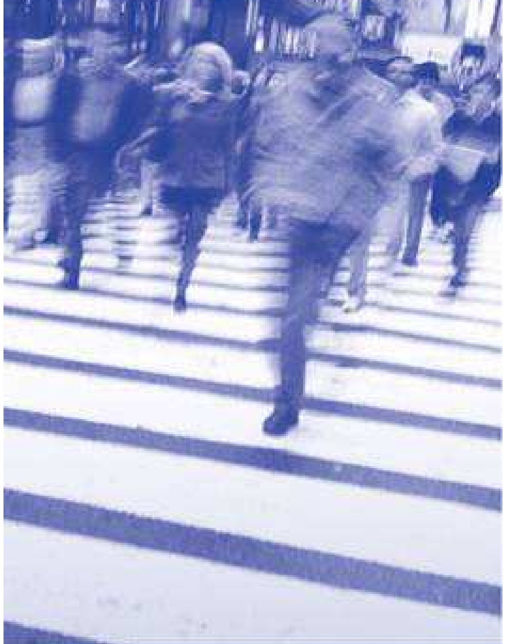

CIVITAS
Cleaner and better transport in cities

ARCHIMEDES
AALBORG • BRIGHTON & HOVE • DONOSTIA -SAN SEBASTIÁN • IAŞI • MONZA • ÚSTÍ NAD LABEM

Monza

R82.1 – Study of Public Transport Priority Management in Monza

City of Monza

February 2011

THE CIVITAS INITIATIVE
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Quality Control	Alan Lewis
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1 Introduction

1.1 Background CIVITAS

CIVITAS - cleaner and better transport in cities - stands for CIty-VITAlity-Sustainability. With the CIVITAS Initiative, the EC aims to generate a decisive breakthrough by supporting and evaluating the implementation of ambitious integrated sustainable urban transport strategies that should make a real difference for the welfare of the European citizen.

CIVITAS I started in early 2002 (within the 5th Framework Research Programme);
CIVITAS II started in early 2005 (within the 6th Framework Research Programme) and
CIVITAS PLUS started in late 2008 (within the 7th Framework Research Programme).

The objective of CIVITAS-Plus is to test and increase the understanding of the frameworks, processes and packaging required to successfully introduce bold, integrated and innovative strategies for clean and sustainable urban transport that address concerns related to energy-efficiency, transport policy and road safety, alternative fuels and the environment.

Within CIVITAS I (2002-2006) there are 19 cities clustered in 4 demonstration projects, within CIVITAS II (2005-2009) 17 cities in 4 demonstration projects, whilst within CIVITAS PLUS (2008-2012) 25 cities in 5 demonstration projects are taking part. These demonstration cities all over Europe will be funded by the European Commission.

Objectives:

- to promote and implement sustainable, clean and (energy) efficient urban transport measures
- to implement integrated packages of technology and policy measures in the field of energy and transport in 8 categories of measures
- to build up critical mass and markets for innovation

Horizontal projects support the CIVITAS demonstration projects & cities by :

- Cross-site evaluation and Europe wide dissemination in co-operation with the demonstration projects
- The organisation of the annual meeting of CIVITAS Forum members
- Providing the Secretariat for the Political Advisory Committee (PAC)
- Development of policy recommendations for a long-term multiplier effect of CIVITAS

Key elements of CIVITAS

- CIVITAS is co-ordinated by cities: it is a programme “of cities for cities”
- Cities are in the heart of local public private partnerships
- Political commitment is a basic requirement
- Cities are living ‘Laboratories' for learning and evaluating

1.2 Background ARCHIMEDES

ARCHIMEDES is an integrating project, bringing together 6 European cities to address problems and opportunities for creating environmentally sustainable, safe and energy efficient transport systems in medium sized urban areas.

The objective of ARCHIMEDES is to introduce innovative, integrated and ambitious strategies for clean, energy-efficient, sustainable urban transport to achieve significant impacts in the policy fields of energy, transport, and environmental sustainability. An ambitious blend of policy tools and measures will increase energy-efficiency in transport, provide safer and more convenient travel for all, using a higher share of clean engine technology and fuels, resulting in an enhanced urban environment (including reduced noise and air pollution). Visible and measurable impacts will result from significantly sized measures in specific innovation areas. Demonstrations of innovative transport technologies, policy measures and partnership working, combined with targeted research, will verify the best frameworks, processes and packaging required to successfully transfer the strategies to other cities.

1.3 Participant Cities

The ARCHIMEDES project focuses on activities in specific innovation areas of each city, known as the CIVITAS corridor or zone (depending on shape and geography). These innovation areas extend to the peri-urban fringe and the administrative boundaries of regional authorities and neighbouring administrations.

The two Learning cities, to which experience and best-practice will be transferred are Monza (Italy) and Ústí nad Labem (Czech Republic). The strategy for the project is to ensure that the tools and measures developed have the widest application throughout Europe, tested via the Learning Cities' activities and interaction with the Lead City partners.

1.3.1 Leading City Innovation Areas

The four Leading cities proposed in the ARCHIMEDES project are:

- Aalborg (Denmark);
- Brighton & Hove (UK);
- Donostia-San Sebastián (Spain); and
- Iasi (Romania).

Together the Lead Cities in ARCHIMEDES cover different geographic parts of Europe. They have the full support of the relevant political representatives for the project, and are well able to implement the innovative range of demonstration activities proposed.

The Lead Cities are joined in their local projects by a small number of key partners that show a high level of commitment to the project objectives of energy-efficient urban transportation. In all cases the public transport company features as a partner in the proposed project.

2 Monza

Monza is a city on the river Lambro, a tributary of the Po, in the Lombardy region of Italy, some 15km north-northeast of Milan. It is the third-largest city of Lombardy and the most important economic, industrial and administrative centre of the Brianza area, supporting a textile industry and a publishing trade. It is best known for its Grand Prix.

The City of Monza, with approximately 121,000 inhabitants, is located 15 km north of Milan, which is the centre of the Lombardia area. This area is one of the engines of the Italian economy; the number of companies is 58,500, i.e. a company for every 13 inhabitants.

Monza is affected by a huge amount of traffic that crosses the city to reach Milan and the highways nodes located between Monza and Milan. It is also an important node in the Railways network, crossed by routes connecting Milan with Como and Switzerland, Lecco and Sondrio, Bergamo and Brianza. "Regione Lombardia", which in the new devolution framework started in 1998, has full responsibility for establishing the Local Public Transportation System (trains, coaches and buses) and has created a new approach for urban rail routes using an approach similar to the German S-Line or Paris RER.

Monza has recently become the head of the new "Monza and Brianza" province, with approximately 750,000 inhabitants, so will gain the full range of administration functions by 2009. Plan-making responsibilities and an influence over peri-urban areas will require the city to develop new competencies.

In this context, the objective of the City of Monza in participating in CIVITAS as a Learning City is to set up an Urban Mobility System where the impact of private traffic can be reduced, creating a new mobility offer, where alternative modes become increasingly significant, leading to improvements to the urban environment and a reduction in energy consumption (and concurrent pollution).

3 Background to the Deliverable

In the context of encouraging sustainable mobility, the use of Public Transport in the City of Monza needs to be increased. In order to achieve this objective, within the ARCHIMEDES framework a clear decision has been made, which has the full support of the government of the Municipality. This is based on the implementation of technological measures to make Public Transport more attractive to citizens.

Through measure no. 81 ("UTC System in Monza"), several intersections have been controlled by the Urban Traffic Control (UTC) System which implements the coordinated and centralised control of traffic lights. The UTC system selected is called RoadManager®. It is designed and implemented by Project Automation, a technological partner of the Municipality of Monza in the ARCHIMEDES project. Please see Deliverables R81.1 and T81.1 for details.

Through measure no. 78 ("Bus Management System in Monza"), the buses of the Public Transport fleet are localised and monitored closely, i.e. it is known where each bus is with respect to its scheduled timetable. Please see deliverables R78.1 and T78.1 for details.

This measure (no. 82, Public Transport Priority System in Monza) is concerned with implementing a framework that allows for the traffic light plans of the intersections (managed by the UTC) to change when the actual situation of the buses would benefit from more green time at these intersections (so long as the overall traffic status allows this.)

The measure covers 2 tasks.

Research Stage: Task 11.8.6 Public Transport Priority Management Study
A study has been undertaken by Project Automation, in agreement with Comune di Monza and with Nord-Est Trasporti (NET) which is the owner of the Public Transport fleet, to propose a conceptual framework to manage Public Transport Priority at the relevant intersections.

Demonstration Stage: Task 8.17 Public Transport Priority System
Eight intersections of the CIVITAS Corridor for Public Transport will be equipped with the proper devices to be put under the control of the UTC System. These devices will apply the Priority Management scheme that emerges from the study carried out in the Research stage, outlined above.

3.1 Summary Description of the Task

Within the main research task, the work has focused on a conceptual approach to increasing public transport use and implementation activities needed to achieve this. In particular, the following activities have been carried out:

1. Detailed statistical analysis of the actual performances of the buses in critical segments of the Corridor. This is required in order to gather quantitative data about delays and to characterise the situations found in the current regulatory framework. This is an important prerequisite to perform the measure (Please see, section 4.2);
2. Definition of criteria to be applied to decide when a priority request should be issued to the UTC system (Please see section 4.3);
3. Management of the priority request and issuing to the UTC System (Please see section 4.4);
4. Fulfilment of the priority request within the UTC system (Please see section 4.5).

Is has to be highlighted that, except a single situation, where a bus lane enters one of the chosen intersections, the buses travel in the same traffic streams as private cars.

4 Description of the Work Done

4.1 The CIVITAS Corridors

Before entering into details of what has been carried out, the corridors are summarised in this section. In Figure 1, the corridor for Public Transport is highlighted with an orange line and the intersections involved are shown as blue crosses. The corridor for private traffic, managed in Measure no. 81, is highlighted with a brown line and intersections are shown with a red cross.

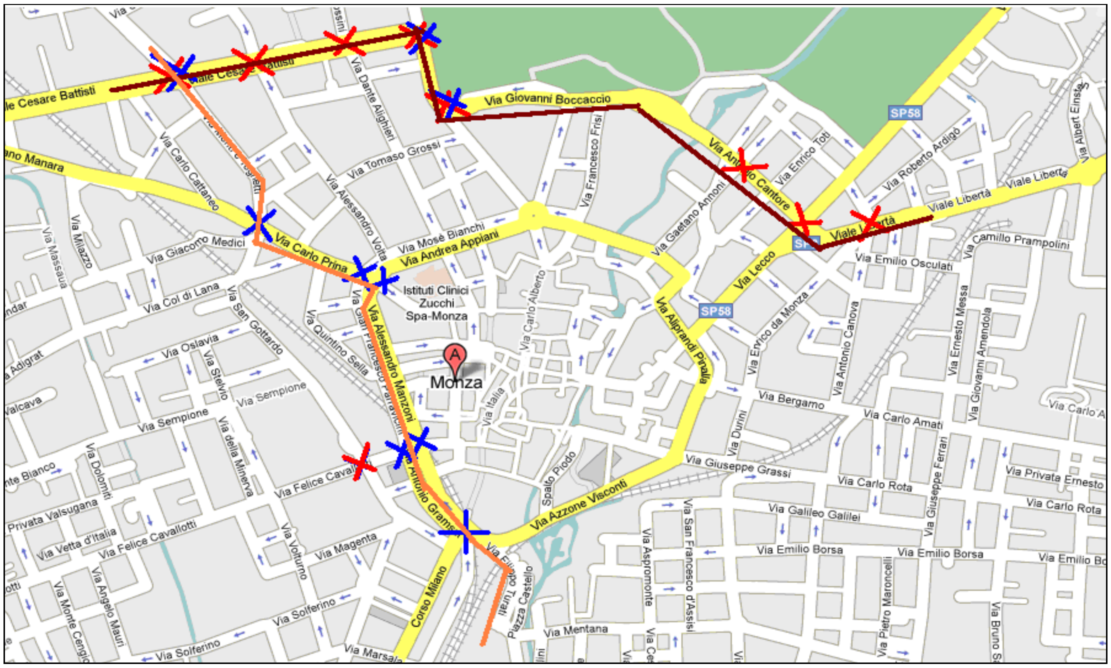


Figure 1 - Monza CIVITAS Corridors

In Figure 2 the lines of Public Transport in the same area of Figure 1 are shown. Each colour represents a different PT line.

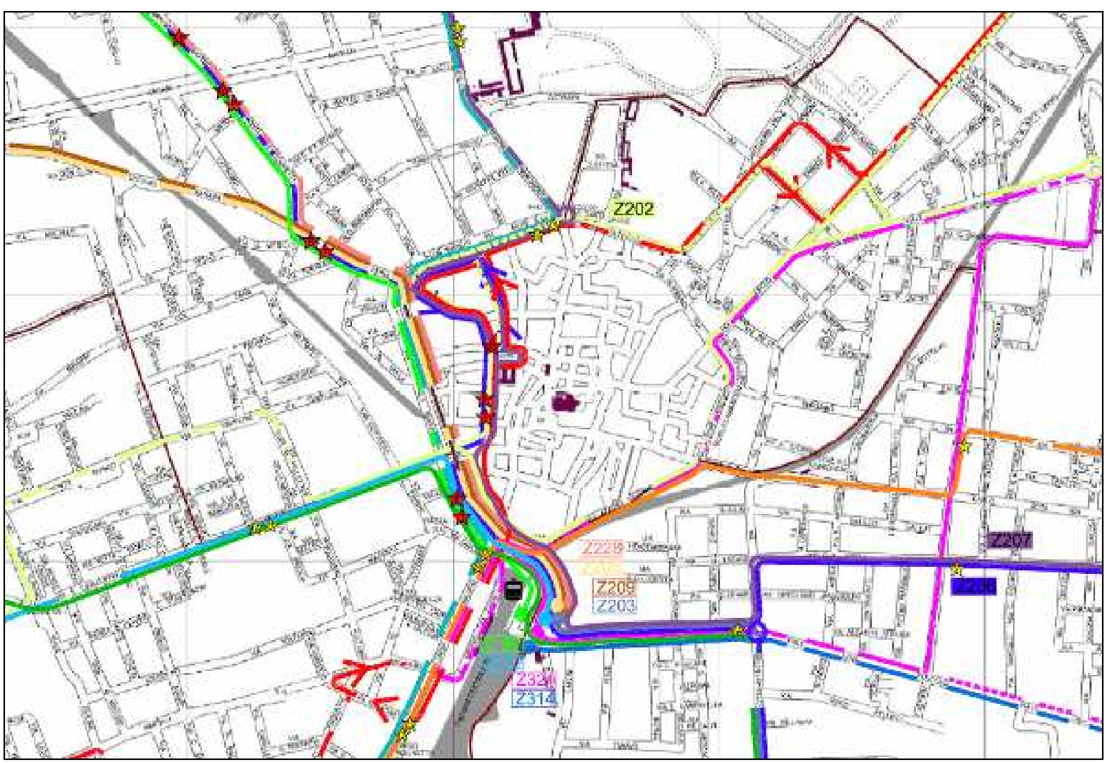


Figure 2- Public Transport lines in the same area of Figure 1

4.2 Statistical Analysis of the Performances of the Buses on the Corridor

4.2.1 Context and Data Description

This task is aimed at delivering a detailed analysis of the travel times of buses in selected stretches of the corridor. For this purpose travel time data since September 13th 2010 up to the end of November 2010 has been collected. The choice of this starting date is due to this being the start of term for schools, which often causes significant demand on public transport and the road network.

As far as travel time data of buses is concerned, as described in detail in the deliverable R78.1, since July 2010 each vehicle of the Public Transport fleet, operated by NET, has been equipped with an On-Board Unit (OBU) consisting of an Industrial PC with specific devices and sensors:

- a GPS device to determine the vehicle position, coded with Lat-Long coordinate system (WGS 84);
- a GPRS communication system to send the information to a Control Centre;

As the driver begins his shift, he identifies himself to the system, typing his personal code on a dedicated keyboard.

Data concerning vehicle positions are produced at a given frequency (sampling interval) and sent to the Control Centre at another given frequency (transmission interval). Once records are received by the Control Centre they are stored in a database table and made available for the analyses described in the next paragraphs.

The data collected through the AVL/AVM system has enabled data to be gathered in the neighborhood of the relevant intersections. In this document, attention will be paid to methodological issues so a specific intersection has been considered. This intersection can be found in the upper left of Figure 1 (Battisti-Boito-Monti Tognetti) and it is also shown in Figure 3. The traffic light at this intersection is already operating within the UTC environment. In addition, this intersection belongs both to the private and the public transport (PT) corridors.

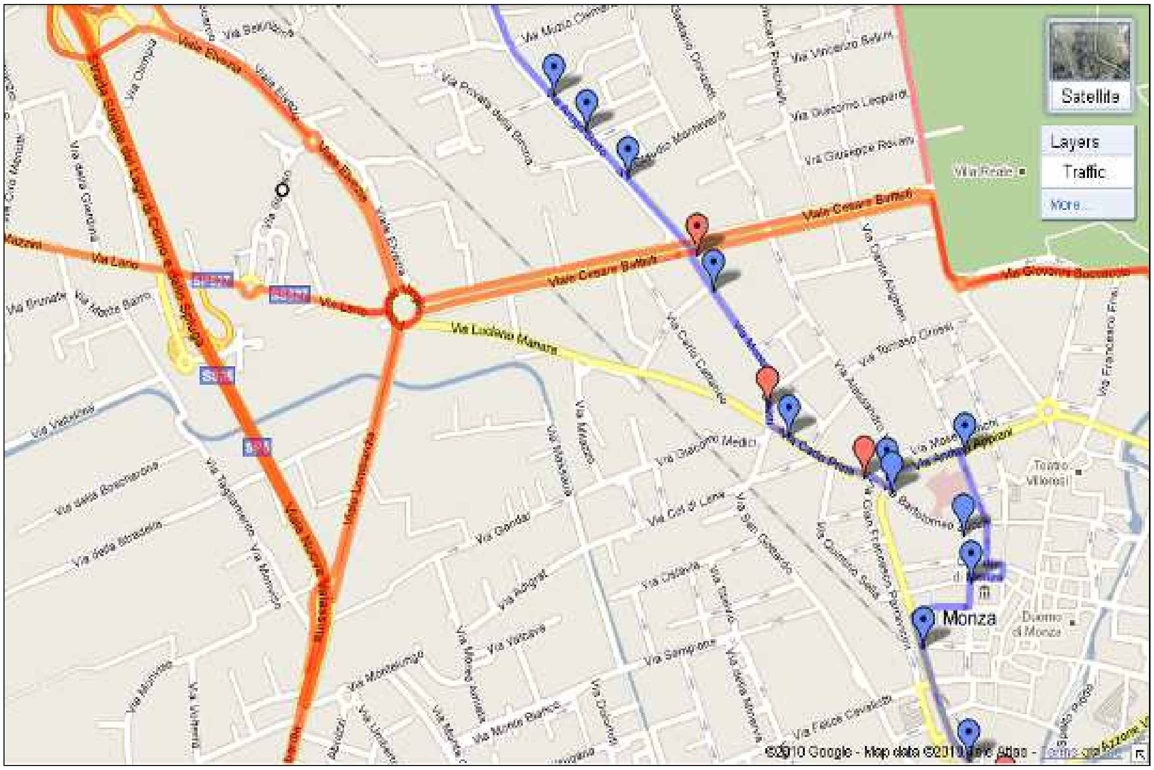


Figure 3 - Markers which identify the bus stops (blue) and other monitoring points (red)

Data analysed concern the lines z206 and z266, which operate on the route identified by the blue line and the monitoring markers in Figure 3. These lines connect the hospital with the centre of the city through the CIVITAS PT corridor.

Please find below, in Table 1, data used in the analyses.:

Field	Example of content	Description
No. of vehicle	1505	Vehicle ID
Mission name	20101020_206#5_1	A “mission” is the set of trips that the vehicle must carry out in a given day
Mission start time	20/10/2010 7.25.01	Timestamp for the mission start
Line	z206	Bus Line
Run	20180000000020600165	Run identification
Stop Id	ATM420	Stop identification for which a transit of the bus is monitored
Expected arrival	20/10/2010 20.22.37	Timestamp the vehicle is expected to be at the Stop Id according to the timetable
Actual arrival	20/10/2010 20.24.03	Timestamp the vehicle has been detected at the Stop Id
Delta	-86	Actual time – Expected time; if positive the bus is in advance, if negative then the bus is delayed

Table 1 - Data collected for the statistical analyses, for lines z206 and z266

In addition to the existing bus stops, some other relevant points (virtual stops) have been defined to monitor the buses in those positions. Such points in the corridor have been chosen to have a monitoring point when bus stops are far from the intersection: should the bus be jammed in that segment, such monitoring points configured before the traffic light allows the bus to be monitored without having to waiting for it to pass through the intersection.

4.2.2 Travel Time Analysis

The first kind of investigation carried out concerns the analysis of travel times amongst pairs of bus stops. This analysis has the following aims:

- it allows analysis of the expected arrival time at a given intersection; in this specific case the attention is paid to the intersection belonging to the corridor where it is possible to satisfy priority requests;
- it provides an estimation of the congestion of the link involved;
- it provides raw data to analyse the behaviour of the Public Transport lines in different traffic conditions (working day or week ends, peak and off-peak hours, etc)

Before starting with the travel time analysis, a pre-processing stage is required. The aim of this stage is to transform raw data into data which can be statistically analysed and extracting the features that can provide information. Thus, the first pre-processing activity consists of computing the travel time between the relevant bus stops to be considered. This information is shown in Table 2:

Attribute	Example	Description
Line	z206	Public Transport Line
Day of the week	Tuesday	
Type of day	Working day	Working day, Saturday, Sunday or Holyday
Bus Stop – begin	ATM117	Bus Stop ID at the begin of the considered stretch
Bus Stop – end	ATM480	Bus Stop ID at the end of the considered stretch.
Expected TS-begin	19/10/2010 14.23.10	Timestamp of transit at the Bus Stop at the begin of Stretch
Actual TS-begin	19/10/2010 14.22.27	Timestamp of transit at the Bus Stop at the end of Stretch
Time slot	14:15	Time slot in which the transit at the Bus stop Begin has occurred. The defined time slot are: (<6.15), [6.15-6.45), [6.45-7.15), ..., [20.15-20.45), [>=20.45).
Expected Travel time	67	Expected travel time between the two bus stops
Actual Travel Time	87	Actual travel time amongst the two bus stops
Offset (begin)	43	Delay/Advance of the bus at the Bus-stop begin
Offset (end)	23	Delay/Advance of the bus at the Bus-stop end
Delta	-20	Delay/Advance due to this stretch

Table 2 - Travel times amongst bus stops: data considered

The second step accomplished in the pre-processing stage is called "data cleaning". Localisation data are filtered to remove records with missing values and outliers. (Outlier detection has been carried out using the F-Spread technique: values greater than the 3rd quartile plus the interquartile range multiplied times a constant value (typically from 1.5 to 5).)

In Figure 4 the distribution of travel times over three day types (working day, Saturdays, Sundays/holidays) are shown.

The graphical representation proposed to show such a distribution is known as a "box-plot" or "box-and-whiskers plot". The inner rectangular red box is low-bounded by the first quartile and high-bounded by the third quartile. The intermediate red horizontal line indicates the median (second quartile) of the distribution. The lower the height of the rectangle, the more concentrated is the distribution of values. Whiskers, bounded by red horizontal lines, represent the values computed as:

First quartile – 1.5 * interquartile range
Third quartile + 1.5 * interquartile range

Which are at the extreme end of the range of valid values.

In the example presented in Figure 4, a set of values indicated as outliers are presented.

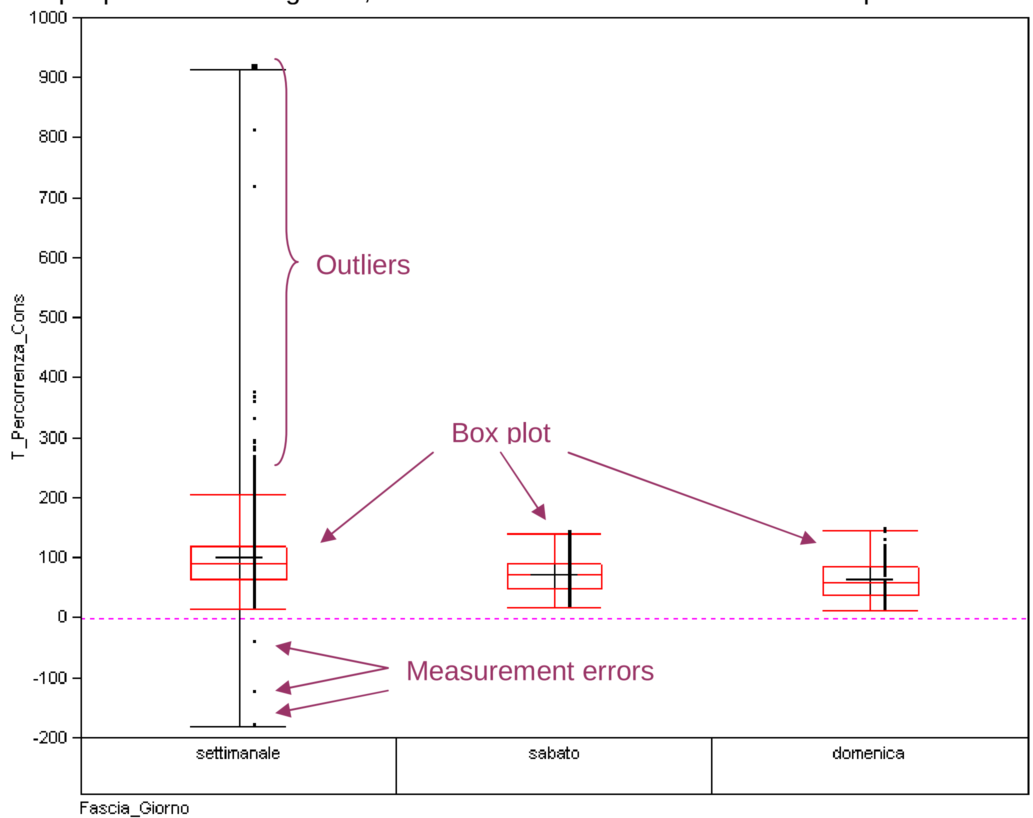


Figure 4 - Distribution of travel times between bus stops ATM117 and ATM480

It has to be highlighted that some high travel times detected could be explained as a one-off behaviour of drivers who, when a long way ahead of their allocated time, wait for some minutes to resynchronise with the timetable.

4.2.3 Computation of Homogeneous Time Slots

The first step to characterise travel times is to find out the time slots where travel time of the buses of Public Transport is negatively affected by general traffic conditions. To do this, travel times after collection, pre-processing and cleaning are processed.

In Figure 5 a real travel time profile collected in tenths of working days amongst the Boito-Battisti (ATM117 direction Centre of Monza, ATM121 direction Monza Hospital) and Battisti-Monti e Tognetti (ATM480 direction Centre of Monza, ATM315 direction Monza Hospital) bus stops are presented.

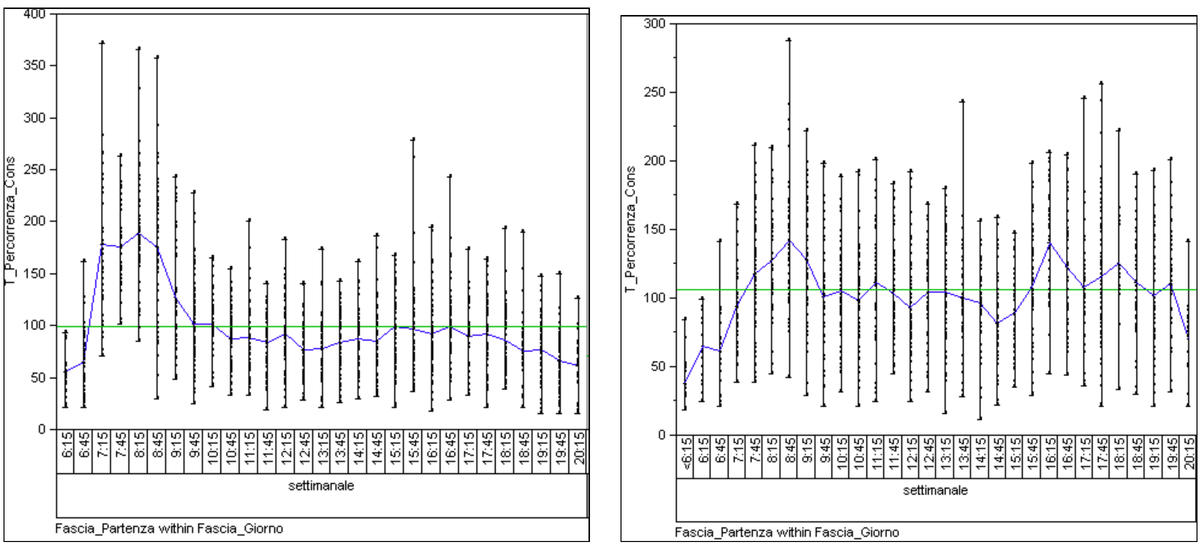


Figure 5 - Travel times between Boito-Battisti and Battisti-Monti e Tognetti bus stops (and viceversa)

Each vertical bar connects the values gathered in the 30-min slots described in Table 2. The longer the bar, the greater the variation of travel times in the sample of that slot.

The blue line connects the average of each sample; the green line is the overall average of the observations of all the samples.

Analysing these graphics, the following aspects emerge:

- travel times have peaks entering Monza from 7am to 9am; it is well known that traffic demand is very high at this time;
- in the opposite direction, the morning peak is not so critical but the increase in travel time measured between 4pm and 6:30 pm is significant.

At weekends, traffic is typically non critical; particular attention will be put on Sundays in Spring 2011, when many people are attracted to the park for recreational purposes

Four time slots can be proposed:
- morning peak on working days (7am to 9:30 am);
- evening peak on working days (4 pm to 6:30 pm)
- off peak on working days
- off peak on weekends

In Figure 6, a comprehensive framework is presented.

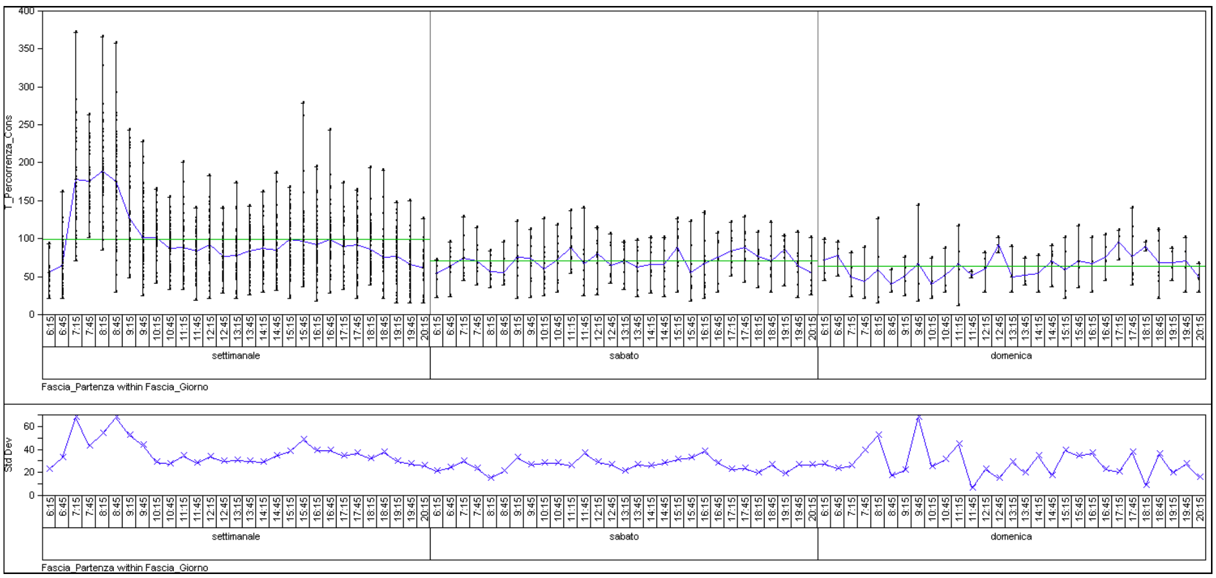


Figure 6 - Travel times in working days, Saturdays and Sundays/Holydays

4.2.4 Study of the Distributions of Travel Times

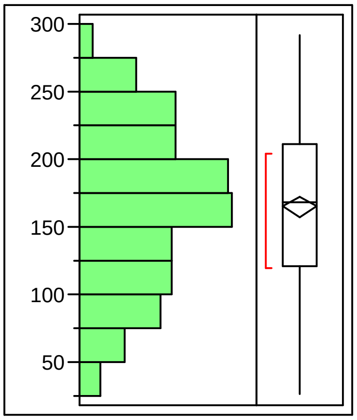
As time slots have been identified, it is important to study the distributions of travel times for each one. This study is aimed at predicting the expected arrival time of buses at the intersections, as a prerequisite to decide when to apply traffic light policies..

The intersection considered as example in this document (Boito_Battisti-Monti Tognetti) belongs to both the corridors identified in Monza and is already connected to the UTC implemented in Measure no. 81 ("UTC System in Monza") and operational.

From the Transport Engineering point of view, this intersection is very important because of the traffic flows which cross it. Moreover, important bus lines cross it as well.

The following images in the next few pages depict the statistical characterisation of the data collected, showing quartiles and moments of the samples.

Type: working days – Time slot: morning peak – Direction: Centre (ATM117-ATM480)

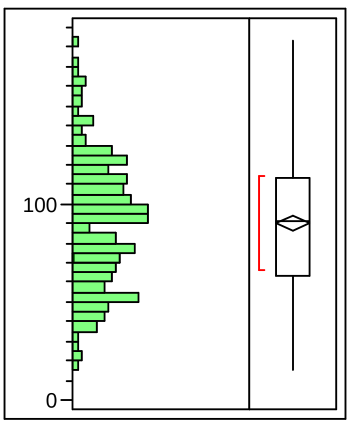


Quartiles		
100.0%	maximum	291,00
99.5%		290,19
97.5%		264,00
90.0%		241,80
75.0%	quartile	211,50
50.0%	median	168,00
25.0%	quartile	121,50
10.0%		82,20
2.5%		48,40
0.5%		27,81
0.0%	minimum	27,00

Moments	
Mean	164,96443
Std Dev	59,511926
Std Err Mean	3,7414827
upper 95% Mean	172,33299
lower 95% Mean	157,59587
N	253
CV %	36,075612

Distribuzione del tempo di percorrenza

Type: working days – Time slot: evening peak – Direction: Centre (ATM117-ATM480)

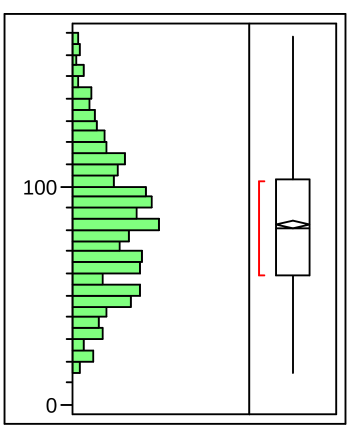


Quartiles		
100.0%	maximum	183,00
99.5%		183,00
97.5%		163,65
90.0%		134,00
75.0%	quartile	113,25
50.0%	median	91,00
25.0%	quartile	63,00
10.0%		45,70
2.5%		28,88
0.5%		16,31
0.0%	minimum	15,00

Moments	
Mean	90,13986
Std Dev	34,353396
Std Err Mean	2,0313589
upper 95% Mean	94,13823
lower 95% Mean	86,141491
N	286
CV %	38,111215

Distribuzione del tempo di percorrenza

Type: working days – Time slot: off peak – Direction: Centre (ATM117-ATM480)

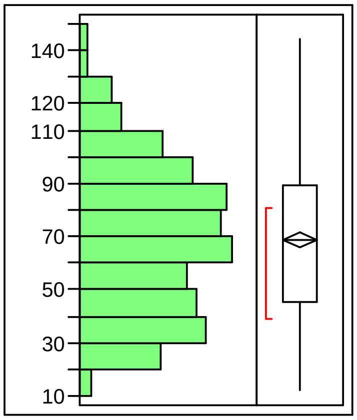


Quartiles		
100.0%	maximum	168,00
99.5%		165,00
97.5%		150,07
90.0%		126,00
75.0%	quartile	102,75
50.0%	median	81,00
25.0%	quartile	59,25
10.0%		42,00
2.5%		24,00
0.5%		18,00
0.0%	minimum	15,00

Moments	
Mean	82,485521
Std Dev	32,132317
Std Err Mean	0,9983025
upper 95% Mean	84,444449
lower 95% Mean	80,526593
N	1036
CV %	38,955099

Distribuzione del tempo di percorrenza

Type: weekends – Time slot: off peak – Direction: Centre (ATM117-ATM480)

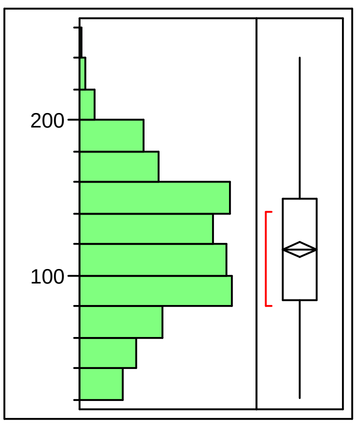


Distribuzione del tempo di percorrenza

Quartiles		
100.0%	maximum	144,00
99.5%		141,11
97.5%		126,00
90.0%		105,00
75.0%	quartile	89,00
50.0%	median	69,00
25.0%	quartile	45,00
10.0%		30,00
2.5%		21,00
0.5%		14,90
0.0%	minimum	12,00

Moments	
Mean	68,867347
Std Dev	28,35801
Std Err Mean	1,4322958
upper 95% Mean	71,683312
lower 95% Mean	66,051382
N	392
CV %	41,17773

Type: working days – Time slot: morning peak – Direction: Hospital (ATM315-ATM121)

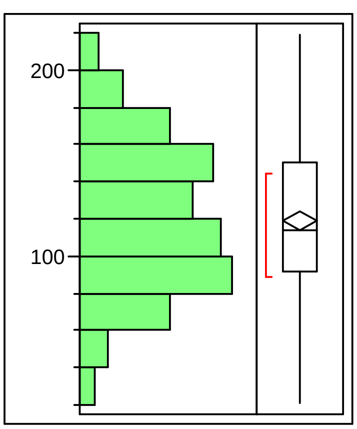


Distribuzione del tempo di percorrenza

Quartiles		
100.0%	maximum	240,00
99.5%		234,77
97.5%		205,13
90.0%		174,00
75.0%	quartile	150,00
50.0%	median	117,00
25.0%	quartile	84,00
10.0%		55,00
2.5%		37,00
0.5%		22,43
0.0%	minimum	21,00

Moments	
Mean	117,27891
Std Dev	44,735595
Std Err Mean	2,6090329
upper 95% Mean	122,41373
lower 95% Mean	112,14409
N	294
CV %	38,14462

Type: working days – Time slot: evening peak – Direction: Hospital (ATM315-ATM121)

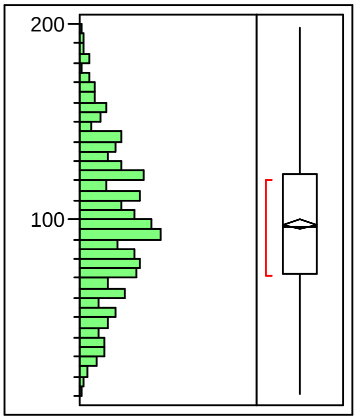


Distribuzione del tempo di percorrenza

Quartiles		
100.0%	maximum	219,00
99.5%		214,71
97.5%		199,05
90.0%		171,40
75.0%	quartile	150,00
50.0%	median	114,00
25.0%	quartile	91,50
10.0%		66,60
2.5%		42,00
0.5%		21,33
0.0%	minimum	21,00

Moments	
Mean	118,93962
Std Dev	40,238354
Std Err Mean	2,4718224
upper 95% Mean	123,80662
lower 95% Mean	114,07263
N	265
CV %	33,830908

Type: working days – Time slot: off peak – Direction: Hospital (ATM315-ATM121)

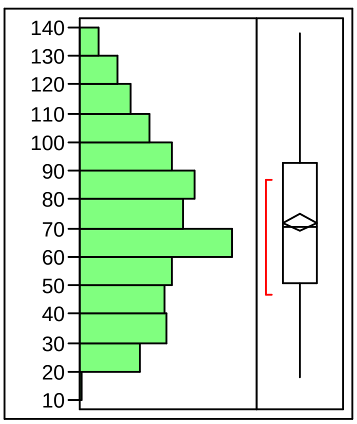


Distribuzione del tempo di percorrenza

Quartiles		
100.0%	maximum	198,00
99.5%		192,12
97.5%		174,00
90.0%		150,00
75.0%	quartile	123,00
50.0%	median	96,00
25.0%	quartile	72,00
10.0%		46,00
2.5%		29,00
0.5%		19,00
0.0%	minimum	11,00

Moments	
Mean	97,653333
Std Dev	38,013788
Std Err Mean	1,2174155
upper 95% Mean	100,04239
lower 95% Mean	95,264274
N	975
CV %	38,927282

Type: weekends – Time slot: off peak – Direction: Hospital (ATM315-ATM121)



Distribuzione del tempo di percorrenza

Quartiles		
100.0%	maximum	138,00
99.5%		138,00
97.5%		126,22
90.0%		114,00
75.0%	quartile	92,75
50.0%	median	70,50
25.0%	quartile	51,00
10.0%		34,70
2.5%		23,93
0.5%		20,36
0.0%	minimum	18,00

Moments	
Mean	71,744382
Std Dev	28,441773
Std Err Mean	1,507411
upper 95% Mean	74,70896
lower 95% Mean	68,779804
N	356
CV %	39,643206

The distributions of travel times show a relatively high standard deviation. This is due to two different factors:

- a variance due to the traffic light cycle (if the bus approaches the intersection with the green light, the waiting time is low; but if the bus approaches the intersection with the red light it must wait about at most one minute);
- a variance due to the unpredictability of traffic.

Considering the intersection proposed, it has to be pointed out that the Coefficient of Variation (Standard Deviation divided by Mean) takes comparable values for the three time slots; this holds also for the other intersections analysed and means that the slots were successfully determined.

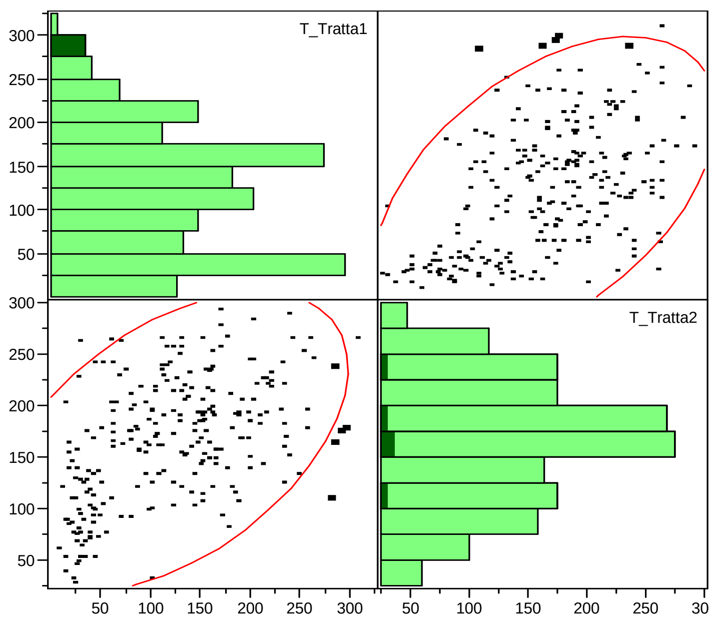
4.2.5 Correlation Analysis for Neighbouring Stretches

A second analysis that has been carried out was aimed at searching for a correlation between travel time of subsequent stretches. The hypothesis to be assessed through data analysis is whether the travel time spent by a bus of the stretch A-B is correlated with the travel time spent on the subsequent stretch B-C.

This problem is interesting for the context in which priority requests can be issued since if travel time A-B predicts travel time B-C, it is possible to anticipate the issuing of eventual priority requests.

In the following images, the study carried out between the travel time of the above mentioned stretches with their predecessors is shown. In particular, a multivariate analysis has been carried out between the stretches ATM116-ATM117 and ATM117-ATM480, in the direction of the Centre of Monza.

Type: working days – Time slot: morning peak – Stretches ATM116-ATM117-ATM480

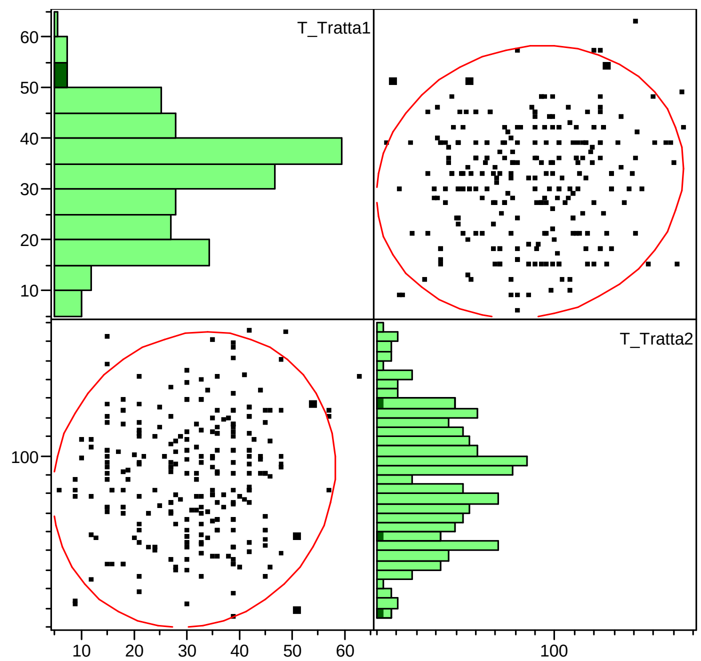


Correlation		
	T_Str_1	**T_Str_2**
T_ Str_1	1,0000	0,4940
T_ Str_2	0,4940	1,0000

In the table above are the correlation coefficients between time spent on Segment 1 and time spent on Segment 2.

To the left is the dispersion diagram between time spent on Segment 1 and time spent on Segment 2.

Type: working days – Time slot: evening peak – Stretches ATM116-ATM117-ATM480

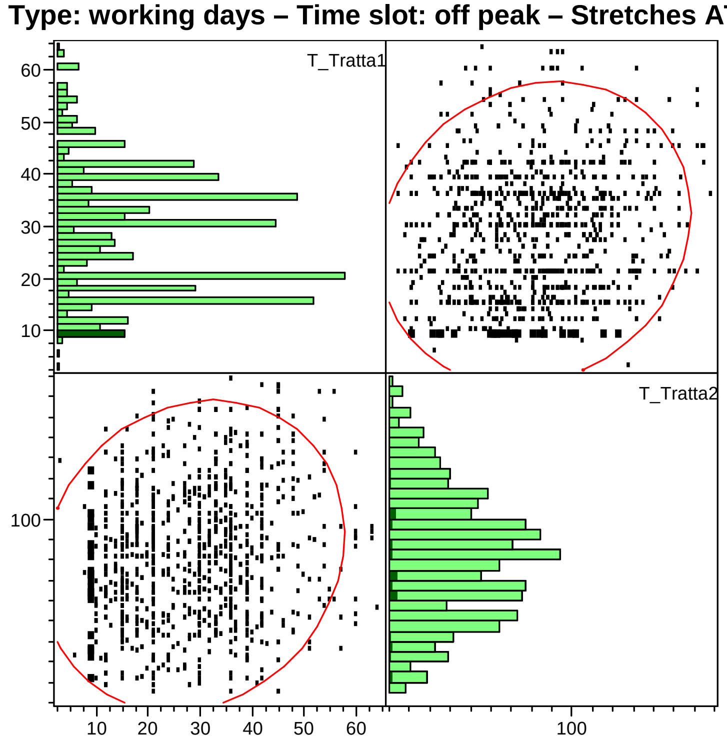


Correlation		
	T_Str_1	**T_Str_2**
T_Str_1	1,0000	0,0992
T_Str_2	0,0992	1,0000

In the table above are the correlation coefficients between time spent on Segment 1 and time spent on Segment 2.

To the left is the dispersion diagram between time spent on Segment 1 and time spent on Segment 2.

Type: working days – Time slot: off peak – Stretches ATM116-ATM117-ATM480

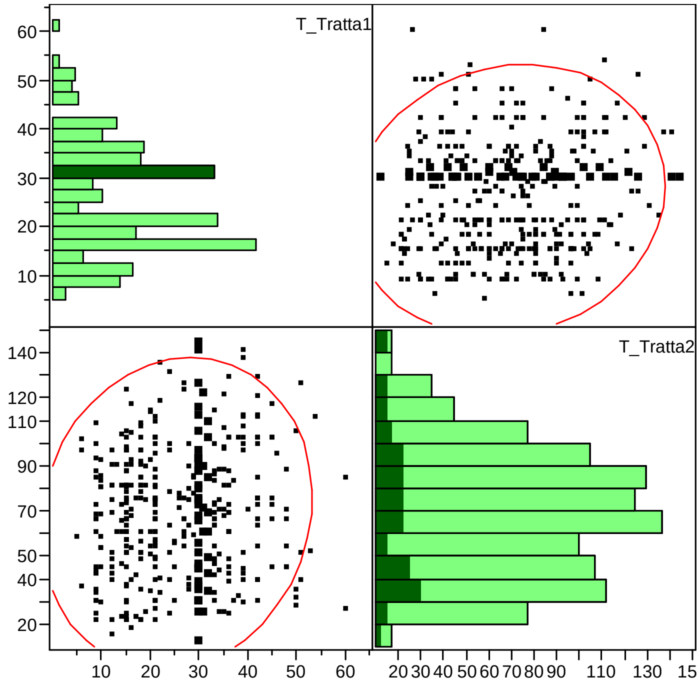


Correlation		
	T_Str_1	**T_Str_2**
T_Str_1	1,0000	0,1372
T_Str_2	0,1372	1,0000

In the table above are the correlation coefficients between time spent on Segment 1 and time spent on Segment 2.

To the left is the dispersion diagram between time spent on Segment 1 and time spent on Segment 2.

Type: weekends – Time slot: off peak – Stretches – Tratta ATM116-ATM117-ATM480



Correlation		
	T_Str_1	**T_Str_2**
T_Str_1	1,0000	0,1052
T_Str_2	0,1052	1,0000

In the table above are the correlation coefficients between time spent on Segment 1 and time spent on Segment 2.

To the left is the dispersion diagram between time spent on Segment 1 and time spent on Segment 2.

Table 3- Multivariate Analysis on travel times of subsequent stretches

The correlation analysis hasn't provided significant results; the reason is the high variance already pointed out in the former analyses.

To explain in detail the results through the graphical displays, it is immediate to see that the travel times belonging to the same histogram for Stretch ATM116-ATM117 don't correspond with one histogram but they are spread across all the histograms.

4.3 Criteria for Issuing a Priority Request to the UTC System

After analysis of travel times and the identification of homogeneous time slots, the criteria for issuing priority request are presented below.

4.3.1 Expected Delay and Priority Rules

A policy decision concerning whether to issue a priority request or not is needed; for this purpose, the concept of "Expected Delay" is proposed. "Expected Delay" is defined as:

ExpDel = Arrival_Time_by_TimeTable - (Actual_LastStop_Time + E[TravelTime])

where:

- *ExpDel, Expected Delay*, is the forecast of the delay that the bus will have at the completion of the current stretch;
- *Arrival_Time_by_TimeTable* is the expected arrival time at the first bus stop after the intersection to be crossed, as defined by timetables;
- *Actual_LastStop_Time* is the actual time gathered at the bus stop right before the intersection;
- E[*TravelTime*] is the expected time between the two stops, computed keeping into account the current time slot previously defined (morning peak, evening peak, off peak)

Relying on the concept of expected delay just defined, it is possible to decide whether to issue a priority request or not.

The criteria adopted are presented in Table 4.

Criterion name	***Rule***	***Color in figures 9-12***	***Criterion description***
Priority300	Expdel + 300 < 0	Red	Priority request is issued if the Expected Delay is greater than 300 seconds
Priority180	Expdel + 180 < 0	Orange	Priority request is issued if the Expected Delay is greater than 180 seconds
PriorityStDev	Expdel + StDev[TravelTime] < 0	Blue	Priority request is issued if the Expected Delay is greater than the standard deviation of travel time for the stretch for that time slot
Priority0	Expdel < 0	Green	Priority request is issued if the Expected Delay is greater than 0

Table 4- Criteria for issuing priority requests

Using the information presented in the following sections it is possible to assess the number of buses for which a priority request is issued according to the four proposed criteria outlined above.

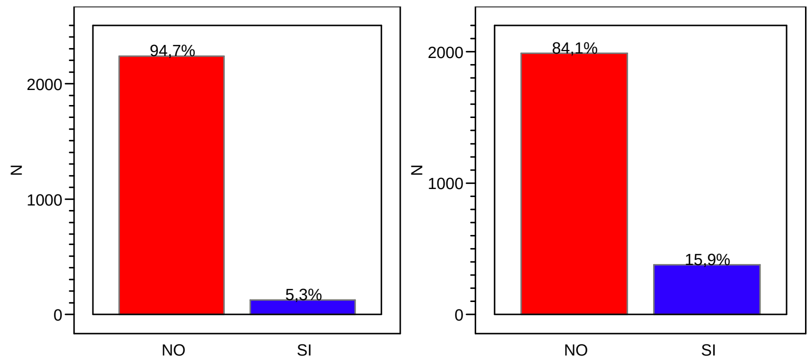


Figure 7- Percentage of buses issuing priority requests at 300 sec and at 180 sec

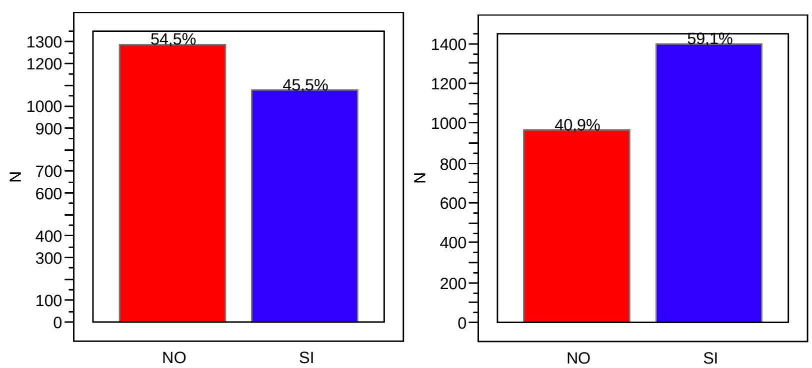
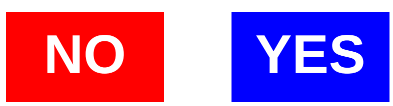


Figure 8 – Percentage of buses issuing priority requests using StdDev and always (0 sec)



4.3.2 Analysis of Expected Delay vs. actual offset occurred

In the following figures the behaviour of the real offset compared with the expected delay computed in advance is presented, grouped by time slots. The different colours represent the single observations for which the request would be issued.

A preliminary consideration concerns the appropriateness of the indicator “Expected Delay”: the high correlation, shown by the good diagonal fitting in the scatter plots of the following graph proves this.

To clearly interpret the graph considering the most restrictive criterion (Priority300), only the bus runs relating to the red point would issue a priority request. In Figure 9, this number is quite significant.

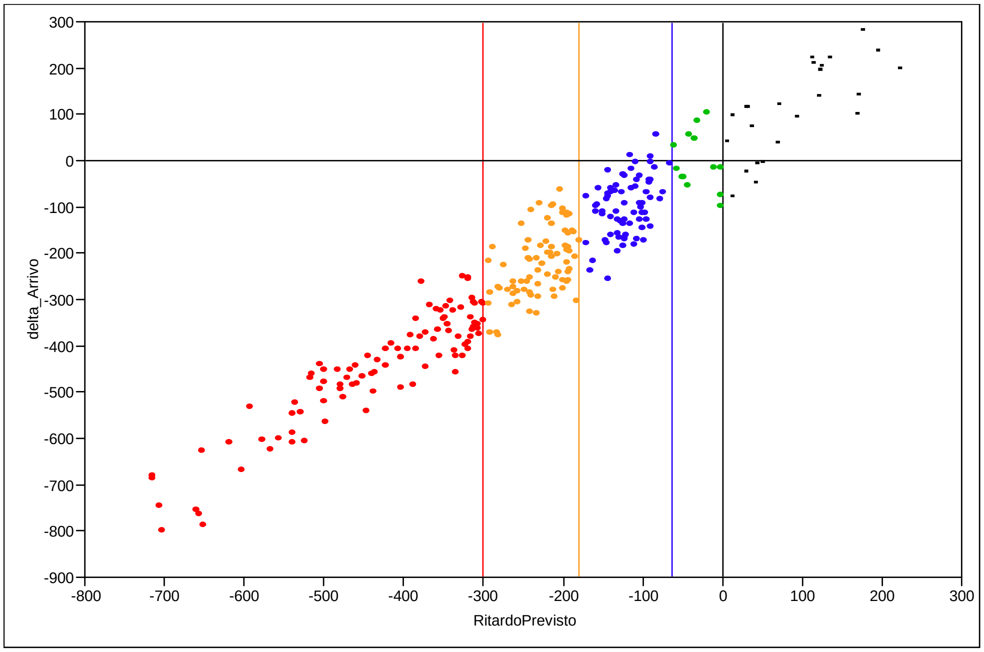


Figure 9 - Priority requests in working days, morning peak hours, direction: Centre

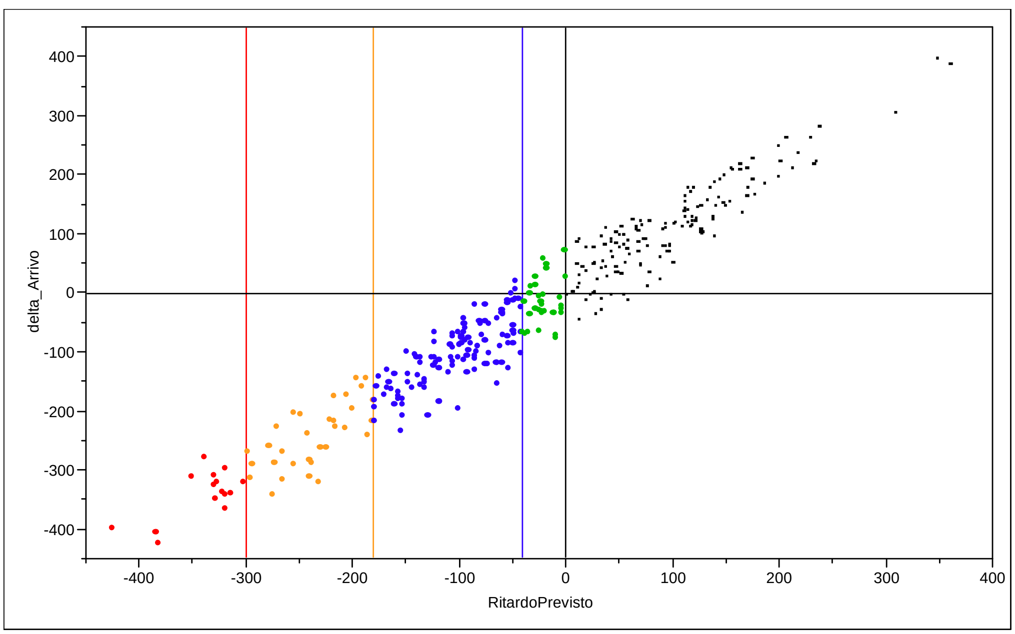


Figure 10 - Priority requests in working days, evening peak hours, direction: Centre

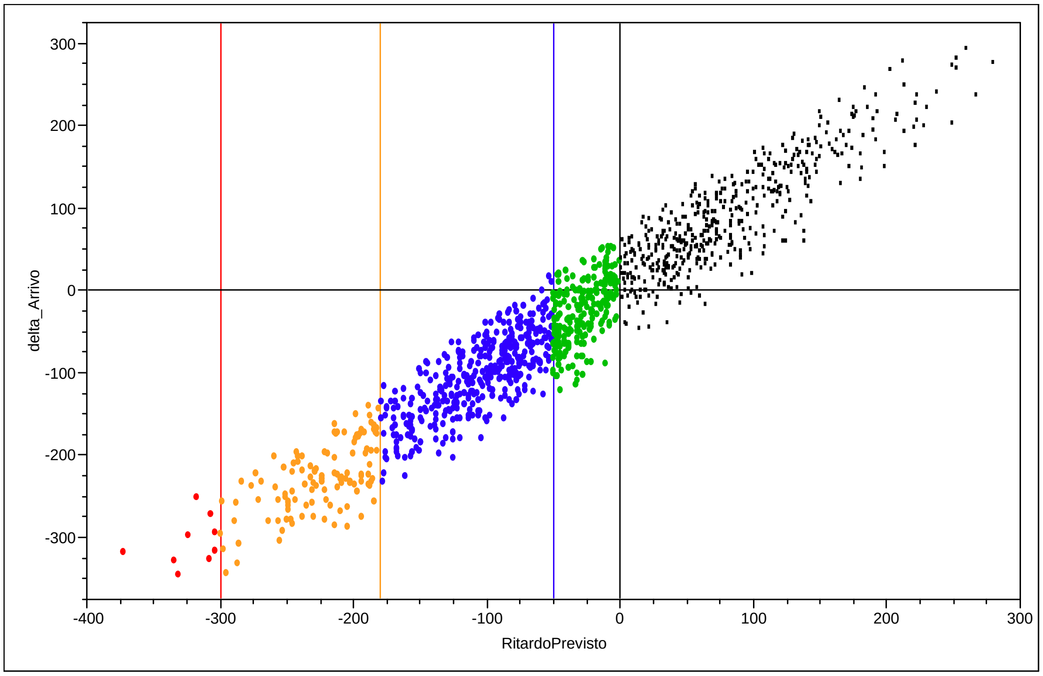


Figure 11 - Priority requests in working days, off peak hours, direction: Centre

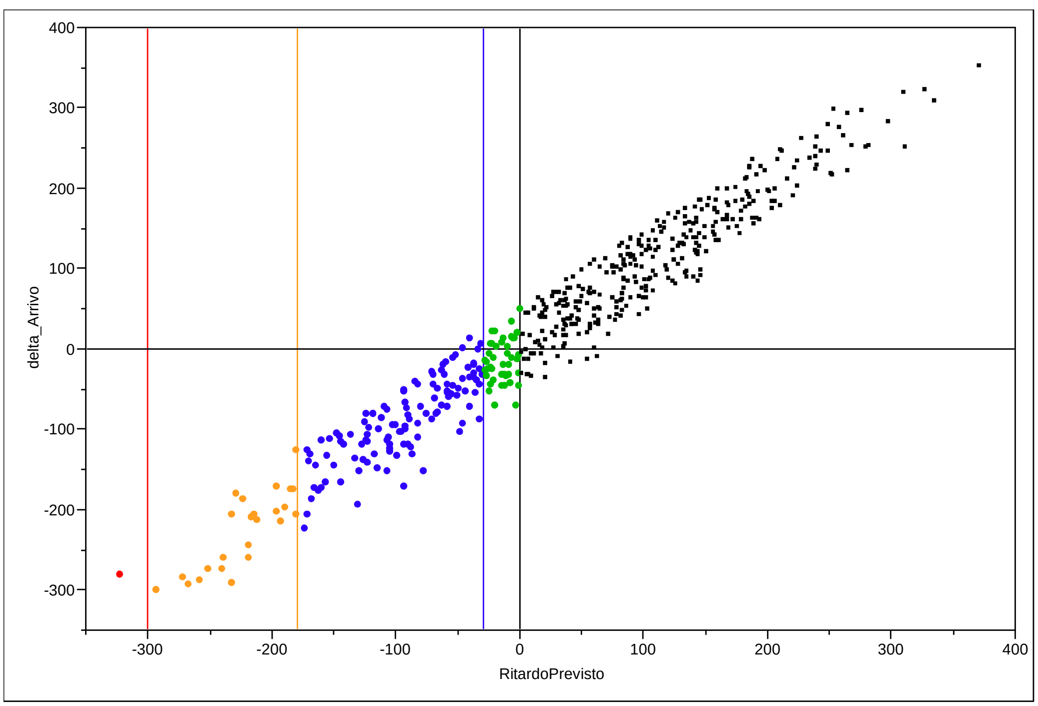


Figure 12 - Priority requests in weekend, off peak hours, direction: Centre

As a final comment concerning what has been presented in this section, is has to be pointed out that the final decision about which criterion will be adopted will be the responsibility of the Municipality; other criteria could be identified in the progress of the project based on other considerations. For example, an intermediate approach could be applied (Priority 180s) but if this worsens the flow of private cars too much a more restrictive scheme could be applied (Priority 300s).

4.4 Management of the Priority Request and Issuing to the UTC System

What has so far been described concerns the production of priority requests. As far as the realisation of these requests is concerned, other organisations need to be involved. These are shown in Figure 13.

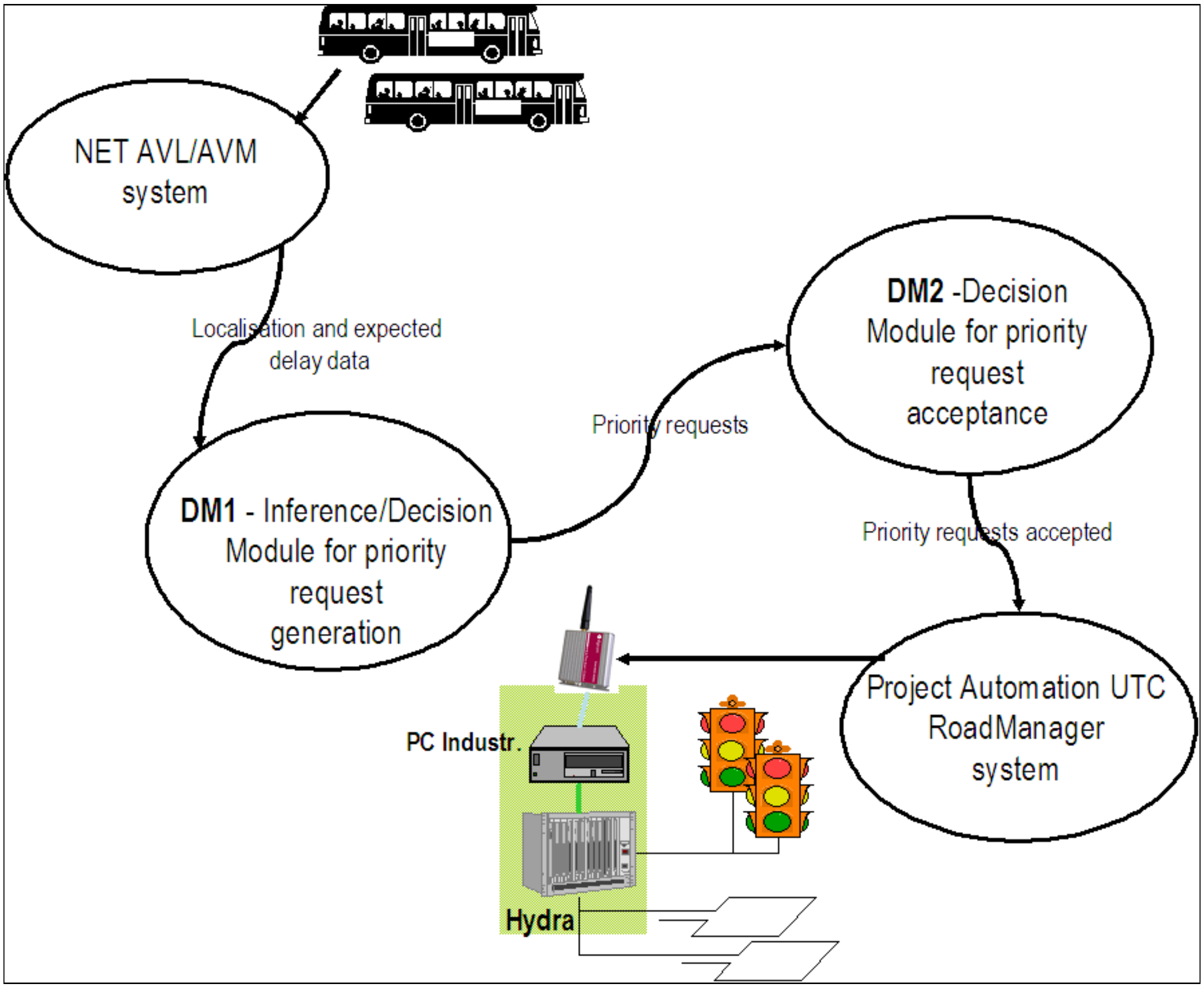


Figure 13 – Functional flow for management of bus priority requests

The functional flow involves four elements:

- the AVL/AVM system which generates localisation and monitoring data of the Public Transport fleet; starting form these data, it is possible to compute the “expected delay” feature, described in paragraph 4.3.1;

- a first decision module (DM1), which is aimed at taking decisions on which priority requests generated by the actual behaviour of the Public Transport service are to be issued (see paragraph 4.4.1);
- a second module DM2 which processes the priority requests issued and must decide which of them can be fulfilled (see paragraph 4.4.2);
- the UTC system, namely the RoadManager Suite running in the city of Monza to manage the centralised traffic lights (see paragraph 4.5).

As far as the technological framework to get data from the AVL/AVM system operational in NET is concerned, see Figure 14. This framework has been described in detail in the deliverables concerning measures 78 and 79, but is it reported here to focus on the functions made available to other applications by a Web Server through appropriate Web Services.

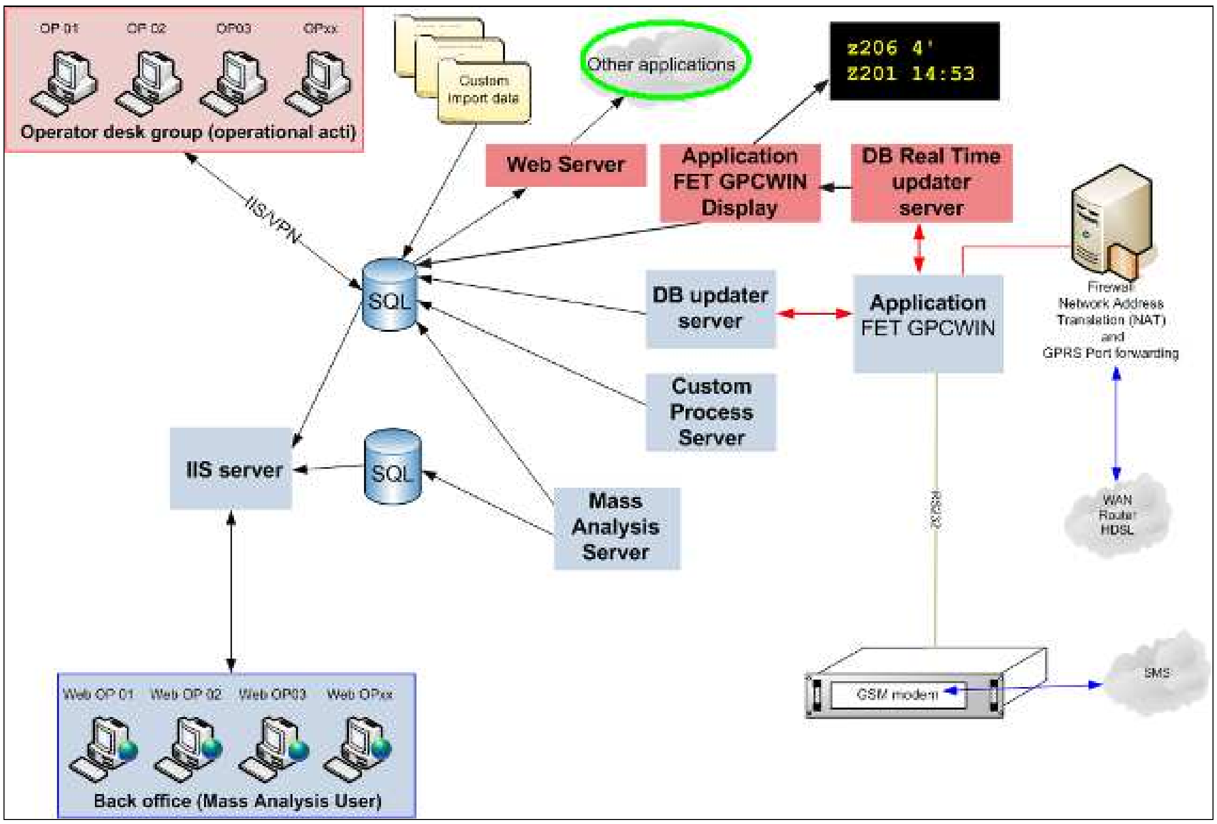


Figure 14 – Technological Framework to get data by AVL/AVM system

4.4.1 Decision Module 1

The first decision module, DM1, is aimed at taking decisions on which priority requests generated by the actual behaviour of the Public Transport service are to be issued. This module will apply one of the decision schemes described in paragraph 4.3.1 (e.g. priority request issued if expected delay greater than 300 seconds, greater than 180 seconds and so on) that will be chosen by the experts in Traffic Office of the Municipality, who are in charge decisions of traffic policies to be applied.

This module is continuously updated since it accesses through appropriate Web-services to a dedicated Web Server made available by AVL/AVM system, in order to keep updated the "Expected Delay" feature which represents a degree of need of priority for a given run of a Public Transport bus.
It has to be pointed out that the generation of priority requests is independent by factors external to the Public Transport Service; such factors will be taken into account by subsequent stage of this process. Requests are generated each time a bus is delayed according to the chosen criterion.

4.4.2 Decision Module 2

The second decision module, DM2, processes the priority requests issued and must decide which of them can be fulfilled.
Decisions can be undertaken following a wide set of criteria, both qualitative and quantitative, depending on the real information available; possible decision variables to undertake a decision that can vary along time, are:

- Satisfaction of priority requests stated by authorised people (e.g. the traffic engineers of the Municipality) enabled/disabled;
- Status of the Traffic along the Corridor, if appropriate sensors are available; this is not the case of the city of Monza at this time, nor likely in the immediate future;
- Maximum number of priority actions satisfied at a given timeframe (e.g. the last 20 minutes) for a given intersection or for a set of coordinated intersection related to the corridor or part of it;
- Temporal threshold within which it is not possible to satisfy other priority requests for a single intersection or a group of coordinated intersections, to avoid heavy side effects on private traffic.

Another important objective of this decision module is to solve conflicts among different priority requests. To do this, the following topics must be defined:
- correspondence between priority requests and signal groups of the Traffic Light Controller, and, consequently, with the stages of the traffic light plan.

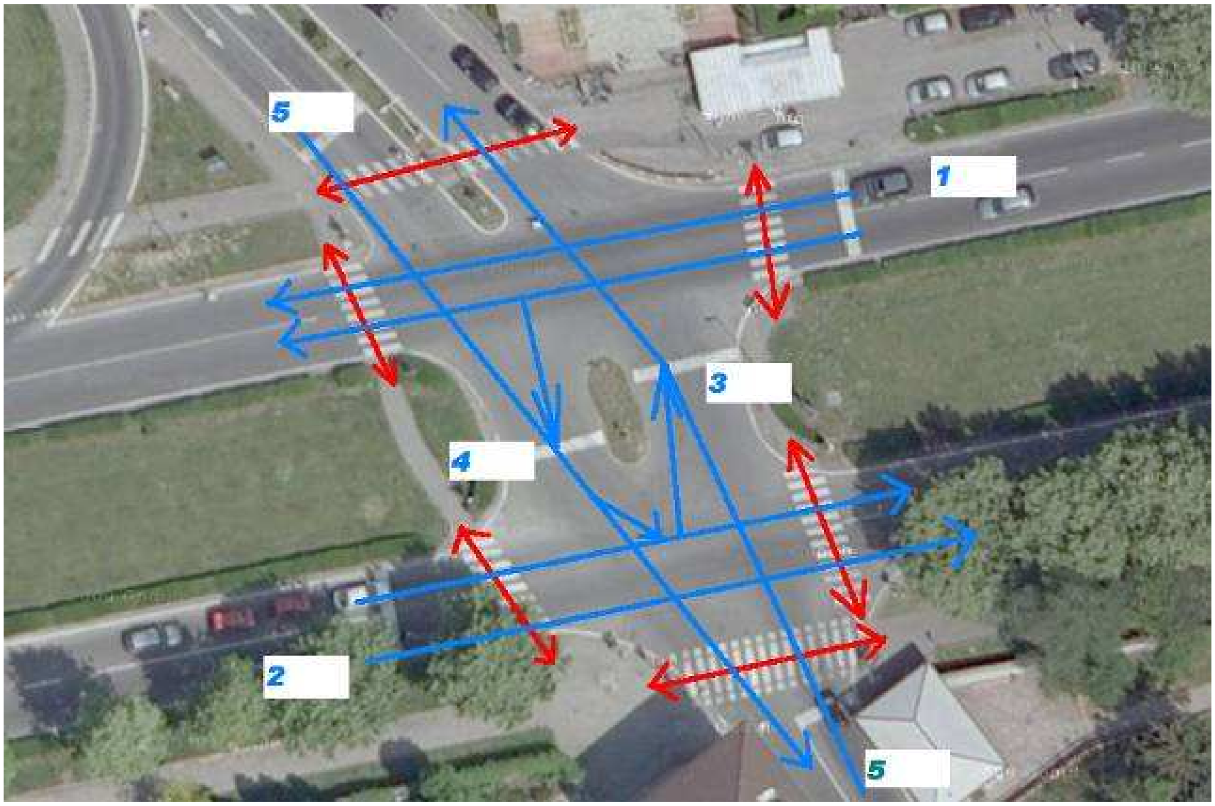


Figure 15 - Intersection no. 19 (Boito-Battisti)

In the example depicted in Figure 15, the movements for vehicles are expressed by the blue arrows and marked with an identification number (1 to 5) which represents the Signal Group number of the Traffic Light Controller. Signal Groups 1 and 2 are dedicated to the main flow, i.e. the CIVITAS Corridor for private traffic explained in deliverable T81.1.

Signal group 5 manages the CIVITAS Corridor for the Public Transport, driving the movements for vehicles coming from the Centre of the City (the road on the lower part in the picture) and coming from the City Hospital (the road on the higher part in the picture).
In the relationships among stages and Priority requests are shown:

Stages/Prior. Req.	R1	R2
F1		
F2		
F3	X	X

Table 5 - Relationships stages - priority requests at Intersection 19

Table 5 shows information that expresses the relationship between stages and requests. In particular, for this situation, the two requests are compatible, since they are managed by the same stage of the plan. This is a lucky situation, but it is quite common that different priority requests are served in different stages of the plan or that there are only partial commonalities.

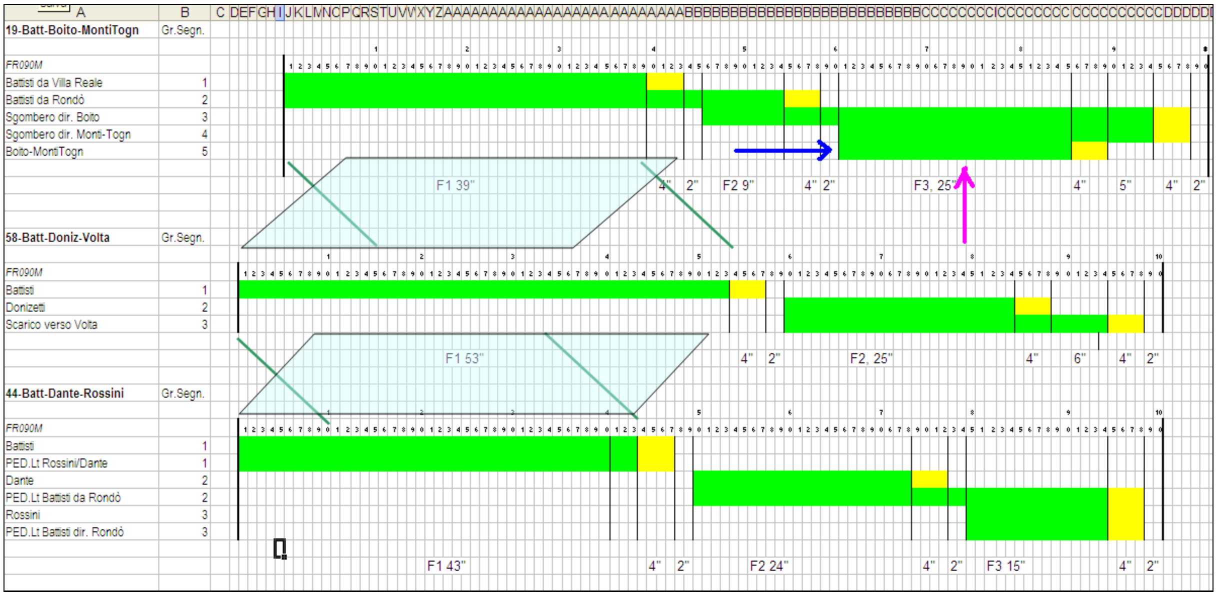


Figure 16 - Coordination group involving the intersection no. 19

Figure 16 represent the plans of three coordinated intersection, the blue arrow indicates the signal group involved with the transit of buses and the magenta arrow indicates the stage of the traffic light plan when the signal group 5 gets green.

To show a more general situation, another intersection on the CIVITAS Corridor for Public Transport is depicted. It is the intersection that follows the former one on the Corridor, in the direction of the Centre of the City, as shown in Figure 17.

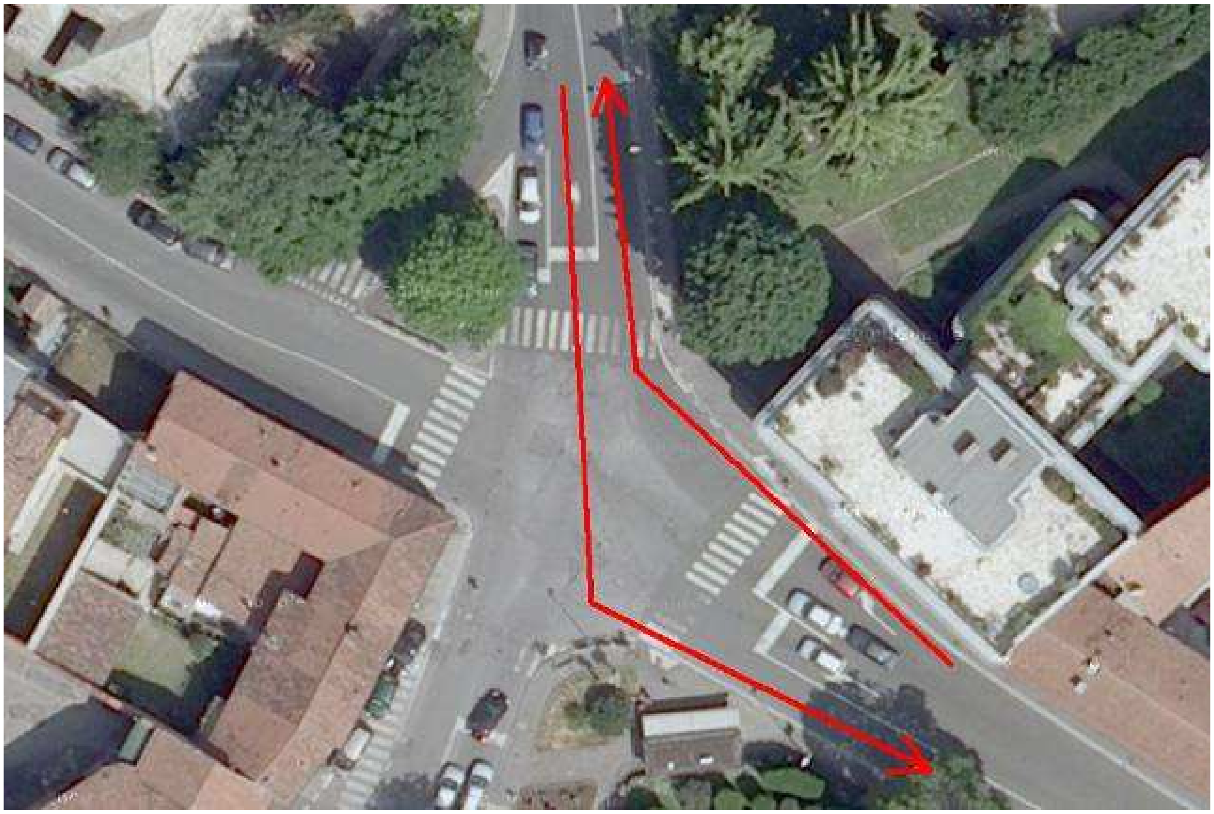


Figure 17 - Intersection Monti e Tognetti – Prina with the routes of the buses

The sequence of the stages of the traffic light plan is presented in Figure 18.

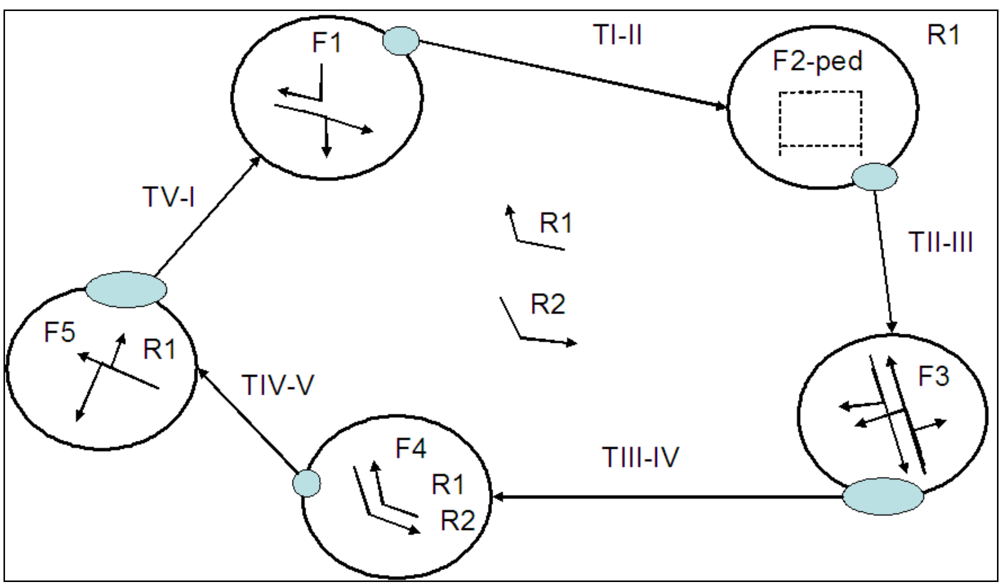


Figure 18 - Intersection Monti e Tognetti – Prina: The stages of the Traffic Light Plan

Five stages are configured in the plan; each one of them takes a fixed time and the sequence of the stages is fixed. As expressed in Table 6, the priority request R1 can be satisfied in stages F4 and F5 whilst the priority request R2 can only be served in Stage F5.

Stages/Prior. Req.	R1	R2
F1		
F2-ped		
F3		
F4	X	X
F5	X	

Table 6 - Relationships stages - priority requests at Intersection Monti e Tognetti - Prina

The last aspect to be considered in DM2 concerns the rules to decide which priority request will be chosen to be served in case of conflicting priority requests. Two aspects are taken into account: the first quantifies the importance of the request with respect to the other ones in the time slots identified (see Table 7); the second one expresses the penalty that the fulfilment of such priority request has on private traffic (see Table 7).

Time slots	***Working day morning peak***	***Working day evening peak***	***Working day off peak***	***Week ends***
Priority Request				
R1	4	4	6	3
R2	5	5	7	4
R3	2	2	4	1

Table 7 – Importance of priority requests w.r.t. time slots

In Table 7 a typical set of weights that express the importance of the requests with respect to time slots are presented. The greater the number, the more important the priority request in that time slot. As multiple priority requests are issued by DM1, if more than one concerns a single intersections or a coordinated set of intersections, they are weighted on the values assigned for the current time slot.

Time slots	***Working day morning peak***	***Working day evening peak***	***Working day off peak***	***Week ends***
Priority Request				
R1	5	4	2	2
R2	9	7	4	6
R3	3	2	1	2

Table 8 – Penalty coefficients of priority requests fulfilment on private traffic

In Table 8 the penalty coefficients of priority requests fulfilment on private traffic are presented; the greater the coefficient, the heavier the impact of the priority request on private traffic.

A formula is proposed to get a comprehensive index to allow DM2 to take the decision about the priority request to be sent to the UTC system to be served in case of conflicts, which takes into account the coefficients so far described.

The formula is:

G(Ri) = (a*I(Ri) - b*C(Ri))*#Ri

Where:
- I (Ri) is the importance assigned to priority request I;
- C (Ri) is the cost assigned to priority request I;
- #Ri is the number of priority requests active for the current intersection as identified by DM1;
- a and b are weigth coefficients for Importance and Cost

Through the application of this formula, DM2 takes decisions about the requests to be fulfilled, which are then sent to the UTC Roadmanager to be served.

4.5 Fulfilment of the Priority Request within the UTC System

The traffic light plans concerning the intersections belonging to the corridor for Public Transport priority management will be designed and coded to fulfil priority requests. The central component of the UTC system will forward to its peripheral software component managing the relevant intersection the proper information to serve the priority request to be delivered.

Specifically, each traffic light plan which is involved in priority management for Public Transport will be designed and coded to manage priority requests. Continuing the example concerning the intersection no. 19, Boito-Battisti, (which belongs to both the Monza CIVITAS corridors, depicted in Figure 15 and whose reference traffic light plan is presented in Figure 16), the plan adjusted to manage priority requests is shown in Figure 19.

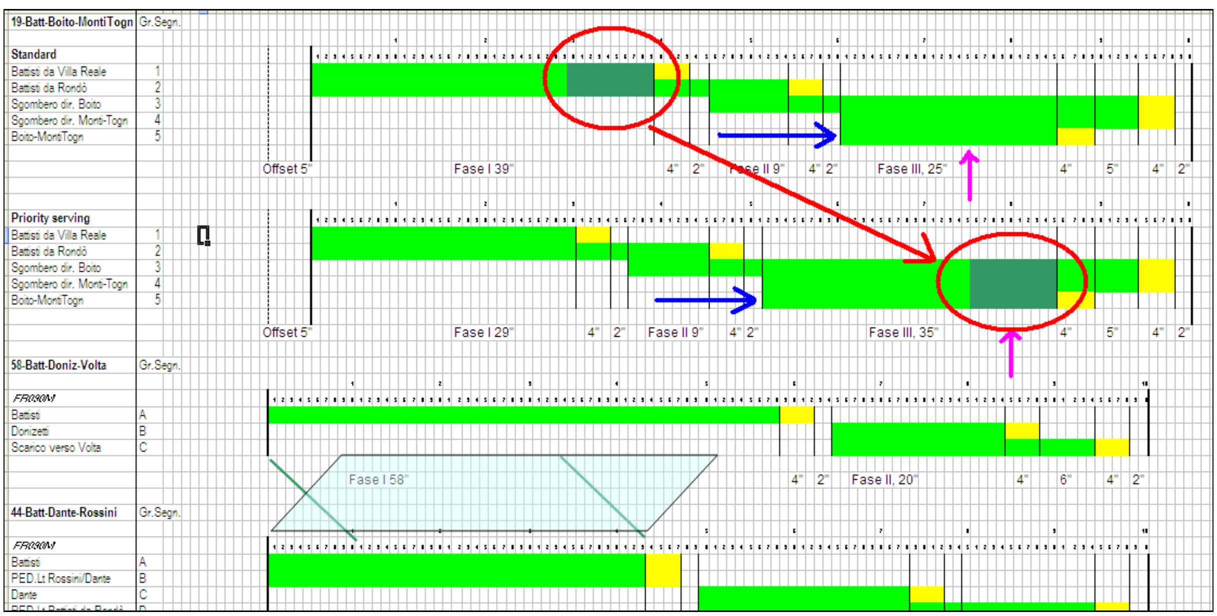


Figure 19 - Traffic light plans with priority management for Public Transport

In Figure 16 the signal groups were already marked with the coloured arrow and the stage to be preferred; in Figure 19 other information are added: the second traffic light plan from the top is the plan activated when a priority request has to be fulfilled.

Specifically, the proposed approach consists of a different split assignment: to fulfil the priority request, ten seconds of green time are moved from Stage I to Stage III, as pointed out by the dark green time slot red-circled. The number of cycles for which this different split holds may depend on the relevant bus completing its transit of the intersection or on a maximum number of cycles for which this different split can be applied, knowing that this plan penalises the private corridor leading to increased congestion on the other roads.

During the demonstration stage of the project all these parameters will be tuned to provide a good starting point for the evaluation session.

As far as some technological details of the traffic light plan coding are concerned, the plan will remain the same; the durations of the Stages I and III will be conditioned on the status of a variable name "Priority_ON" which will become TRUE when the priority scheme has to be applied and FALSE viceversa. The cycle time will remain the same but the green split percentage will change in accordance with the above-mentioned policy.

5 Accomplishments

5.1 Main Outcomes

The application of a priority management approach for Public Transport, together with precise information on the real arrival time of buses is a good opportunity to attract more people to use Public Transport Services in Monza.

The effective collection of data relating to the movement of the buses of the fleet across the city, (which has been accomplished through measure 78,) as well as the implementation of an UTC system are necessary preconditions to carry out this measure. The demonstration stage will be used to assess and consolidate the approach proposed in this study.

5.2 Problems Identified

No functional issues have as yet been identified as problems.

5.3 Mitigating Activities

Not applicable.

5.4 Future Plans

The proposed approach, both on the conceptual and technological side, is open to the management of other Public Transport fleets operating in Monza. In particular, referring to the functional flow depicted in Figure 13, other AVL/AVM system are used by other fleet: a software interface, based on Webservice, could be the way to feed the Decision Module 1 with priority requests originated by other fleets. Following this approach, each fleet will refer to its AVL/AVM system; only relevant information will be gathered from it if priority actions could be helpful to increase the service level.

The number of traffic lights can be extended as well: the UTC system can manage without problems the eighty traffic light controllers operating in Monza.