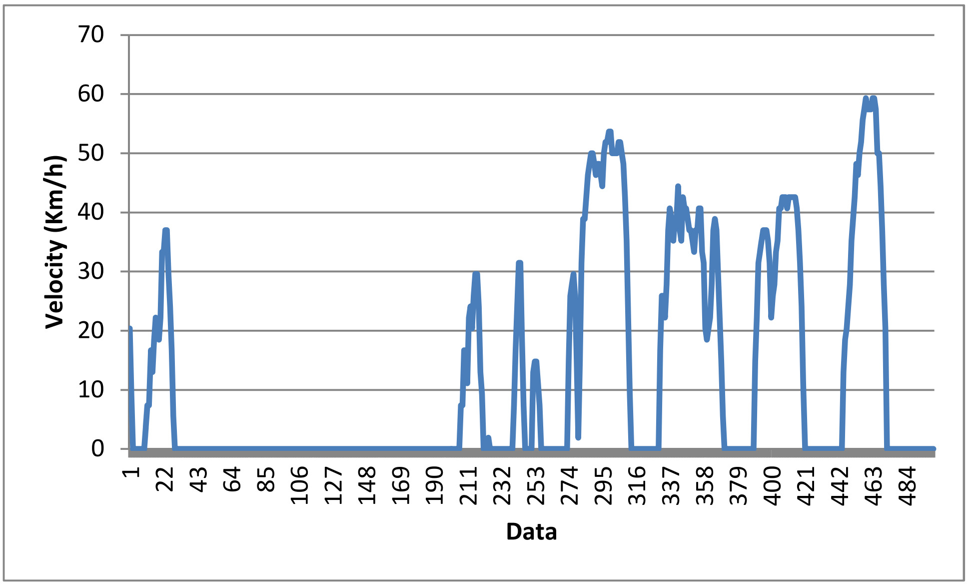

Figure A.22 – Graphic of the test 18, between 12h46 and 13h03 (FCD)

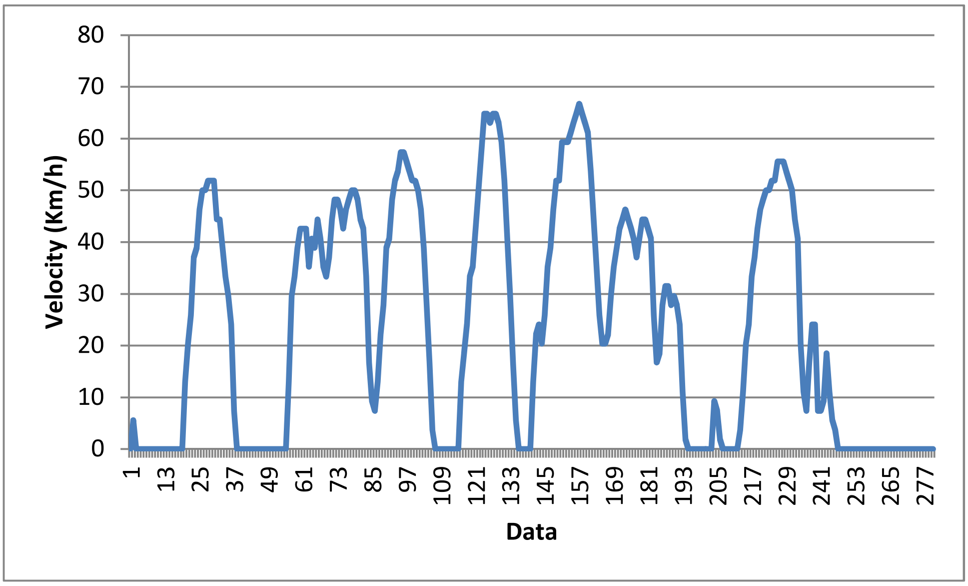

Figure A.23 – Graphic of the test 19, between 13h04 and 13h14 (FCD)

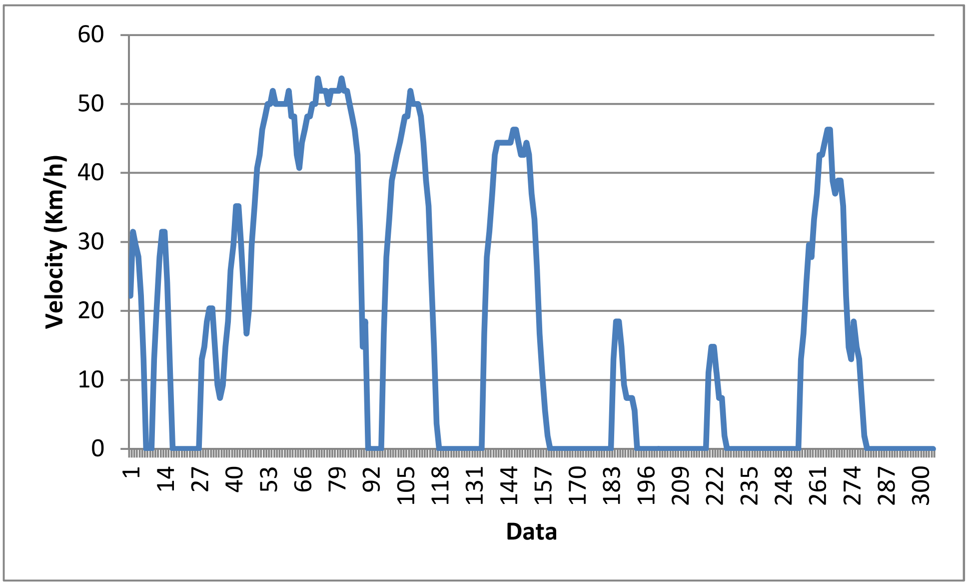

Figure A.24 – Graphic of the test 20, between 14h01 and 14h12 (FCD)

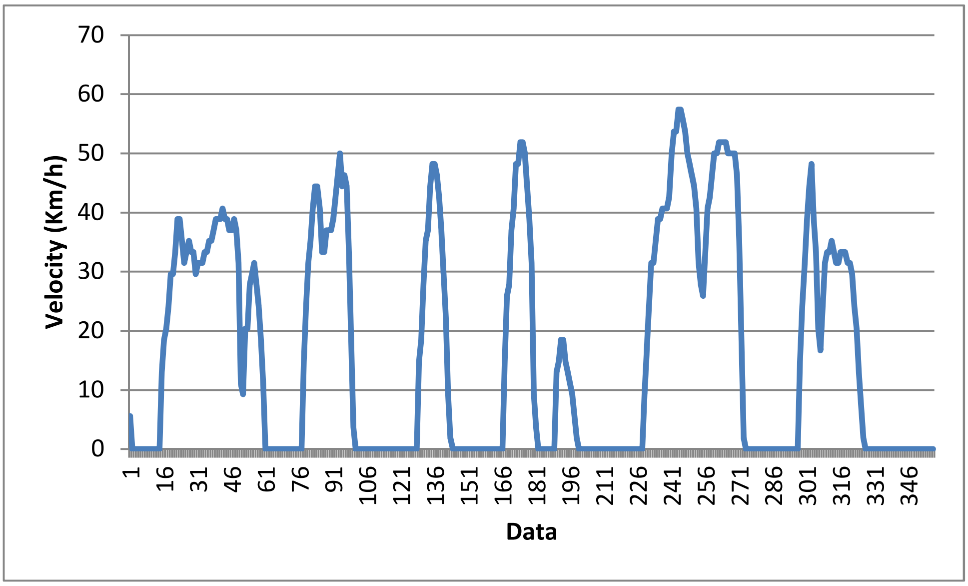

Figure A.25 – Graphic of the test 21, between 14h18 and 14h31 (FCD)

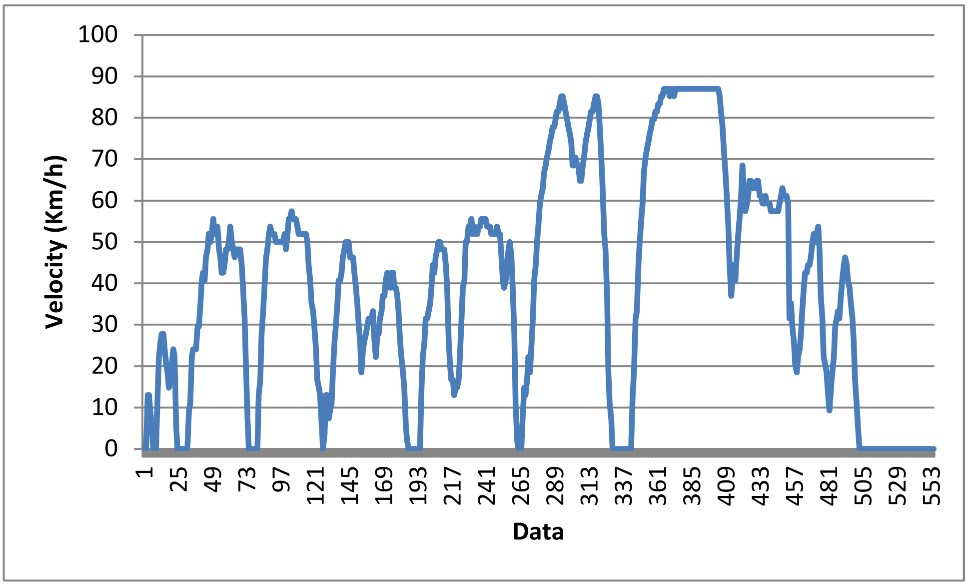

Figure A.26 – Graphic of the test 22, between 14h34 and 14h53 (FCD)

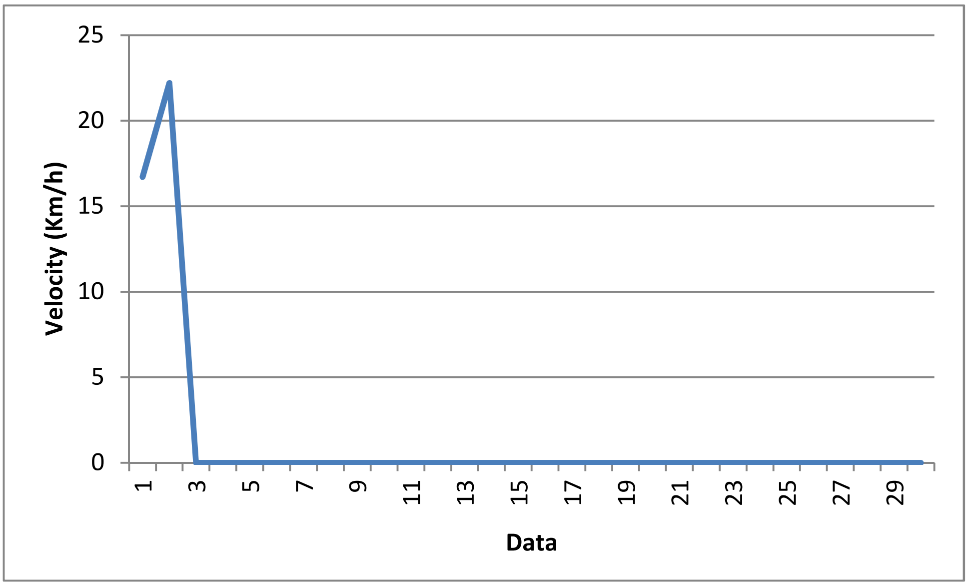

Figure A.27 – Graphic of the test 23, between 15h04 and 15h05 (FCD)