Measure title: **UTC System in Monza**

City: **Monza** *Project:* **ARCHIMEDES** *Measure number:* **81**

Executive summary

The aim of the measure 81 is to design and implement an Urban Traffic Control (UTC) technological system that contributes to maximize the flow of traffic through the identified CIVITAS corridor in the city of Monza.

Urban Traffic Control systems have been developed to manage in a coordinated way intersections driven by traffic lights. One of the main advantages gained by the application of UTC systems is to make available the opportunity to vary green times, duration of cycle times, green waves depending on traffic conditions, day of the week, hour of the day and so on.

In ARCHIMEDES, the approach selected for managing the intersections included in the corridor identified in Monza is the "plan selection approach". The UTC selected is RoadManager® designed and implemented by Project Automation, a technological partner of the Municipality of Monza in the ARCHIMEDES project.

RoadManager® is already in use in several Italian cities and it is designed to manage priority requests issued by Automatic Vehicle Location/Automatic Vehicle Management (AVL/AVM) technological systems in use on Public Transport fleets as well. This is an important requirement for Archimedes in Monza, since Measure 82 is devoted to manage such priority requests.

The research stage of the measure has focused on setting up a technological framework to allow the centralisation of traffic light equipping the intersection of the CIVITAS corridors. In particular, the selected corridor is about 4 kilometres long; along the corridor 8 traffic lights are installed, as shown in Figure 1.All these traffic lights are controlled by RoadManager® UTC system; the average traffic flow, as shown in Table 1, about 15,000 vehicles/day in the working days per single direction. The speed limit is 50 Km/h along the whole corridor.

The implementation stage has allowed to implement and to make operational the UTC in the selected intersections in the city of Monza, with a very good stability.

Evaluation activities have been aimed at measuring the results achieved, expressed through the following key results:

- the proposed approach has been proved successful, in terms of impact evaluation, assessing key indicators: +5% for traffic flow, -20% for traffic density; there has been a significant improvement of the performances of the corridor, especially through the regularisation of the behaviour in peak-hour; cycle time reduction of coordinated traffic light plan from 160" to 150" at peak hours and from 160" to 125" in off-peak hours has produced the effect of a better regularisation of platoons, measured through a reduced variance without worsening the overall performances and reducing waiting times for pedestrians and cyclists. Before data campaign was carried out in September 2011; after data campaign was carried out in June 2012, in comparable traffic situations just after the stabilization after the implementation of new traffic plans.
- CBA has proved that the benefits obtained are greater than the incurred costs, having estimated the Value of Time saved; in particular, Table C 2.6.10 shows that after seven years the incurred costs are covered and the other three years generate a positive return on the investments accomplished. It has to be highlighted that Value of Time is estimated and therefore derived by the Level Of Service (after is "C") following HCM guidelines with respect to an uncoordinated situation . This derived value gives a comprehensive view, thus considering both reduced delay and travel time reduction.
- the overall process set-up for carrying out this measure, established involving the Municipality and the industrial partner of the project, led to a substantial increase of skill and attitudes for the traffic experts of the Municipality; barriers have been positively overcome;

The measure can be successfully taken-up by other cities. Traffic light management is often underestimated as leverage to apply traffic control strategies, at least in Italy; many Italian cities and towns still have a poorer approach with respect to other European Countries. In fact, it is still common in Italy to find traffic light installation with no sensors and thus with fixed time green for each movement approaching the intersection. Continuous and very profitable relationships have been established between the technical staff of the technological partner involved in the project, and the technical and administrative staff of the municipality; which realized that these new approaches ensure much better results in terms of traffic management, in the framework of Intelligent Transportation Systems. This process, that has been established along Archimedes, has become a reference also for the future.

A Introduction

A1.1 Objectives

The measure objectives are:

(A) High level / longer term:

- To reduce traffic congestion on important city corridors

(B) Strategic level:

- To optimize private traffic flow
- Measure level:

(1) To define an experimental city corridor, namely the "CIVITAS Corridor"

(2) To experiment on such CIVITAS Corridor in the city of Monza the effectiveness of the UTC approach, which means the capability to define a set of control strategies involving coordinated intersections and to apply the most proper strategies with respect to the objective of Traffic Managers and current traffic status

(3) To setup and test a technological platform able to manage also Public Transport Priority requests, as depicted in Measure no. 82

The Corridor has been selected since it is the main route to bypass the Centre of the City on the North, and it is depicted in the following picture. The corridor consists of eight intersections, pointed out by the red crosses. The brown arrows show important routes of the Public Transport Service; this means that the objective function to be optimized concerns the blue routes as far as private traffic is concerned, but priority requests by Public Transport buses have been taken into account by measure no. 82.

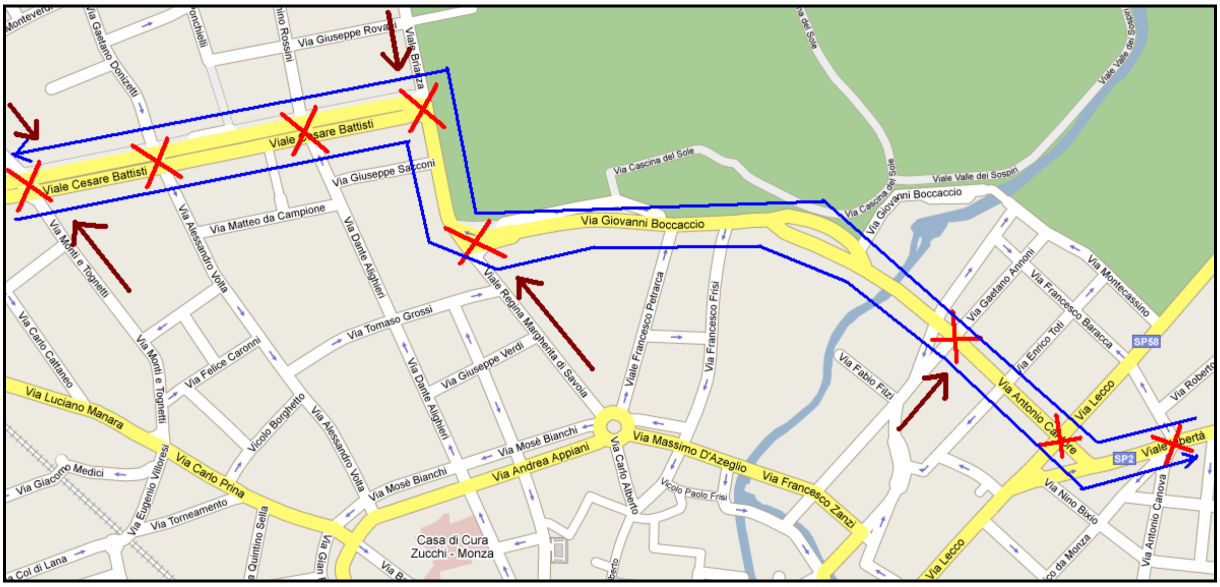

Figure 1 - Monza corridor for measure no. 81

A1.2 Target groups

- Car drivers
- Pedestrians, cyclists
- Commuters from outside and from inside
- Fleet operators (please see Measure no. 82)

A2 Description

The aim of the measure is to design and implement an Urban traffic control system that contributes to maximize the flow of traffic through the city of Monza.

The control policy so far applied, without an UTC System, is no longer suitable to meet the requirements of a complex traffic control policy; in order to maximise the throughput of the entire road network, it is becoming crucial to coordinate groups of intersections that are close to one another; only in this case it is possible to achieve green waves on critical directions, that can vary along the day meeting traffic demand.

A study has been carried out by Project Automation (PA) to apply existing UTC systems to relevant intersections to optimise traffic light control as well as to define the requirement to support Public Transport Priority Management, exploiting information gathered by AVL/AVM System, as provideed by Measure no. 78. The results of this study are reported in Deliverable R81.1, delivered in September 2009.

Each intersection put under control of the UTC system is under the control of a Central Computer; in ARCHIMEDES, the approach selected for managing the intersections included in the corridor identified in Monza is the “plan selection approach”, as described in deliverable T81.1. The UTC selected is RoadManager®, designed and implemented by Project Automation, technological partner of the Municipality of Monza in the ARCHIMEDES project.

In RoadManager the strategies are defined, through sets of coordinated traffic light plans designed and implemented to manage the different traffic situations encountered. Details are available in Deliverable T81.1, delivered n January 2011.

The measure covers 2 tasks:

Research Stage: Task 11.8.5 UTC System Technical Design

A study has been carried out to apply existing UTC systems to relevant intersections to optimise traffic light control as well as to define the requirement to support Public Transport Priority Management, exploiting information gathered by AVL/AVM System.

Demonstration Stage: Task 8.16 UTC System

In corporation with PA and TPM the city of Monza has designed an Urban Traffic Control System (UTC) involving several important intersections as well as Public Transport lines. The city of Monza has implemented the system with contribution to planning and equipment costs from ARCHIMEDES, with cost of purchase of 21,000 Euros in month 16.

A3 Person in charge for evaluation of this measure

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B Measure implementation

B1 Innovative aspects

The innovative aspects of the measure are:

- **New conceptual approach** – The application of an Urban Traffic Control system is a new challenge for the city of Monza. So far optimization activities on traffic light programming have been carried out locally on important intersections. The adoption of UTC will allow traffic managers of the Municipality to arrange new processes to manage traffic lights as key factor for calibrating mobility offer provided by road network.
- **Use of new technology/ITS** – Urban Traffic Control systems are classical ITS for traffic management. Thus also on the technological point of view, the adoption of UTC is a new issue for Monza.
- **Targeting specific user groups** – This measure addresses the need of pedestrian, cyclists and car-drivers. These user groups are very numerous so the results achieved have significant impact. Especially for the intersection included in the corridor close to the Park of Monza, accessed every working day by hundreds of persons (thousands during the week-end), the need of finding a right trade-off between the needs of pedestrians and cyclists and the needs of drivers is a crucial aspect, tuned many times during the demonstration stage and still under focus in the evaluation stage.
- **New organisational arrangements or relationships** – The impact of the adoption of an UTC system for traffic light management was not only on processes, as described in the "New Conceptual Approach" bullet and on technology, as described in the "Use of new technology/ITS" bullet, but also on organisation. Traffic managers of the Municipality have extended their direct intervention capability..

B2 Research and Technology Development

A study has been carried out by PA to apply existing UTC systems to relevant intersections to optimise traffic light control as well as to define the requirement to support Public Transport Priority Management, exploiting information gathered by AVL/AVM System. The results of this study are reported in Deliverable R81.1, delivered n September 2009.

A set of relevant intersection have been chosen and the Monza CIVITAS Corridor has been identified. The activities carried out were:

(R1.1) upgrade of the Traffic Light Controller to allow the centralization (remote-controlled intersection);

(R1.2) installation of an industrial PC in the technical cabinet where the Traffic Light Controller is installed to host software processes pursuing centralization;

(R1.3) establishment of a wireless network connection with the Central Computer;

(R1.4) setup of the equipment at Central level (server PC, client PCs), installation of the RoadManager UTC application (licensed by Project Automation)

(R1.5) basic test on a intersection used as tested

B3 Situation before CIVITAS

Before CIVITAS, optimization acitivities on traffic light programming have been carrying out locally on important intersections. This has meant that every intervention required that a team of experts had to reach the intersection, access the cabinet, connect a PC to the Traffc Light Controlled and download onto the Traffic Light Controller the updated traffic light plan. This cumbersome procedure caused interventions execution only in worst traffic situations. Interventions for regular tuning were no longer carried out.

B4 Actual implementation of the measure

The demonstration stage for this measure has been implemented through the following tasks, reported in detail in the already mentioned deliverable T81.1:

Stage 1: Design and Coding of Traffic Light Plans *(September 2009 – June 2010)* – In this stage a set of activities have been carried out, such as:

- (1.1) collection, documentation, analysis of performances of the current traffic lights plan: type of plan (fixed/variable cycle), cycle time, percentage of green time for the movements of the intersection, relationships stages-movements,…
- (1.2) analysis of traffic flows in several conditions: working days, holydays, special days; morning peak hours, evening peak hours, late mornings, afternoons, evenings,…
- (1.3) definition of the groups with correlated intersections to be modelled in the UTC system in the managed conditions (working days, holydays, special days; morning peak hours, evening peak hours, late mornings, afternoons, evenings)
- (1.4) design of coordination diagrams with relevant green waves for the groups identified
- (1.5) plan coding and laboratory test to allow the installation in the real environment

Stage 2: UTC Startup and Performances Analysis *(June 2010 – December 2010)* – In this stage the UTC system is made operational and it is loaded with a first set of plan for the relevant intersections. Particular care was put on the results on traffic flows, especially in the most critical situations, to avoid unexpected jams.

Stage 3: Analysis and improvement of the performance of the System *(January 2011 to July 2011)* – This stage was devoted to provide data and information to the Evaluation Stage. The plans made operational could be reviewed in order to match in the best way the results expected.

Stage 4: Evaluation stage *(June 2011 – June 2012)* - During this stage measurements has been collected to carry out impact evaluation.

B5 Inter-relationships with other measures

The measure is related to other measures as follows:

- **At the site level**: This measure is tightly related to Measure no. 82; the UTC made operational is a prerequisite to manage also Public Transport priority requests.
- **At the measure level**: Monza has referred to Measure 16, “High Quality Bus Corridor in Donostia – San Sebastian”, to share the policies adopted in the Donostia UTC to implement PT Priority.

C Impact Evaluation Finding

C1 Measurement methodology

C1.1 Impacts and indicators

C1.1.0 Scope of the impact

The indicators chosen and listed in the table below, were selected because **directly** related to the introduction of the UTC measure and actually evaluable by a quantitative engineer's assessment.

Other indicators could describe the impact of UTC, let say in domains of:

Economy, where a cost-benefit balance is possible between investments+operations costs and operations returns.; usually this analysis supports an expert judgement about the project proposal deserving a financement.In UTC case returns are not accountable, as no revenues are expected from UTC service. Nonetheless they spoke of "externalities" as the **money** savings coming from shorter journey time, or energy demand and pollution decrease.;The conversion of engineer's parameters (e.g.delay) in actual money savings,on account of externalities, is more an academic than operative indicator, that way was not dealt with during the work.

Energy savings – no indicators of this group are considered, mainly because of the project "scale" which cannot assure a clear and demonstrable energy savings : moreover ,even if a more fluid traffic implies reduction in fuel consumption, this issue is not the primary benefit expected from this measure

Environment impact – focus has been put on the measurement of the pollutants in a point of the corridor; this has been accomplished by the Public Body that has in charge the sensors network and responsibility of Air Quality monitoring; please see following section C 2.3 .

Society impact– this group of indicators is not considered due to the strict technological role of the UTC measure; the acceptance of the expected benefits on traffic behaviour will be trivially accepted by several categories of stakeholders.

Transport impacts. Impacts on Transport System are considered and measured, both before and after the interventions, as described in the sequel;. the expected impact of actuated/adaptive signalling system (UTC) is to make the control strategy more dynamically **traffic – dependent** than **fixed-time** can do by peak and peak-off times. This has been implemented by a controlled variation of green time allocation (split time) when arrival rate changes. Delays are thus consequent to this scheme and can be known and gauged in an engineering style. The indicator known as "Level of Service" (LoS) is a ranking of the intersection delay according to a predefined absolute scale. We found and adopted LoS as the best description which could be, homogeneously, deployed in actuated and fixed-time schemes. Other indicators like Quality of Service or Road Safety, are considered either more pertaining to Public Transport requirements (trains punctuality, network accessibility) or to road infrastructure operations & management , thus not usefuly applicable to an UTC system evaluation.

C1.1.1 Selection of indicators

NO.	EVALUATION CATEGORY	EVALUATION SUB-CATEGORY	IMPACT	INDICATOR	DESCRIPTION	DATA /UNITS
	ECONOMY					
2a		**Costs**	Operating Costs	Operating costs	Costs per year for the entire system	Euros/year, quantitative, derived or measurement
2b			Capital Costs	Capital costs	Costs per intersection	Euros/intersection; the cost of the control centre is spread over the intersections centralised
2c			Maintenance costs	Maintenance costs	Costs per year of the entire system	Euros/year
	ENVIRONMENT					
5		**Pollution/Nuisance**	Air Quality	CO levels	CO concentration	Ppm or g/m3, quantitative, measurement
5a				O3 levels	O3 concentration	Ppm or g/m3, quantitative, measurement
6				NOx levels	NOx concentration	Ppm or g/m3, quantitative, measurement
7				Particulate levels	Particulate PM10 and/or PM2.5 concentration	Ppm or g/m3, quantitative, measurement
	TRANSPORT					
21		**Transport System**	Traffic Levels	Traffic flow - peak	Average vehicles per hour by vehicle type - peak	Veh per hour, quantitative, measured
22				Traffic flow - off peak	Average vehicles per hour by vehicle type – off peak	Veh per hour, quantitative, measured
23			Congestion Levels	Traffic Density - peak	Sensor Occupation rate over measured points	percentage occupation sensor over th time unit, quantitative, measured

NO.	EVALUATION CATEGORY	EVALUATION SUB-CATEGORY	IMPACT	INDICATOR	DESCRIPTION	DATA /UNITS
24				Traffic Density - off peak	Sensor Occupation rate over measured points	percentage occupation sensor over th time unit, quantitative, measured
24a				Level of Service (LoS)	Traffic Light Level Of Service, according to HCM	Class, Enumerative, computed

C1.1.2 Methods for evaluation of indicators

No.	INDICATOR	TARGET VALUE	Source of data and methods	Frequency of Data Collection
2a	Operating Costs	The minimum allowed	Expenditures to keep the system operational (communication lines)	Yearly from the start of demonstration tasks
2b	Capital Costs	The minimum allowed	Amount of money spent by the Municipality to implement the system	Once, at intervention completed
2c	Maintenance Costs	The minimum allowed	Predictive and corrective maintenance activities, base and application software upgrade	Yearly from the start of demonstration tasks
5	CO levels	As low as possible	Campaign carried out through a mobile lab according to the Italian law: probe for CO must be between 1.6 and 5 meters above ground	Once during the project
5a	O3 levels	As low as possible	Campaign carried out through a mobile lab according to the Italian law: probe for O3 must be between 1.5 and 4 meters above ground	Once during the project
6	NOx levels	As low as possible	Campaign carried out through a mobile lab according to the Italian law: probe for NOx must be between 1.5 and 4 meters above ground	Once during the project
7	Particulate levels	As low as possible	Campaign carried out through a mobile lab according to the Italian law: probe for PMx must be between 1.5 and 4 meters above ground	Once during the project
21, 22	Traffic flow – peak/off peak	The maximum allowed	No. of vehicles driving the Corridor The measures will be automatically collected	Data will be collected twice during the project, before and after
23, 24	Traffic Density – peak/off peak	Suggested speed for getting the maximum capacity of the Corridor	Sensor occupation rate of the critical section(s) of the Corridor. The measures will be automatically collected	Data will be collected twice during the project , before and after

Measure title: **UTC System in Monza**

City: **Monza** *Project:* **ARCHIMEDES** *Measure number:* **81**

No.	INDICATOR	TARGET VALUE	Source of data and methods	Frequency of Data Collection
24a	Traffic Light Level of Service (LoS)	The capacity of the Corridor	Traffic Light Level Of Service, according to HCM, applying formulas to data manually and automatically collected	Data will be collected once during the project, only “after”

C1.1.3 Planning of before and after data collection

EVALUATION TASK	INDICATORS INVOLVED	COMPLETED BY (DATE)	RESPONSIBLE ORGANISATION AND PERSON
Measuring Operating Costs	2b	Month 40 (only after data)	PA – P.G. Confalonieri
Measuring Capital Costs	2b	Month 40 (only after data)	PA – P.G. Confalonieri
Measuring Maintenance Costs	2c	Month 40 (only after data)	PA – P.G. Confalonieri
Campaign for Air Quality Measurement	5, 5a, 6, 7	Month 24 (only before data)	ARPA (Public Body in charge for Environmental Monitoring)
Measuring Traffic Flow (peak, off peak), “Before”	21, 22	Month 32(before data)	PA – P.G. Confalonieri
Measuring Traffic Flow (peak, off peak), “After”	21, 22	Month 44(after data)	PA – P.G. Confalonieri
Measuring Traffic Density (peak, off peak), “Before”	23, 24	Month 32(before data)	PA – P.G. Confalonieri
Measuring Traffic Density (peak, off peak), “After”	23, 24	Month 44(after data)	PA – P.G. Confalonieri
Computing Traffic Light Level of Service	24a	Month 44(after data)	PA – R. Moro

C1.2 Establishing a Baseline

Before ARCHIMEDES, the performances of the traffic lights system along the Corridor were strictly dependent on the actual traffic light plans coded in the traffic light controllers managing the eight intersections. The Corridor taken into account in this Measure has been depicted in Figure 1 and it can be logically split in two sections, as shown in Figure 2:

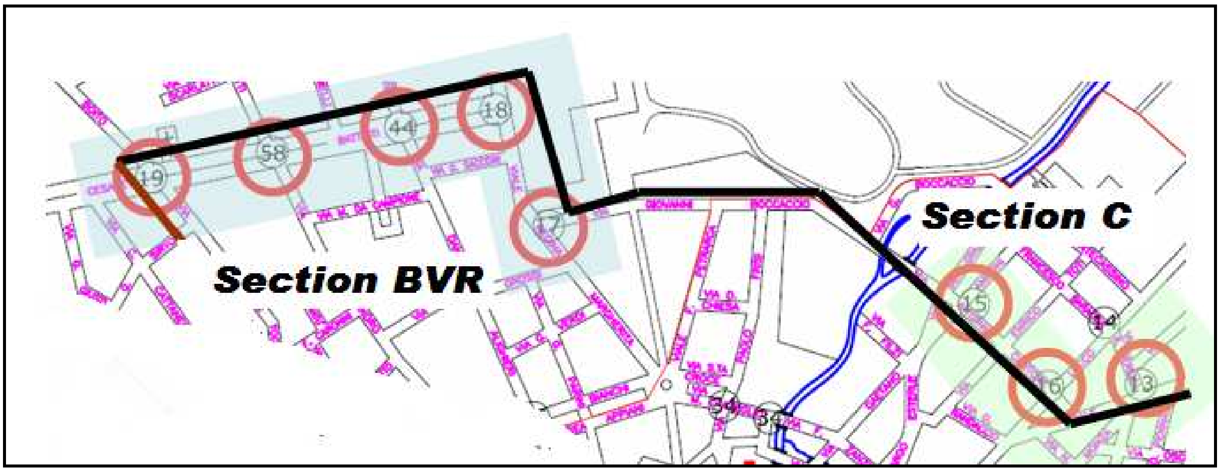

Figure 2 - The two sections of the Corridor for Measure no. 81

- the section called “Battisti-Villa Reale (BVR)” constituted of the five intersections on the left;

- the section called “Cantore (C)” constituted of the remaining three intersections on the right;

The plans managing the Corridor have been improved along time, since this Corridor is very critical for the high demand of traffic travelling on it (please see deliverable T81.1 for further details). The higher criticality concerns the section (BVR) so the most significant part of evaluation will address this section.

The baseline consists of the following situation:

- section BVR (please see Figure 3):

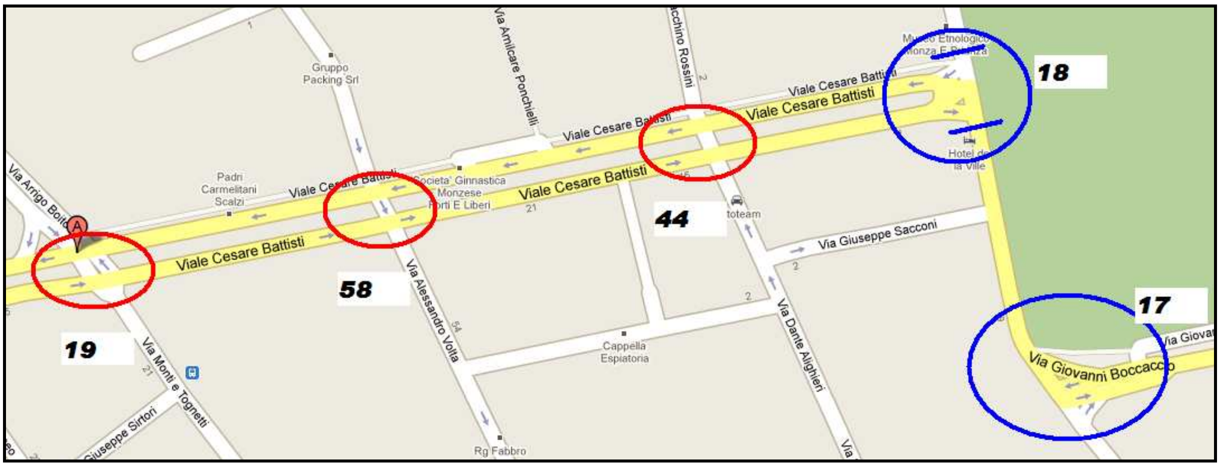

Figure 3 - The Section "BVR, Battisti - Villa Reale"

- The three traffic lights on viale Battisti (no. 19, 58, 44, pointed out by red circles) are neither synchronised nor coordinated

- The two traffic lights close to Villa Reale (no. 17 and 18, pointed out by blue circles) are synchronised and coordinated, since this is the real bottleneck of the entire corridor; the most critical segment is the stretch between the two intersection, as depicted in Figure 4. In addition, very crucial points of these intersections are the two pedestrian crossings that have an important demand throughout the entire day, for access to the Monza Park and to a secondary schools, that are very close to them. During the working days, the traffic light plans used without ARCHIMEDES have a cycle time of 160", causing a very long waiting time for pedestrians and cyclists. Figure 4 also shows the sensors (5094 to 5099) which measure traffic flows and traffic densities used in following sections to evaluate before and after data.

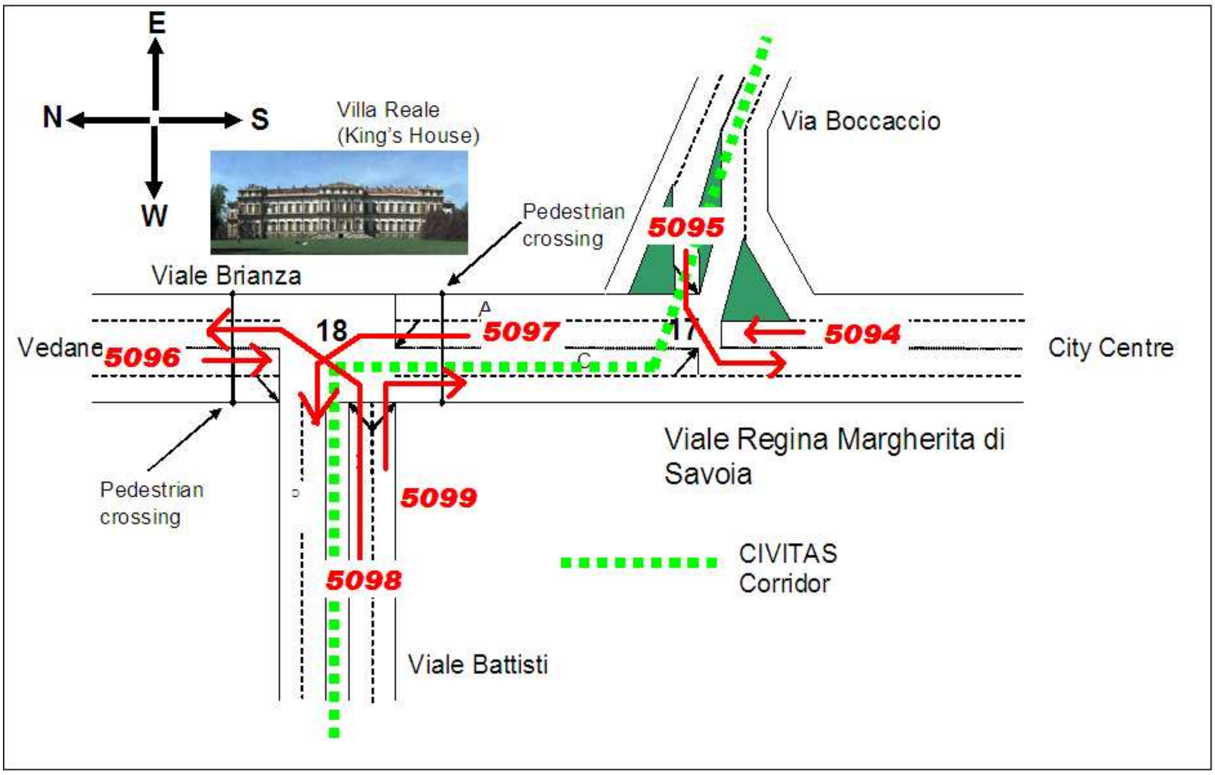

Figure 4 - Details of Villa Reale intersections, no. 17 and 18

- section C: The three traffic light plans are coordinated over a cycle time of 90 seconds, with a green wave in the from West to East. This structure has been confirmed within ARCHIMEDES, but some significant adjustments will be carried out. The central intersection (no. 16) is the most critical one as far as the performances of this section are concerned.

C1.3 Building the Business-as-Usual scenario

Without the implementation of an UTC system, interventions to tune the Traffic Lights system to meet the demand requirements on the corridor are very difficult to pursue; in addition they would require the presence of a technical staff at the intersection.

Therefore, in the Business as Usual scenario, the behaviour of the system remain unchanged: the throughput of the Corridor without UTC has reached since time its upper bound.

This means that changes in the traffic volume wouldn't find, therefore in traffic demand, an appropriate offer in term of capacity on the selected route.

C2 Measure results

The results are presented under sub headings corresponding to the areas used for indicators – economy, environment and transport. The other sections are not relevant with this measure.

C2.1 Economy

In this section, the attention is devoted to costs, as reported in the following table.

Table C2.1.1

Indicator	Before (date)	B-a-U (date)	After (date)	Difference: After –Before	Difference: After – B-a-U
No. 2A: Operating Costs	N/A	N/A	1,440.00 € / year (*) (31st Oct 2010)	N/A	N/A
No. 2B: Capital Costs	N/A	N/A	56,000.00 € (**) (31st Oct 2010)	N/A	N/A
No. 2C: Maintenance Costs	N/A	80.00 €/y	400.00 € /year (***) (31st Oct 2010)	N/A	N/A

(*) 180.00 € per year for comm. line * 8 intersections = 1,440.00€

(**) 5,000.00 € per intersection * 8 intersections for new traffic light controller; 2,000.00 € per intersection * 8 intersections for centralisation through UTC system; = 56,000.00 €

(***) 50.00 € per year * 8 intersections = 400.00€; before centralisation through UTC, standard maintenance activities take 10 € per year * 8 intersections = 80.00 €

C2.2 Energy

Not Applicable.

C2.3 Environment

In this section, the attention is devoted to a set of pollutants which has been monitored. It has to be highlighted that the site is a typical urban one submitted to traffic. The monitored pollutants are:

- Nitrogen Oxides (NOx)
- Carbon Monoxide (CO)
- Ozone (O3);
- Particulate Matter 10 (PM10)

Examining the repository of Regione Lombardia containing pollutants data ("INEMAR1"), at its most recent version dated 2008, the most important contributor for these pollutants is vehicular traffic, at these percentages values:

- Nitrogen Oxides (NOx): 78 %
- Carbon Monoxide (CO): 83,1 %
- Ozone (O3): 57,3 %
- Particulate Matter 10 (PM10): 77,3 %

The results achieved in this measurement campaign show that the concentration levels of measured pollutants strongly depends on meteorological conditions; the data collected in the campaign period have been compared with data collected by permanent measuring points, showing a good correlation degree for pollutants. This means that what has been measured in this campaign with a measurement point set up in the corridor is comparable with the ground values of pollutants across the city of Monza and neighbouring towns.

This leads to the conclusion that this data, measured before the implementation of the measure, can be considered affordable also for the latter stages of the Archimedes project, avoiding to setup another campaign.

As far as the specific pollutants are concerned, the results are reported in Annex 1.

Table C2.3.1: Air Quality Results

Indicator	Before (date)	B-a-U (date)	After (date)	Difference: After –Before	Difference: After – B-a-U
No.5: CO levels	1.35 µg/m3 (*)	N/A	N/A	N/A	N/A
No.5: O3 levels	121 µg/m3 (**)	N/A	N/A	N/A	N/A
No.6: NOx levels	82 µg/m3 (***)	N/A	N/A	N/A	N/A
No.7: Particulate levels	41 µg/m3 (***)	N/A	N/A	N/A	N/A

(*) Please see Figure 8 for details; in table there is the maximum value reached

(**) Please see Figure 9 for details; in table there is the maximum value reached

(***) Please see Figure 7 for details; in table there is the maximum value reached

(****) Please see Figure 10 for details; in table there is the maximum value reached

C2.4 Transport

In this section, the attention is devoted to a set of indicators concerning the impact of traffic.

As described in Section C1.2 ("Establishing a baseline"), the corridor has been split in two sections: The "Battisti-Villa Reale (BVR)" and the "Cantore (C)" section. This section will separately address these sections.

Table C2.4.1 show the comparison between before and after data for the West-to-East route (detector no. 5099) and for the East-to-West route (detector no. 5097)

Table C2.4.1:

Indicator	Before (date)	BaU (date)	After (date)	Difference: After –Before	Difference: After–BaU
No. 21: Traffic flow – peak Detector: 5099	Avg: 80 v/5m Stdev: 15 (Sep, 15th to 27th, 2011)	N/A	Avg: 66 v/5m Stdev: 7 (June 2012)	-14 v/5m After slightly worse than before	N/A
No. 22: Traffic flow – off peak Detector: 5099	Avg: 60 v/5m Stdev: 15 (Sep, 15th to 27th, 2011)	N/A	Avg: 66 v/5m Stdev: 7 (June 2012)	+6 v/5m After slightly better than before	N/A

No. 23: Traffic density – peak Detector: 5099	Avg: 2500/3000 Stdev: 500 (Sep, 15th to 27th, 2011)	N/A	Avg: 2350/3000 Stdev: 250 (June 2012)	-150/3000 After slightly better than before	N/A
No. 24: Traffic density – off peak Detector: 5099	Avg: 2250/3000 Stdev: 500 (Sep, 15th to 27th, 2011)	N/A	Avg: 2000/3000 Stdev: 250 (June 2012)	-250/3000 After better than before	N/A
No. 21: Traffic flow – peak Detector: 5097	Avg: 70 v/5m Stdev: 15 (Sep, 15th to 27th, 2011)	N/A	Avg: 70 v/5m Stdev: 7 (June 2012)	0 v/5m The same	N/A
No. 22: Traffic flow – off peak Detector: 5097	Avg: 60 v/5m Stdev: 15 (Sep, 15th to 27th, 2011)	N/A	Avg: 70 v/5m Stdev: 7 (June 2012)	10 v/5m After better than before	N/A
No. 23: Traffic density – peak Detector: 5097	Avg: 2700/3000 Stdev: 550 (Sep, 15th to 27th, 2011)	N/A	Avg: 2350/3000 Stdev: 250 (June 2012)	-350/3000 After better than before	N/A
No. 24: Traffic density – off peak Detector: 5097	Avg: 2700/3000 Stdev: 550 (Sep, 15th to 27th, 2011)	N/A	Avg: 1950/3000 Stdev: 250 (June 2012)	Avg: -750/3000 After better than before	N/A

General considerations concerning reported data are the following:

- traffic counts in table C.2.4.1 show a quite stationary response. This was widely expected since the project beginning because upstream/downstream flows were close to their saturation value.The Flow-density curve describes this behaviour showing a system stable working point. Moreover the demonstration stage of the new traffic ligth management system took some months to be consolidated. Many slight but important adjustments were carried out mainly to find out the optimal offsets between the two intersections.
- the reduction of the standard deviation in all the situations (both for traffic flow and traffic density for nearly all the movements). This phenomenon is evident at a glance comparing the red points of left picture (“before data”) with the red points of right picture (“after data”); the reduction of standard deviation is a fundamental objective in Statistical Process Control to control processes so this issue is an important result;
- a slightly reduced throughput of the new plans with respect to the former ones for West-to-East route; this is due to then cycle time reduction (160” to 150” in peak hours and to 125” in off-peak hours) and it is particularly evident for detectors 5099 and 5096; this is an acceptable price paid to increase the process control described in the previous bullet and to maintain good throughput levels on other movements.

C2.4.1.2 Study of the Level of Service of the Villa Reale traffic light system

This section is intended to provide a sound evaluation of the Level of Service of the intersection managed by the new traffic light plan developed within the ARCHIMEDES project concerning the bottleneck of the corridor (intersections 17 and 18, close to the "Villa Reale" ancient building), whose traffic data has been shown in the previous paragraph. This indicator has been included in the impact evaluation stage to assess that the final result achieved in terms of coordinated traffic light plans managing the critical bottleneck of the entire corridor achieves satisfactory objectives. This kind of analysis was never carried out before; the comparison between "before" and "after" situations is left to indicators 21 to 24 described in Annex 2 and summarised in the previous section.

Table C2.4.1(b):

Indicator	Before (date)	B-a-U (date)	After (date)	Difference: After –Before	Difference: After – B-a-U
New: Level Of Service (Intersection 17)	N/A	N/A	D (*) (June 2012)	N/A	N/A
New: Level Of Service (Intersection 18)	N/A	N/A	E (*) (June 2012)	N/A	N/A
New: Level Of Service (Intersection 17 and 18 coordinated)	N/A	N/A	C (*) (June 2012)	N/A	N/A

(*) Please see Table 6 and Table 8 below for details

C2.5 Society

Not Applicable.

C2.6 Cost benefit analysis

A Cost Benefit Analysis has been carried out to assess the economic impact of this measure. In particular CBA has been carried out applying the Net Present Value approach over a lifecycle of 10 years that is a typical time horizon for this kind of technological interventions. The equipment purchased has in fact MTBF compatible with this horizon. In the following paragraphs are detailed data used in the formula and a copy of the Excel sheet used for the computations is reported. Such Excel file is available, if needed.

The Discount rate chosen is 5%, a typical value used for this kind of investments.

The most difficult task to accomplish CBA in this context consists of the estimation of monetary values for the revenues expected in the lifecycle horizon. Following the suggestions and the references obtained by POINTER, an important document has been downloaded and analysed. It is the "Handbook on estimation of external costs in the transport sector", produced within the study "Internalisation Measures and Policies for All external Cost of Transport (IMPACT)", Version 1.1, released in Delft on Feb. 2008. Chapter 3 of this document, "Best Practices for Cost Category", has been considered; paragraph 3.1.1 "Type of cost and main drivers" describes that "… Travel time increases constitute the most important component of congestion. Applying standard valuations of travel time losses this category commonly accounts of 90% of economic congestion costs… (page 23)". Mentioning (AFFORD, 2000 - D. Milne, E. Niskanen, E. Verhoef: "Operationalisation of Marginal Cost Pricing within Urban Transport Project AFFORD funded by the EC 4th RTD framework program, Deliverable 1), at page 24, it is stated that "…Bottleneck congestion appears at road junctions, railway stations, ports and airports. Additional user costs are driven by the capacity and load-dependent processing time of the facility, including queuing effects. The kilometres travelled by vehicles are irrelevant for this type of congestion. In road transport, bottleneck effects are most relevant in urban networks". At page 26, a general approach for facing these costs is proposed; in this scheme, the "valuation of travel time savings"; again, at page 28, presenting the list of input values to be considered, it is stated that "…the Value of Time (VOT) is required for translating time losses… into monetary units". Finally, at page 29, some precise references to achieve this are proposed (e.g. UNITE, HEATCO).

Just to mention concrete values, the UNITE approach indicates that the Value of Time for Road Transport is 21€ per person-hour for business (1998) and 4€ per person-hour for private and leisure.

Given these assumptions, the next task consists of getting actual values to be applied in Monza context, in particular on the corridor arranged for this measure; The most significant impact on Travel Time and therefore on its value (VOT) concerns the three traffic lights on viale Battisti (intersections no. 19, 44 and 58; please see Figure 2). Due to the traffic lights centralisation achieved in this measure, a green wave has been implemented, reducing the travel time for a significant number of vehicles travelling on the corridor, as explained later on through this section. The other part of Corridor has not been considered in this CBA since the Transport Analysis carried out in Section C 2.4 has proven that the effectiveness of the new coordinated traffic light plans was mainly on variance reduction and a better management of platoons of vehicles.

Air quality factor hasn't been considered as well, due to the negligible impact of the number of vehicles affected on the total number of vehicle running every day across the Monza and Milan area.

To obtain such actual estimations on VOT, the following item must be computed:

- A) the number of vehicles travelling on viale Battisti, so which can benefit of the new approach;
- B) the estimation of average travel time saving when the approach is effective (e.g. in congested situation, the new control scheme is not effective);
- C) the percentage of such vehicle that can benefit of the green wave in terms of travel time reduction;

At this point, an estimation of the monetary value of VOT can be obtained. It has to be highlighted that for this analysis a reasonable approximation of the value is sufficient to prove the return on the investment done, whose costs are precisely described in the tables in the next paragraphs.

A) As far as the determination of the number of vehicles travelling on viale Battisti, this data can be exactly computed accessing the relational database containing traffic data measured by the inductive loop detectors, as shown in Figure 4.

The distribution of daily data is very stable in working day, as described in section C.2.4.1.1. The exact number of vehicles on the viale Battisti section of the corridor is the sum of vehicles detected by loop no. 5098 and 5099; a query result is proposed in Table 1.

Day	Hour	Det_ID	CNT-5098	Det_ID	CNT-5099	Tot W-E
10	0	5098	57	5099	193	250
10	1	5098	30	5099	80	110
10	2	5098	18	5099	36	54
10	3	5098	7	5099	20	27
10	4	5098	9	5099	47	56
10	5	5098	22	5099	199	221
10	6	5098	111	5099	371	482
10	7	5098	220	5099	719	939
10	8	5098	266	5099	710	976
10	9	5098	244	5099	732	976
10	10	5098	247	5099	670	917
10	11	5098	291	5099	665	956
10	12	5098	266	5099	589	855
10	13	5098	213	5099	560	773
10	14	5098	279	5099	716	995
10	15	5098	277	5099	672	949
10	16	5098	280	5099	718	998
10	17	5098	249	5099	721	970
10	18	5098	300	5099	733	1033
10	19	5098	248	5099	648	896
10	20	5098	133	5099	517	650
10	21	5098	131	5099	369	500
10	22	5098	67	5099	225	292
10	23	5098	50	5099	214	264
					Total	15139

Table 1 - Counting of vehicle on viale Battisti, Sep. 10th, 2012

This means that 15,000 is the number of vehicle that has been chosen to represent the typical flow in viale Battisti for each direction.

B) Travel time saving along a sequence of signal-coordinated intersections can be evaluated, against a baseline case of uncoordinated signals, by a comparison of their "control delays" values. Control delay represents the average delay affecting a vehicle because of signal presence. The comparison makes sense when traffic flow is smooth, i.e. out of oversaturation region. Peak-off hours show this feature.

Under this assumption, Highway Capacity Manual (2000) from TRB (Transport Research Board) defines total control delay as the sum of three terms, with a correction factor PF ("Progression Factor", please see Table 2) on the first:

$$D = PF \times d_{uniform} + d_{incremental} + d_{initial\ queue}$$

From peak-off time assumption, we have $d_{initial\ queue} = 0$; also the random arrival contribution $d_{incremental}$ can be thought as negligible. Thus only the first term is significant. HCM provides (we here quote Exhibit 16-4) a classification of type of traffic arrival processes. We assumed arrival type AT3 for the "uncoordinated signal" baseline case and type AT4 for "coordinated" case.

EXHIBIT 16-4. ARRIVAL TYPES

Arrival Type Description

AT3

Random arrivals in which the main platoon contains less than 40 percent of the lane group volume. This AT is representative of operations at isolated and non interconnected signalized intersections characterized by highly dispersed platoons. It may also be used to represent coordinated operation in which the benefits of progression are minimal.

AT4

Moderately dense platoon arriving in the middle of the green phase or dispersed platoon containing 40 to 80 percent of the lane group volume, arriving throughout the green phase. This AT is representative of favorable progression on a two-way street.

The “Progression Factor”, or PF, represents the type of arrival and the degree of platooning. The lower this factor the better is the flow. The maximum value 1.0 is in connection to the worst case of traffic. Table 2 shows which numerical factors should be used in delay calculation with different type of arrival AT and g/c ratio.

g/c ratio	AT3	AT4
0.40	1.0	0.895
0.50	1.0	0.767
0.60	1.0	0.576

Table 2 - PF (progression factors)

Finally, uniform delay contribution is given by HCM equation:

$$d_{uniform} = \frac{c\,(1-g/c)}{2[1-\min(1,X)\,g/c]}$$

where X = saturation index

c=cycle length

g=green time

In the present case we consider any hour traffic volume as passing through the series of three control delays, as generated by signals. For baseline case AT3/uncoordinated signals delays are all weighted with the worst progression factor 1.0, independently from their g/c ratio. At the contrary, for coordinated case, we use the more favourable PF's in the table, i.e PF=0,895 for intersection 44 and (by interpolation of HCM table values) PF=0,67 for the others.

The difference between AT3/uncoordinated and AT4/coordinated cases yields a "time-saving" value on a "per vehicle" basis. As the target is to get a correspondent money saving we proceed in two steps. First we calculate how many vehicles can benefit of time savings in the two different cases. Thus we have, by definition of arrival type AT4, that a share from 40% to 80% of volumes would benefit of good progression factors and of an effective time saving. With uncoordinated signal, by definition of arrival type AT3, almost the 100% of volumes will suffer the worst progression factor and worst delays as well.

As value of time can be averaged to 12 €/hour (please see paragraph C.2.6.4, with the references to UNITE programme; 12€ is an average between 4€ and 21€, described above); so a daily total saving has been computed, referred to a peak-off time of eleven hours and the West to East travel direction. This is definitely ranging between an upper figure of 80 Euro and a lower of 40. These lower and upper bounds are in strict connection with the AT4 assumption, where a range between 40% and 80% share of total vehicles saves time. Detailed computations are shown in Table 3.

				Time and Money Savings with signal coordination					
travel direction W-E									
peak-off time									
	volume	**AT3**	**AT4**		**Time [hours]**	**saving**	**avg Value of time**	**money savings/day**	
daytime	**veh/h**	**delay/veh**	**delay/veh**	**Δt/veh[sec]**	**Hyp 40%**	**hyp 80%**		**lower bound**	**upper bound**
0	250	42	32	10	0,27	0,54			
1	110	40	30	9	0,11	0,23			
2	54	39	30	9	0,05	0,11			
3	27	38	29	9	0,03	0,05			
4	56	39	30	9	0,06	0,11			
5	221	41	32	10	0,24	0,47			
6	482	45	34	11	0,56	1,13			
subtotal					**1,32**	**2,64**	€ 12,00	€ 15,85	€ 31,70
20	650	50	38	12	0,84	1,68			
21	500	47	36	11	0,60	1,21			
22	292	43	33	10	0,32	0,64			
23	264	42	32	10	0,29	0,57			
subtotal					**2,05**	**4,11**	€ 12,00	€ 24,65	€ 49,30
day total								**€ 40,50**	**€ 81,00**

Table 3 - Detailed computations

Day saving should be expanded over a whole year time, considering 200 days; the same result holds the opposite (East-West) current.

Therefore, considering the minimum gain, 40€/day, 200 days and both directions, the income for each year is:

Yearly expected income = 40 €/day * 200 days * 2 directions = 16,000.00€

From year 2013 on, an important infrastructural intervention will be completed and activated in Monza. This will lead to a reduction of the number of vehicles running on the Corridor. Thus from the second year on, the yearly expected income will be 13,000.00€.

C2.6.1 Evaluation period for CBA

- Defining reference case for CBA: since the reference scenario is the "Do-Nothing" one, including only basic maintenance for the Traffic Light Controllers, the CBA for this measure has been applied considering the capital costs spent for equipping the traffic light systems installed at the relevant intersections; details are described in deliverable R81.1. Summarising, a new cabinet, a new traffic light controller with remote-control capabilities, new centralising devices (industrial PC, access router) have been taken into account. As far as operational costs, the cost of communication lines has been considered; finally, a standard maintenance cost for each intersection has been reported.
- Defining lifetime of the measure: 10 year is the expected lifecycle for the equipment chosen for this intervention.
- Discount rate: the value proposed in the NPV computation is 0.1, a typical value for this type of investments.

C2.6.2 Method and values for modification

- Description of how the impacts are monetised: this issue has been described as introduction to CBA;
- References of values used

C2.6.3 Life time cost and benefit

Table C2.6.1 Capital cost in the evaluation period (not discounted)

	Cases for comparison	Cost (e.g. €200,000)
Year 1	CIVITAS measure	56,000.00 €
	Reference case (or BAU)	-

5,000.00€ per intersection * 8 intersections for new traffic light controllers

+ 2,000.00 € per intersection * 8 intersections for centralisation

Table C2.6.2 Operation cost in the evaluation period (not discounted)

	Cases for comparison	Values (e.g. €200,000)
Year 1	CIVITAS measure	1,440.00 €
	Reference case (or BAU)	-
. .	. .	. .
Year 10	CIVITAS measure	1,440.00 €
	Reference case (or BAU)	-

(180.00 € per year for comm. line * 8 intersections)

Table C2.6.3 Maintenance cost in the evaluation period (not discounted)

	Cases for comparison	Values (e.g. €200,000)
Year 1	CIVITAS measure	400.00 €
	Reference case (or BAU)	80,00 €
. .	. .	. .
Year 10	CIVITAS measure	400.00 €
	Reference case (or BAU)	80.00 €

(50.00 € per year * 8 intersections)

Table C2.6.4 Revenue in the evaluation period (not discounted)

	Cases for comparison	Values (e.g. €200,000)
Year 1	CIVITAS measure	16,000.00 €
	Reference case (or BAU)	-
Year 2	CIVITAS measure	13,000.00 € (*)
	Reference case (or BAU)	-
. .	. .	. .
Year 10	CIVITAS measure	13,000.00 € (*)
	Reference case (or BAU)	-

(*) from 2013 on, major changement in Monza road network will reduce traffic demand on the corridor

C2.6.4 Compare the lifetime costs and benefits

Table C2.6.10 Lifetime cost/benefit of CIVITAS measure (discounted, with rate = 0.05)

	Capital cost	Operation cost	Maintenance cost	Other cost	Reve-nue	Savings from accident reductions	Savings from time Journey savings	Savings from reductions of environmental emissions	Total cost	Total Benefit	Cumulated cost
Year 1	56000	0	0						56000		
Year 2	0	1440	320				16000		1760	13562	-42438.00
Year 3	0	1440	320				13000		1760	10195	-32243.00
Year 4	0	1440	320				13000		1760	9710	-22533.00
Year 5	0	1440	320				13000		1760	9247	-13286.00
Year 6	0	1440	320				13000		1760	8807	-4479.00
Year 7	0	1440	320				13000		1760	8387	3908.00
Year 8	0	1440	320				13000		1760	7988	11896.00
Year 9	0	1440	320				13000		1760	7608	19504.00
Year 10	0	1440	320				13000		1760	7245	26749.00
Total	€ 56.000,00	€ 16.560,00	€ 2.880,00				€ 120.000,00				

Rate:	**0.05**	PV	NPV	Oper/Maint costs	Income	Mnth-amoun
Year	Act rate:					
0	1	-56000.00	-56000.00	-56000.00	0.00	-56000.00
1	1.05	13562.00	-42438.00	1760.00	16000.00	14240.00
2	1.1025	10195.00	-32243.00	1760.00	13000.00	11240.00
3	1.1576	9710.00	-22533.00	1760.00	13000.00	11240.00
4	1.2155	9247.00	-13286.00	1760.00	13000.00	11240.00
5	1.2763	8807.00	-4479.00	1760.00	13000.00	11240.00
6	1.3401	8387.00	3908.00	1760.00	13000.00	11240.00
7	1.4071	7988.00	11896.00	1760.00	13000.00	11240.00
8	1.4775	7608.00	19504.00	1760.00	13000.00	11240.00
9	1.5513	7245.00	26749.00	1760.00	13000.00	11240.00

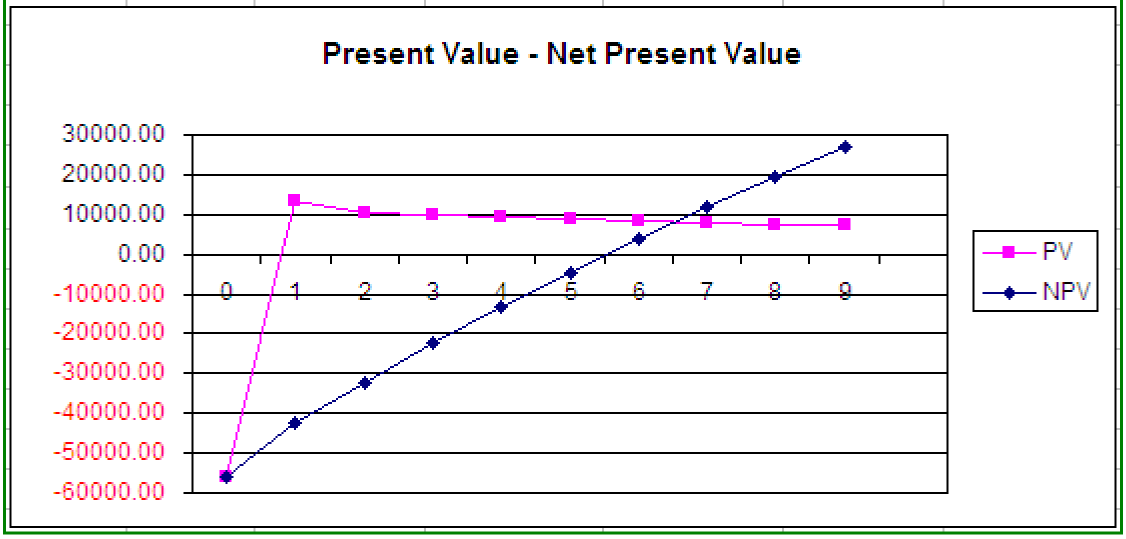

Figure 5 - CBA formulas and results from the Excel sheet

C2.6.5 Summary of CBA results

CBA shows that, under the assumptions presented in the previous paragraphs, the benefits are much higher than the incurred costs.

C3 Achievement of quantifiable targets and objectives

No.	Target	Rating
21-22	Traffic flow (peak-off peak) – + 5% - Please see Table C 2.4.1	**★ (1)**
23-24	Traffic density (peak-off peak) – -20% - Please see Table C 2.4.1	**★ (2)**
24a	Level of Service of the intersection/Corridor – “C” - Please see Table C 2.4.1b	**★ (3)**

NA = Not Assessed O = Not Achieved ★ = Substantially achieved (at least 50%)
★★ = Achieved in full ★★★ = Exceeded

(1): from a quantitative point of view, traffic flow is slightly increased with less variance (behaviour more stable along the entire day) and shorter traffic light cycle time (160” to 150” peak, 160” to 125” off-peak) with reduced waiting time for pedestrians and cyclists

(2) from a quantitative point of view, density, estimated by sensor occupation rate, has been reduced by 20% (aggregate value considering all detectors measuring flow and occupation rate); please see Annex 2 for detail

(3) Level of service due to the accomplishment of the measure, according to HCM, is “C” - please see Table 2.4.1(b)

C4 Up-scaling of results

To understand the impacts of the measure if it were applied to a larger area or number of services etc. the observed results need to be up-scaled.

What achieved in Measure no. 81 can easily be upscaled, extending the number of intersections included under the control of the UTC system.

Being the UTC system is operational, it is quite easy to add new intersections to the UTC. The process of adding a new intersection to the system requires the steps described in the MLEP: revamping of Traffic Light Controller, installation of an industrial PC, establishment of a Communication Line with the UTC Server, plan coding, configuration of the new intersection in the UTC system, test.

As stated in the DoW, Monza has about 80 intersections equipped with Traffic Lights; there is no coordinated control at the moment even if a significant number of such intersections are equipped with inductive loops to optimise local control. This means that several other important intersections could be brought under the control of the UTC system, creating new corridors.

Measure 82 will require a set of such intersections that are going to be added to the UTC; the choice concerns intersections where the number of Public Transport lines crossing such intersections is significant.

Should the result of the UTC implementation in Archimedes be positive, further corridors will be identified, the relevant intersections equipped and connected to the UTC.

For the next version (D-deliverable) it should be considered what would be a relevant scale for Monza considering the road network and the intersections equipped with traffic lights and how this larger scale would impact on the performance indicator (especially the indicators for economics).

C5 Appraisal of evaluation approach

As far as the evaluation approach is concerned, the availability of inductive loops equipping the intersections 17 and 18, that have been centralised through the UTC system, allowed to analyse very precise data concerning counting of vehicles and occupation rate if the loops themselves, both before the activation of the measure and after it.

To evaluate the level of service of the coordinated traffic light plan of the bottleneck of the entire corridor as well as to provide an accurate CBA, mathematical formulas from HCM have been applied, after on site data collection.

Without the automatic collection of data it would have been more difficult to prove the goodness of the new plan as well as the reduction of standard deviation. Due to the huge quantity of vehicles measured and the availability of measured data, the statistical analysis of such data has been found an effective approach; this means that data contains much information and the effort done, which could be referred to as essential “data mining”, has been fruitful.

In addition, this kind of analysis could be repeated in future, as demand change is expected to happen, due to important road infrastructure that will be activated within one year.

C6 Summary of evaluation results

The following key results have been achieved through the evaluation session for this measure:

- there has been a significant improvement of the performances of the corridor, especially through the regularisation of the behaviour in peak-hour; please see Table C 2.4.1 for the summary of results and Annex 2 for details. Cycle time reduction from 160” to 150” at peak hours and from 160” to 125” in off-peak hours has produced the effect of a better regularisation of platoons, measured through a reduced variance without worsening the overall performances and reducing waiting times for pedestrians and cyclists.
- the benefits, obtained estimating the Value of (saved) Time through the standard reference table are greater than the incurred costs; this has been assessed through CBA; in particular, Table C 2.6.10 shows that after seven years the incurred costs are covered and the other three years generate a return on the investments accomplished.
- the level of service of the bottleneck part of the corridor got a good ranking, according to the HCM. This indicator is another way to assess and therefore to confirm the benefits obtained by the application of the new coordinated traffic light plans; details and formulas can be found in Annex 3.

The quantitative approach to analyse traffic data and the mathematical analysis applying HCM reference formulas have been considered.

C7 Future activities relating to the measure

As far as the measure is concerned, through measure no. 82 the centralisation of traffic light has been extending to other important intersections. The centralisation achieved in Archimedes through this measure has been the first systematic and complete approach to coordinate traffic light on a very important corridor of the city.

As far as longer terms of evaluation of the impacts generated by this measure, as reported in the former paragraph, the capability to store in a relational database the traffic data collected will allow to easily re-evaluate the behaviour of the system in subsequent time, both to assess the stability along time of the system effectiveness and to check its goodness against important variations of the traffic demand.

D Process Evaluation Findings

D.0 Focused measure

	1	The expected impact on the transport system, environment, economy and/ or society / people is very high
	2	The measure as enabling factor to apply priority at intersections for Public Transport fleet
	3	The measure fits into the city policy towards sustainable urban transport and / or towards sustainability in general

D1 Deviations from the original plan

There have been no deviations from the original plan.

D2 Barriers and drivers

D.2.1 Barriers

Preparation phase

- **BP_1. Barrier Field: 4 (Problem related) Technical issues, positively solved:**
  - Upgrading of Traffic Light Controllers (TLC) through specific vendor,
  - Partial revamping of traffic lights intersections, making each movement (pedestrian, vehicle) independent from each other, to ensure the capability to turn green light on with the maximum freedom;
  - Procedures to activate UMTS communication lines to connect each intersection with the control centre

Implementation phase

- **BI_1: Barrier Field: 8 (Organisational) Organisational problems, positively solved:**
  - Because of the new approach proposed, the current know-how of key measure persons in the Traffic Dept of the Municipality was not adequate to the new need; specific sessions, including Learning History Workshops have been held
  - Three different external suppliers had to agree on a shared plan to coordinate their intervention to make the system operational
  - Need to spend much time in critical peak hours to assess the goodness of the traffic light plans to fulfil the expected objectives

Operation phase

- **BO_1: Barrier Field: 8 (Organisational) Organisational problems** – The system has been made operational as expected but not all the persons in charge at the Local Police, that sometimes are called for emergency interventions at the intersections of the corridor, are aware of the new system. In particular, this means that commands to be issued to the new system to set a traffic light at Flashing Amber state are not yet provided through the specific software interface but with manual interventions, opening the cabinet and exposing new electronic devices to the rain or other possible sources of damage. Specific Training and Learning sessions will be held in Fall 2012 to overcome this lack of knowledge.

D2.2 Drivers

Preparation phase

- **DP_1: Driver field: 1 (Political) Political commitment** – Strong political commitment of Mobility Deputy Mayor to implement the measure in order to improve the capacity of the road network
- **DP_2: Driver field: 3 (Cultural) Cultural driver**: High expected acceptance of the measure by city users and by commuters, expecting since time a better coordination of the traffic lights of neighbouring intersections

Implementation phase

- **DI_1: Driver field: 8 (Organisational) Organisational commitment** – Willingness to make the technical components operational as important prerequisite to tune the traffic light plans

- **DI_2: Driver field: 4 (Problem related) Need of Traffic Data,** as way to measure the traffic flows and to support the adjustments on traffic light plans; this has been done enabling collection of data in a relational database

Operation phase

- **DO_1: Driver field: 8 (Organisational) Organisational issues** – This measure has a high level of innovativeness with respect to the knowledge required to traffic and mobility experts of the Municipality to manage traffic light system as an effective way to tune the actual mobility offer in the city. The availability of several traffic light plans and different coordination policies allow to implement traffic control strategies to face the different traffic conditions and evolution
- **DO_2: Driver field: 8 (Organisational) Organisational issues for the future –** In Spring 2013 a great evolution of the road network in the city of Monza is expected, due to activation of the new West Ring through a new 2 km long tunnel. This will lead to a reallocation of the traffic across the road network; the availability of the Urban Traffic Control system to easily configure and activate new traffic control strategies will allow fast reaction time in managing the new traffic scenario.

D.2.3 Activities

Preparation phase

- **AP_1: Activity Field 4 (Problem related) Completion of the research study** – The research stage has been dedicated to the study of traffic control strategies that can be made operational through this measure; microsimulation tasks have been accomplished to simulate the effects of such new strategies on the network, assuming several demand values entering the corridor, to assess the expected behaviour of the system in critical situations

- **AP_2: Activity Field 4 (Problem related) Testing in lab of the equipment to be installed on the street** – The stage has been carried out before starting implementation, as described in details in deliverable R81.1

Implementation phase

- **AI_1: Activity Field 4 (Problem related) Installation of the equipment for traffic light centralization** – The equipment positively tested in the lab have been installed in the cabinets where the traffic light controllers are present. Also the wireless access router with the SIM card have been installed, in order to enable the communication between the control centre and the traffic light controllers; details are described in deliverables R81.1 and T 81.1.
- **AI_2: Activity Field 4 (Problem related) Traffic light plan coding** – Traffic light plans for applying traffic control strategies as made available by the new coordinated and centralised approach has been developed; details are described in deliverable T 81.1

Operation phase

- **AO_1: Activity Field 4 (Problem related) Activation of the system –** focusing on the several groups of intersections involved, the new traffic light plans have been applied, adjusted and evaluated (please see the other section of this document)
- **AO_2: Activity Field 4 (Problem related) Analysis and tuning of the system -** the system has been made operational, but slight adjustments have been applied to tune the traffic light plans to face all possible conditions

D3 Participation of stakeholders

D.3.1. Measure Partners

- **Comune of Monza** – Mobility and Transportation Department of the Municipality has defined the guidelines for traffic control strategies (which carriageways have to be preferred, which coordination schemes have to be applied depending on the different traffic profiles…)
- **Project Automation –** Project Automation, as ARCHIMEDES technical partner, has ensured all the support needed in all the stage of the measure; design, implementation, testing, evaluation and tuning;

D.3.2 Stakeholders

- **Car drivers (commuters, city users, citizens) –** They can now find an optimal management of the traffic light system for the corridor;
- **Pedestrian and Cyclists –** A reduction of the cycle time of the traffic light plans (160” to 150” at peak traffic conditions, 160” to 125” at off-peak traffic conditions) at the critical bottleneck of the entire corridor (intersection no. 18 close to Villa Reale) resulted in a reduction of waiting time;

- **PT operators –** At the critical bottleneck of the entire corridor (intersection no. 18 close to Villa Reale), better performances affect also Public Transport.

D.4 Recommendations

D.4.1 Recommendations: measure replication

- **Planning**. Traffic light management is an important leverage to accomplish traffic control strategies in urban road networks; dissemination actions will help other cities to realize this concept so other cities can plan the adoption of thus approach;
- **Support measures**: training programs will help traffic experts and local policemen of the municipalities to manage traffic lights in effective way through this system;
- **Full scope of the measure**: A centralized mobility centre may be very helpful to provide tools and techniques to manage all the aspects of urban mobility in ITS perspective (demand management, variable message signs to provide real time information, parking policy, access control to city centres, traffic measurement,…).

D.4.2 Recommendations: process

- **Planning**. Effective urban mobility management requires a strong cooperation with other public bodies in charge with territorial planners on wider scale (Regione Lombardia, Province of Monza e Brianza, City of Milan with is the destination of thousands of trips every working day,..)
- **Knowledge deployment:** training programs will help traffic experts and local policemen of the municipalities to manage traffic lights in effective way through this system;
- **Dissemination to stakeholders**: The results achieved need to be shared with local population, city users and local media (traditional and Web newspapers) to spread across the city the consciousness that important mobility processes tare managed

Annex 1 – Details of Air Quality Campaign

Nitrogen Oxide (NO)

The highest hourly average concentrations have been gathered in the periods where the dispersion capacity of pollutants is poor, due to the lack of wind.

In working days, the typical distribution shows a bimodal behaviour in correspondence of morning and evening traffic peaks.

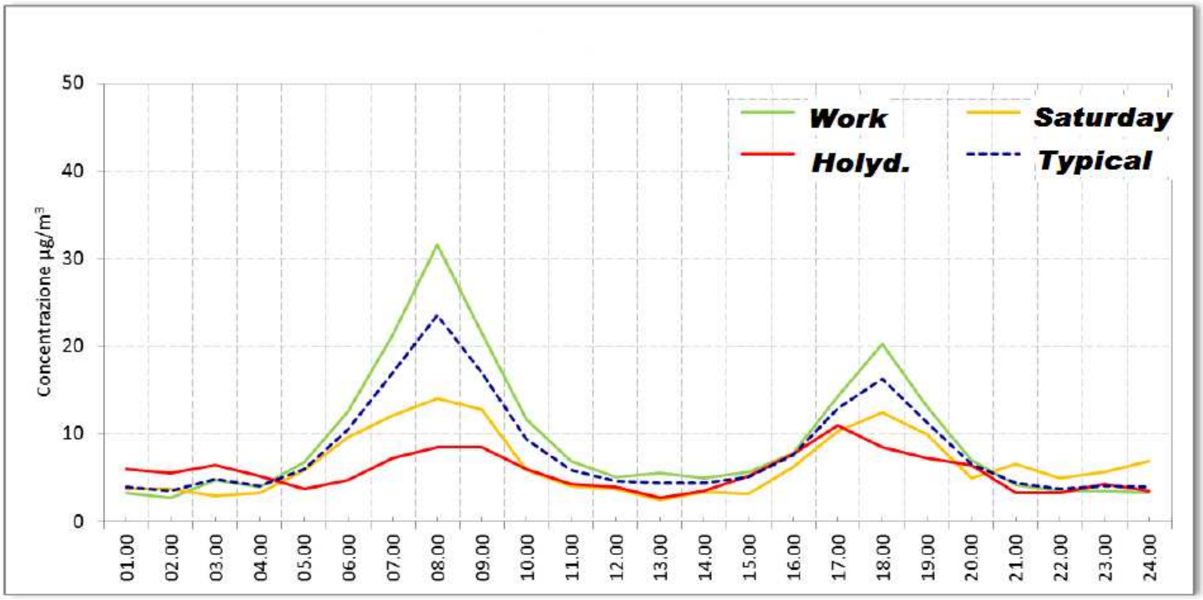

Figure 6 - NO Concentration

Nitrogen Dioxide (NO2)

The typical behaviour shows a limited variation of daily concentrations; as for NO pollutant, in morning and evening traffic peaks values are higher. In holydays and Saturdays, the daily trend is similar but with much lower values.

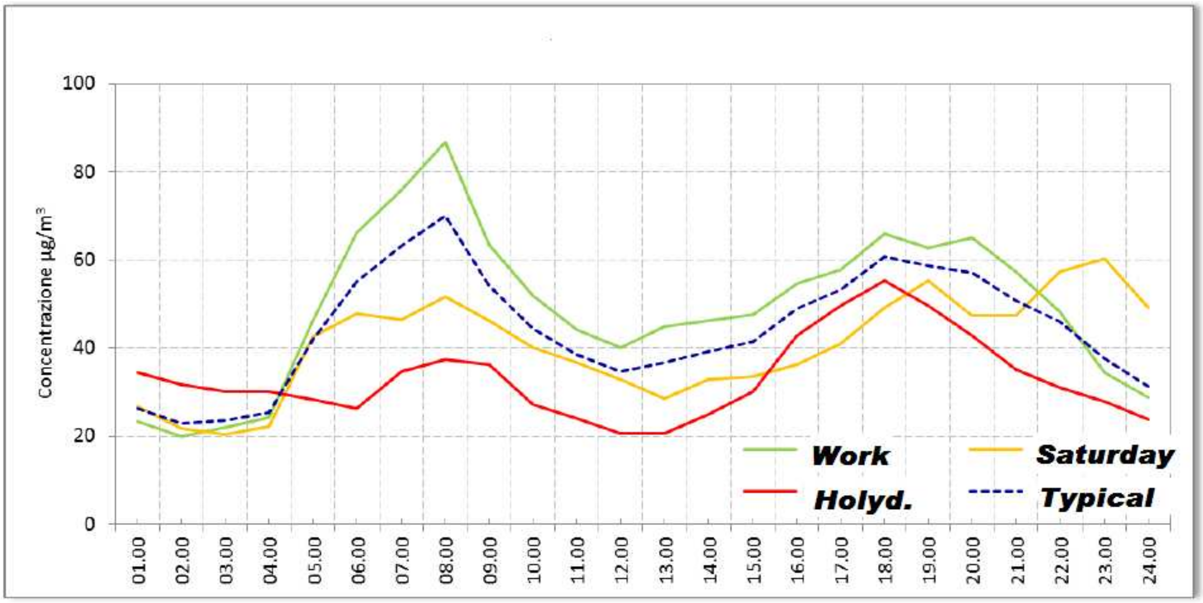

Figure 7 - NO2 concentration

Carbon Monoxide (CO)

The typical behaviour shows a limited variation along the day: concentration remains substantially constant; there is only a slight increase in the morning peak traffic hours.

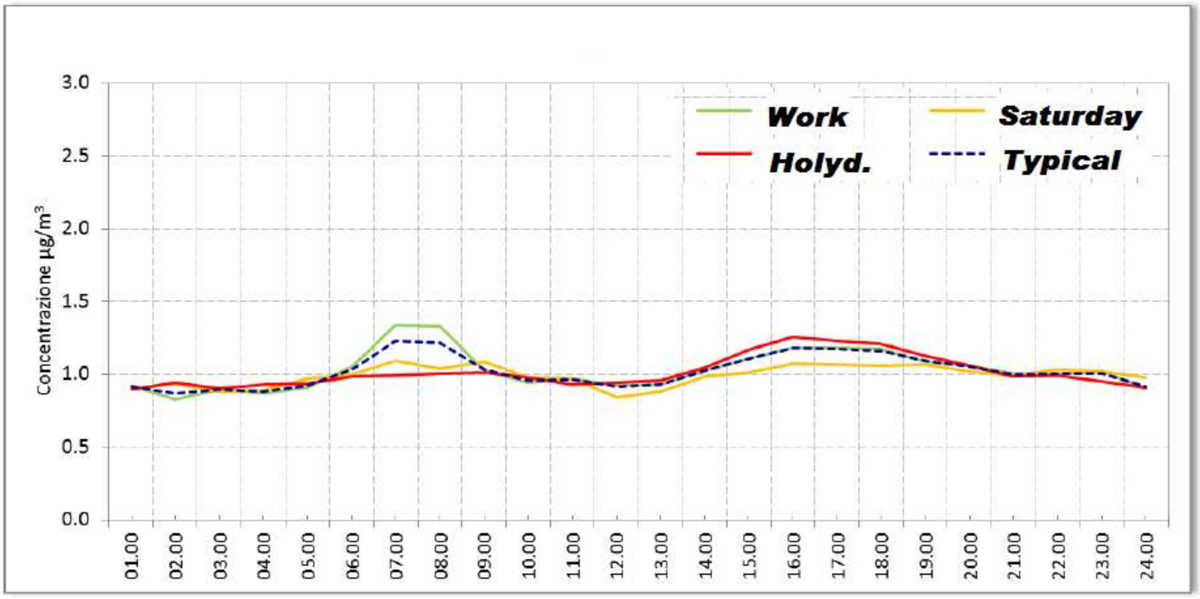

Figure 8 - CO Concentration

Ozone (O3):

The picture reports an increase of values at the first hours of the day, due to the NO reduction; a second and stronger peak is reported when the sunstroke is higher, i.e. at the central hours of the day, independently of day of the week.

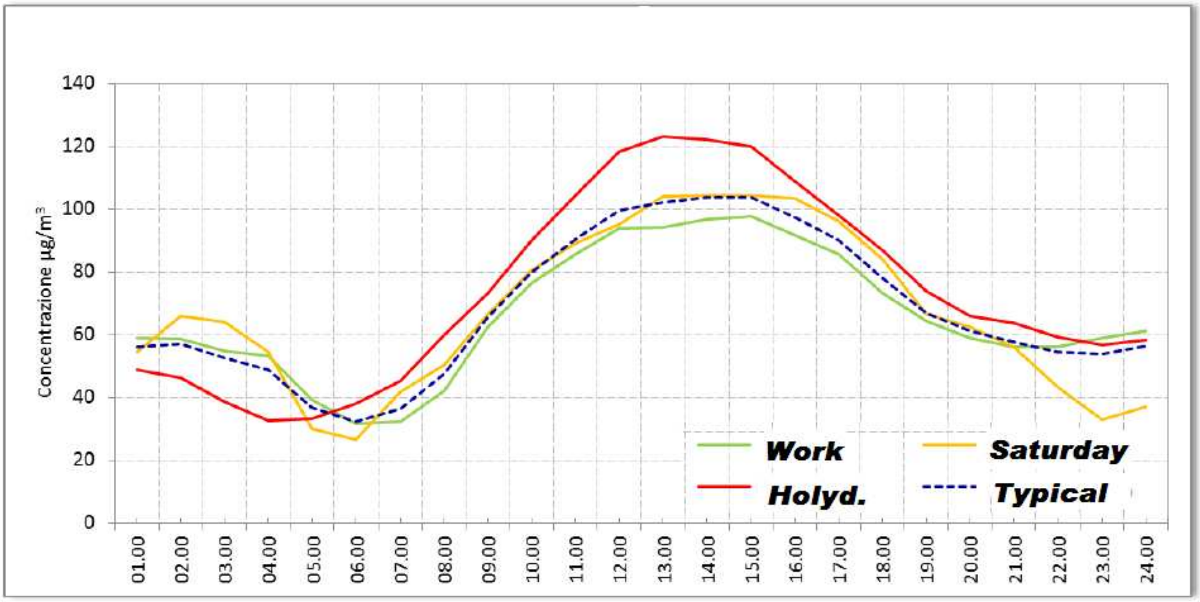

Figure 9 - O3 Concentration

Particulate Matter 10 (PM10)

The PM10 distribution doesn't show correlation with traffic behaviour (please see Figure 10) but it shows a very strong correlation with other measurement points spread across the area where Monza is located (please see Figure 11, where the results of an analysis carried out last January). This means that the contribution of local traffic is negligible with respect to the geographic position of Monza.

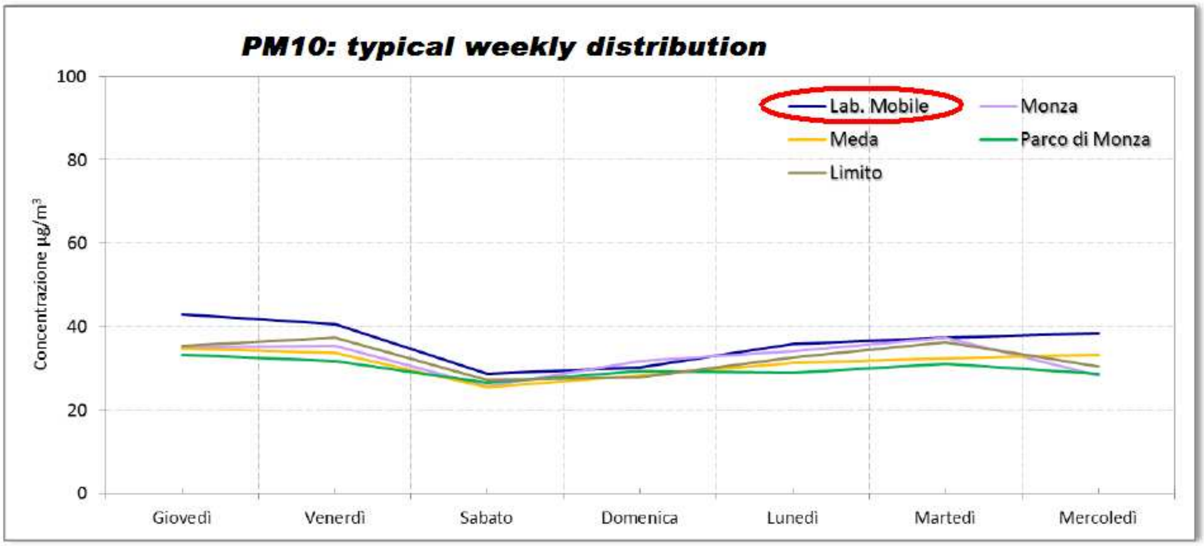

Figure 10 - PM10 weekly distribution

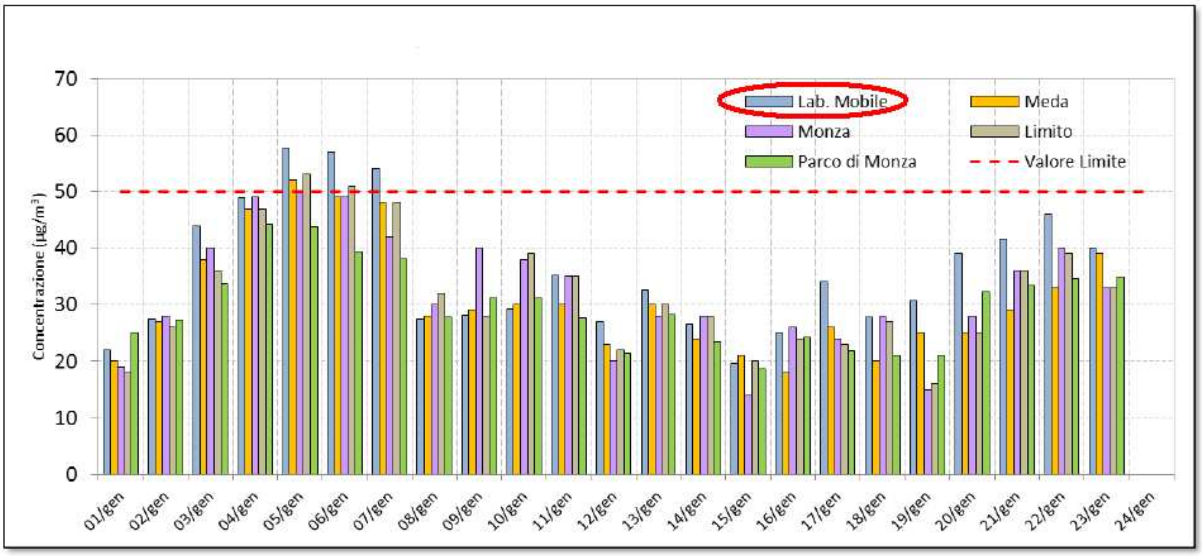

Figure 11 - PM10 correlation among different measurement points

Annex 2: Transport: details about traffic flow and density along the corridor

A 2.1 Battisti-Villa Reale (BVR) Section: analyses on traffic data

Within this section, the most critical point of the corridor, i.e. the "Villa Reale" node, consisting of the two related intersections 17 and 18, is analysed. Since this is the bottleneck , the impact analysis has been carried out in detail for this node. After these considerations, the other part of the section is addressed (intersections 19, 58 and 44). The presence of inductive loops at intersections 17 and 18 to tune the performances of the traffic light plan has been exploited to automatically gather the measure for indicators 21 to 24, as depicted in table C2.4.1. The exact localisation of these loops is shown in Figure 12.

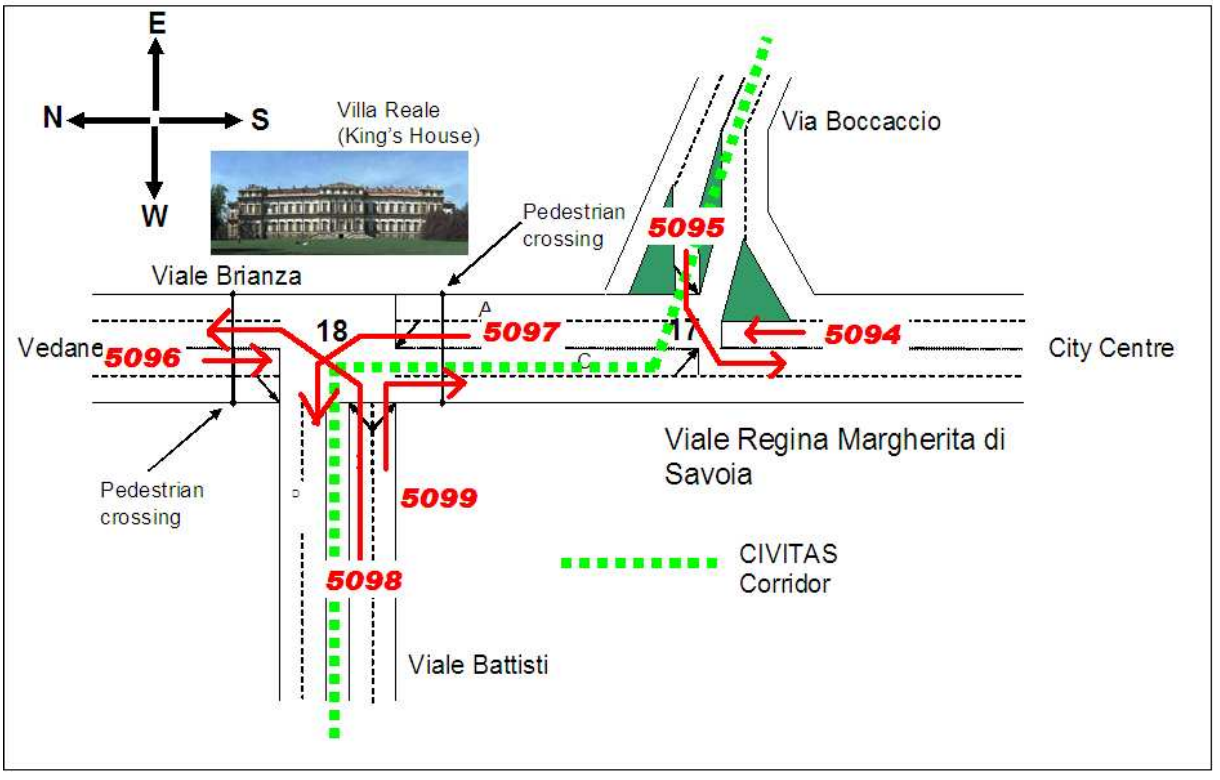

Figure 12 - Inductive loops at Villa Reale node

Following, couples of pictures are reported to show the traffic flow (vehicle counts, indicators 21 and 22) and the occupation rate (estimators of the traffic density, indicators 23 and 24), detected by the relevant detectors before and after the introduction of the new traffic plans (before data in the picture on the left, after data in the picture on the right).

Peak and off-peak data are reported in the same chart, since each plot shows on the x-axis the 288 5-minutes slots of every day (24 hours * 12 5min slots).

Each pictures is commented emphasizing the detected traffic behaviour before and after the intervention focusing on working days. On Saturdays, Sundays and holydays, no specific problems were reported, since the traffic is very calm.

The analysis concerning before data has been carried out using data collected in ten working day from Sep. 15th 2011 on, i.e. when all the degrees of school restarted their activity, avoiding the days when the new traffic plans developed in Archimedes were active. The analysis of the new traffic plans has been carried out using data collected in the working days in March, April, May and June 2012.

Data are presented through mean (blue pattern) and standard deviation (red pattern). This means that each blue point represents the sample mean of all the observations collected in the working days of selected period at a given 5min slot (e.g. 9:10am). For example, the sample of "after data" consists of about 60 observations (60 working days in the three months considered).

The red point shows the standard deviation of the same sample.

The greatest quantity of vehicles has been measured by detector no. 5097 in the East-West direction of the corridor and by detector no. 5099 in the West-East direction. The other detectors measure flows of vehicles that must however be taken into account to ensure that such other movements are not submitted to long waiting time. This holds especially true for detector no. 5096, which measure a flow very important in the morning and less critical elsewhere.

The new traffic light plans have been aimed at the following objectives, as reported in depth in the deliverable T81.1:

- strong coordination between traffic light no. 17 and traffic light no. 18; the reason is that the region between them is the most critical one and spillbacks must be avoided; with the former plans, in morning peak hours of the working days, the spillback generated by traffic light no.17 toward no. 18 occupied the intersection area of intersection no. 18; the consequences of this problem caused jams on the corridor in the West to East direction (detector 5097);
- too long cycle time, causing pedestrians and cyclists long waiting time with the possibility that some of them could cross the intersection with the red light;

These objectives are in the "after data" reported below and will be highlighted.

A 2.1.1 Corridor in West to East direction (Detector 5099)

The pictures in Figure 13 and in Figure 14 show the traffic behaviour detected on the Corridor in the West-East direction. Each graphic has on the x-axis the 288 (24 hours x 12 5-min slots per hours) "5-min" slots in the day; on the y-axis are reported the values of the mean (blue markers) and of the standard deviation (red markers) of the relevant value (traffic count in the first graphic of the pair, occupation rate in the second graphic of the pair).

Examining in detail the pictures in Figure 13, the blue markers plot a typical "M" shape: the number of vehicles has a very detailed peak in the morning, then the number of vehicles remains quite high up to mid afternoon; then the count decreases, then raises up again at evening peak hour, although this peak is lower than the morning one.

Before data shows a slight reduction on the maximum value of the vehicles but a more concentrated standard deviation. In morning peak hour the movement measured though detector no. 5099 get less green time than in the original plan. This is a design choice, adopted to leave more room in the buffer between intersection no. 18 and intersection no. 17 to avoid the identified problem of spillbacks occupying the area of intersection no. 18 which stop the left turn from viale Regina Margherita to viale Battisti (Corridor, West-East).

Benefits from this choice are clearly visible in Figure 15.

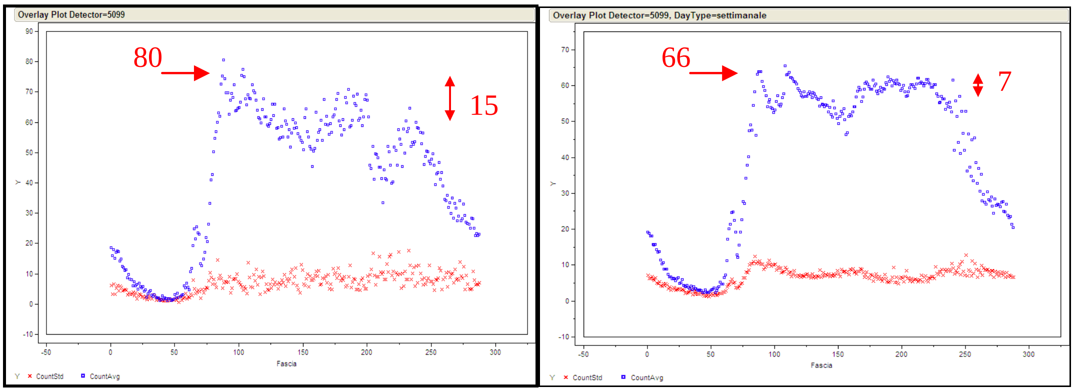

Figure 13 - Detector 5099 (Corridor, West to East), vehicles count, before (left) and after (right)

As far as the occupation rate is concerned, the value on the y-axis represents the number of seconds over a period of 3000 seconds (5 minutes) the detector resulted busy. Figure 14 shows that after data reports lower and more concentrated density values.

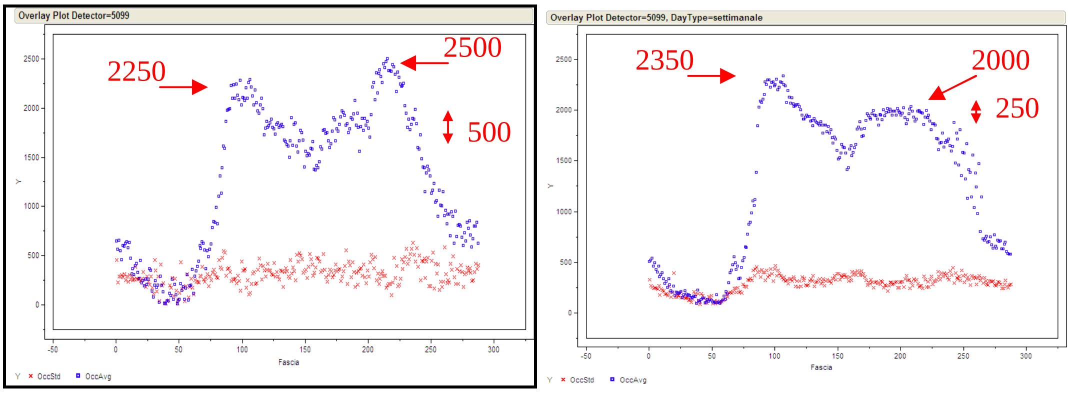

Figure 14 - Detector 5099 (Corridor, West to East), detector occupation rate, before (left) and after (right)

A 2.1.2 Corridor, East to West direction (Detector 5097)

The pictures in Figure 15 and in Figure 16 show the traffic behaviour detected on the Corridor in the East-West direction.

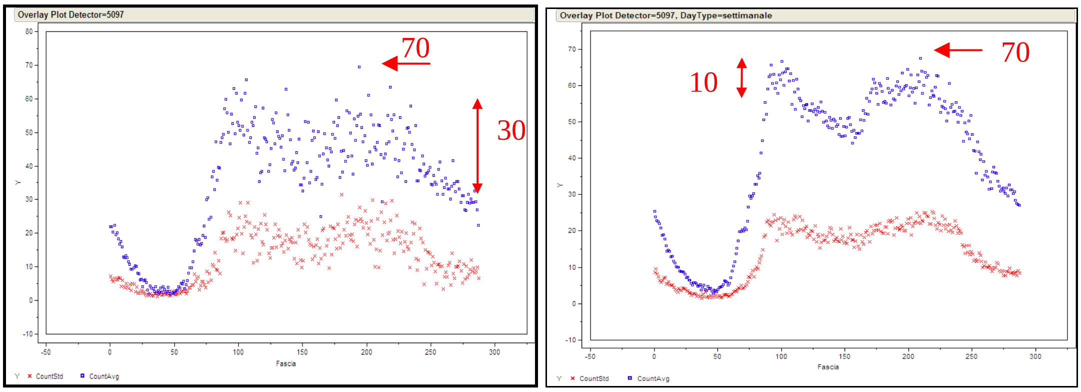

Figure 15 - Detector 5097 (Corridor, East to West), vehicles count, before (left) and after (right)

After data show a more concentrated shape with the same nominal value.

As far as the occupation rate is concerned (please see Figure 16), the variability of "after data" is reduced along the entire day.

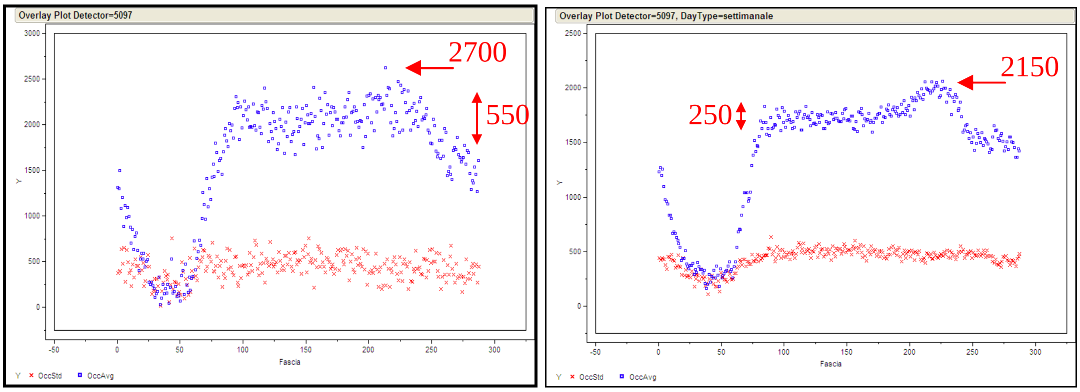

Figure 16 - Detector 5097 (Corridor, East to West), detector occupation rate, before (left) and after (right)

The third movement to be considered is the one coming from the North at intersection no. 18, measured by detector no. 5096. As widely stated in deliverable T81.1, the stretches between intersections 17 and 18, in both directions, are the major constraint of the entire corridor.

In the new traffic light plan the green time for this movement has been slightly reduced; this leads to a slight reduction of maximum vehicle throughput (please see Figure 17) that prevents spillbacks in the area of intersection no. 18 and allows a better global performances for the entire corridor.

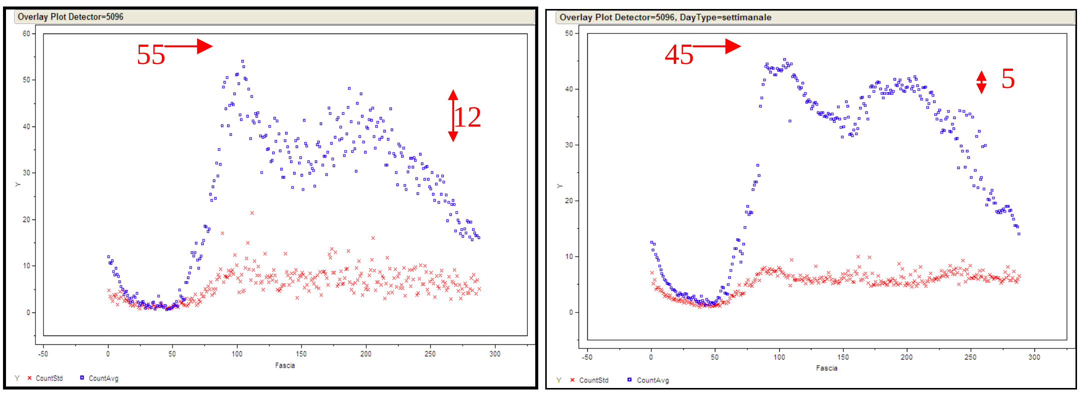

Figure 17 - Detector 5096 (from North), vehicles count, before (left) and after (right)

The density (please see Figure 18) is lower in the "after data" than in "before data".

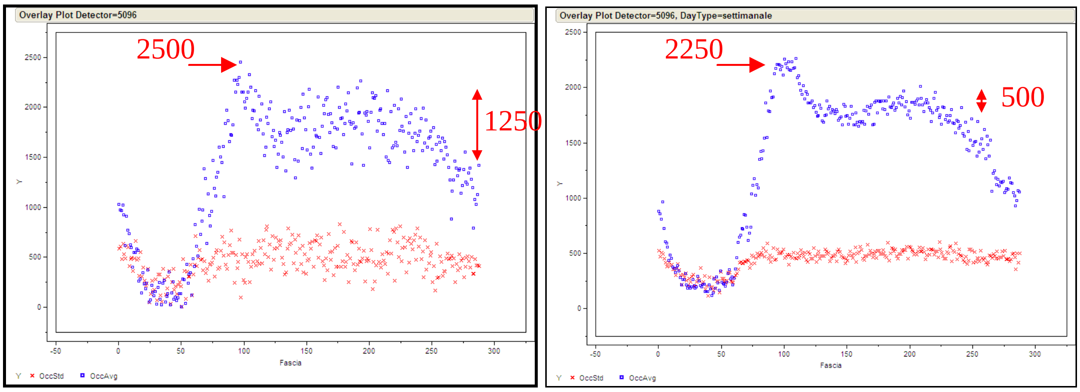

Figure 18 - Detector 5096 (from North), detector occupation rate, before (left) and after (right)

The other three movements shown in are less important in term of number of vehicle counts; nevertheless they have to be considered to avoid that vehicles wait for the green light for too long time. "Before data" and "after data" are substantially the same (please see Figure 19).

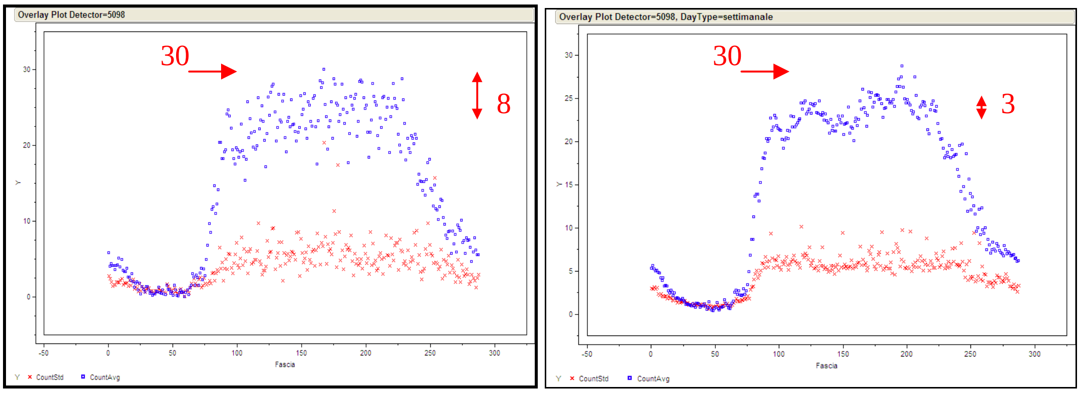

Figure 19 - Detector 5098 (from West to North), vehicles count, before (left) and after (right)

The density is lower and more concentrated in after data (please see Figure 20).

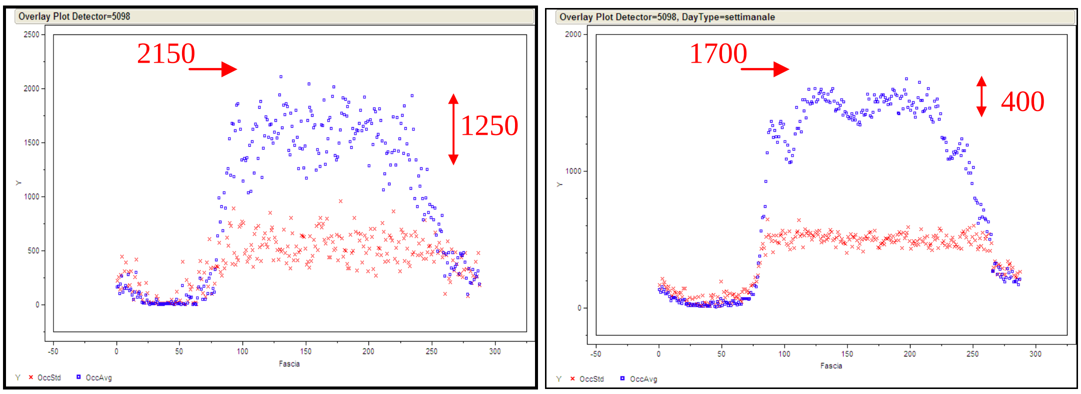

Figure 20 - Detector 5098 (from West to North), detector occupation rate, before (left) and after (right)

The last two movements concern intersection no. 17; data measured by detector no. 5095 represent vehicles that leave the corridor travelling toward the centre of Monza; data measured by detector no.

5094 concern vehicles coming from the centre of Monza that enter the corridor in the North o West direction.

Both these movements are much less important than the previous ones; they are reported to show that the actions carried out to increase the performance on the corridor have not affected them. Please see Figure 21 and Figure 22.

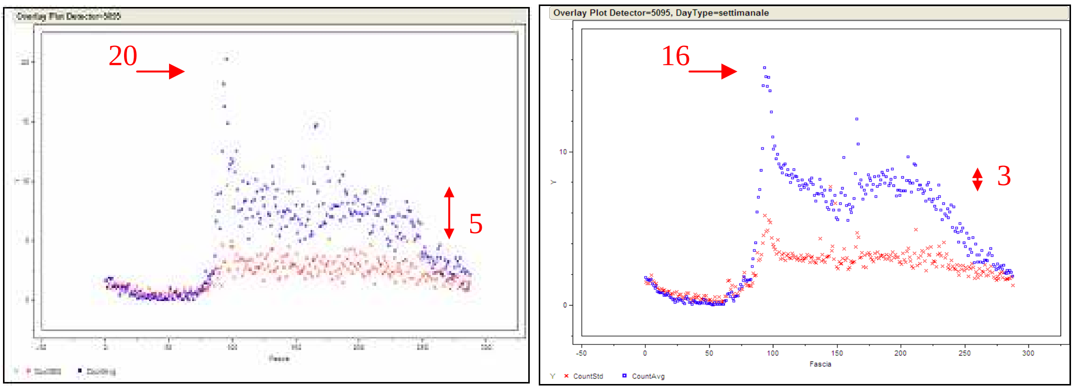

Figure 21 - Detector 5095, vehicles count, before (left) and after (right)

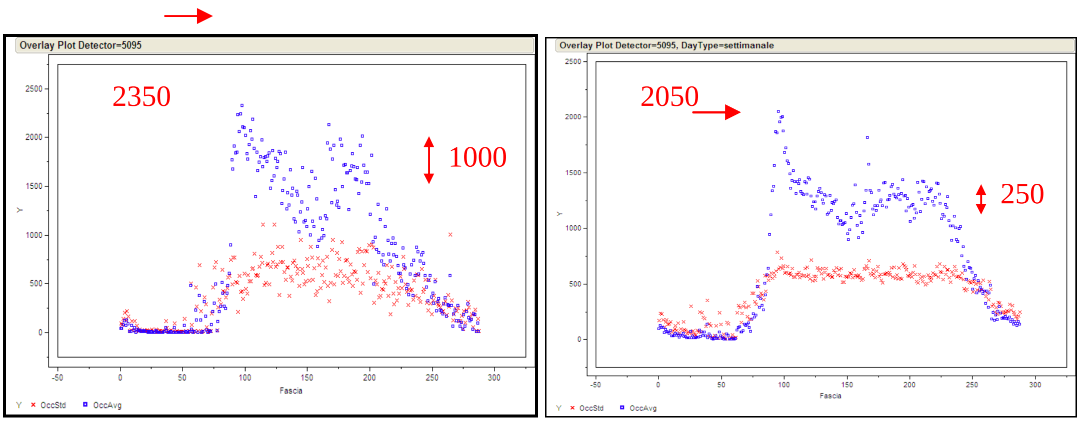

Figure 22 - Detector 5095, detector occupation rate, before (left) and after (right)

As far as detector 5095 is concerned, the average count is limited to 10 vehicles/5m, except the morning peak situation, where the throughput of 15/20 vehicles/5m can be reached.

The last picture reported (Figure 23) describes the number of vehicles leaving the centre; the maximum throughput is reached at evening peak hours. No substantial differences hold between before and after data.

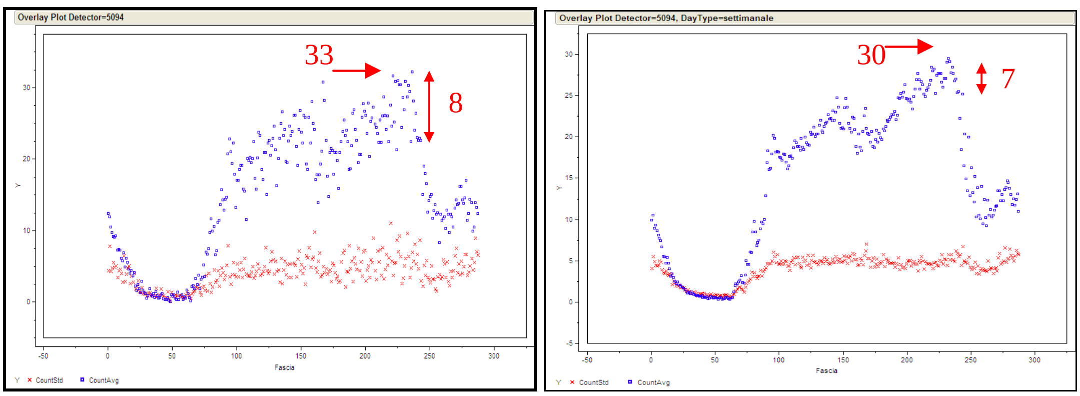

Figure 23 - Detector 5094, vehicles count, before (left) and after (right)

In order to show the difference traffic profiles for non working days, a picture is reported in Figure 24; this picture refers to the Corridor and must be compared with **Errore. L'origine riferimento non è stata trovata.**, copied here for the sake of simplicity as Figure 25 while comparing them together. While in working days the maximum throughput is reached at morning peak hours, on Sundays the peak is reached in late afternoon with a throughput of 60 vehicle/5m. Also in the first hours of the night the traffic is significant, while in the morning the traffic is very low, as expected.

On Saturdays there is an intermediate situation in term of traffic profiles, closer to working days than to Sundays.

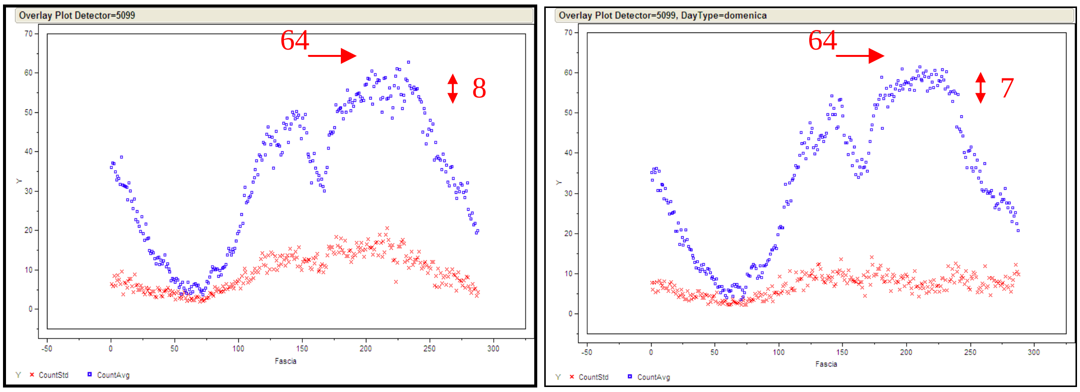

Figure 24- Detector 5099 (Corridor, West to East), vehicles count, Sunday

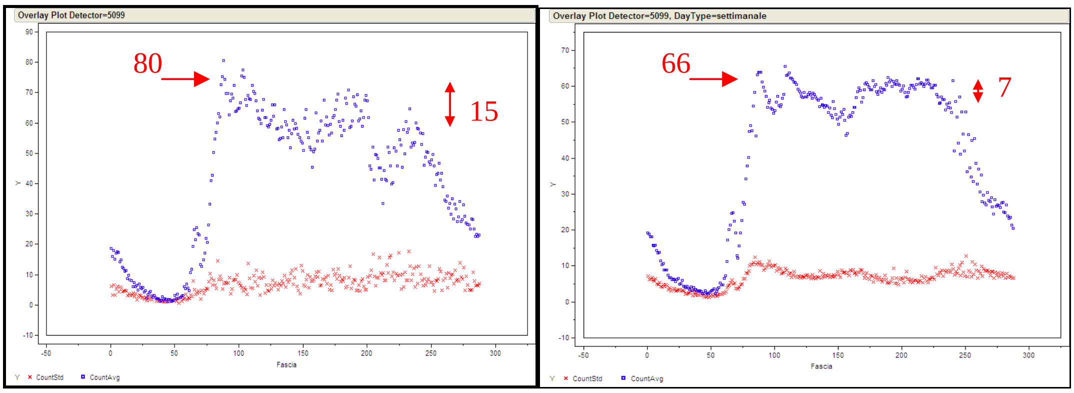

Figure 25 - Detector 5099 (Corridor, West to East), Copy of Figure 13 Errore. L'origine riferimento non è stata trovata. **(working days)**

The second part of "Battisti-Villa Reale (BVR)" section concerns the three intersections on viale Battisti, as reported in Figure 3 where such intersections are highlighted with a red circle.

As far as these intersections are concerned, there aren't detectors installed. The baseline is described in the paragraph C1.2: the traffic plans managing them are neither synchronised nor coordinated. More in detail, the original traffic light plan active on intersection no. 19 had a cycle time of 90", while the plan active on the other two intersection had a cycle time of 100".

The choice done has been to activate the new plan designed and implemented in Archimedes, to achieve a green wave involving the three intersections, synchronising them on a cycle time of 100" with a coordination policy that maximise the green wave in both directions: this means that when the traffic is fluid, e.g. in the central part of the day, the vehicles present at the first intersection of both directions that start when the lamp switch from red to green can cross the three intersections without stopping. The details of the traffic light plans are reported in deliverable T81.1.

As far as the impact evaluation is concerned, the benefit is significant; in section C2.6, dedicated to CBA, the level of service of these three intersections have been studied.

Annex 3: Study of the Level of Service of the Villa Reale traffic light system

A 3.1 Summary

Best practices for intersection signals design are oriented to the search of an optimal capacity allocation among different approaches. Traffic constraints can often influence this search leading to suboptimal choices. This would happen when critical flows are recognised as in need for a most favourable timing and capacity allocation. When this is the case is rather unavoidable to put a penalisation over some of the access for the benefit of others. Traffic engineering is interested in a overall balance of the allocations, thus a validation of the scheme is recommended. This task would provide an assessment of the signal by means of some recognised and accepted metric.

Level of Service (hereafter LoS) is such a possible metric. Practitioners work it out starting from traffic records and classical equations, where terms as capacity (C), saturation flow (S), waiting time and queue lengths are widely used.

Intersection signal is an instance of the classical "arrival-queue-serve" process. *Service delay* is definitely assumed as the performance indicator. In traffic control field, according to American Transportation Research Board (TRB), any service delay corresponds to a predefined Level of Service class. The Highway Capacity Manual (hereafter HCM) presents a LoS's scoreboard with six performance class, from A to F. In the sequel we investigate the most two critical intersections of the ARCHIMEDES Corridor according to such a HCM classification method.

Intersections under study are presented in Figure 12. They have been indicated as #18 Battisti-Brianza and #17 Boccaccio-Regina Margherita. Traffic data have been collected in morning peak hour, mostly between 08.00 and 10.00. During this period prevailing demands are those from Vedano to Battisti and to City Centre as well from Boccaccio to Battisti.

A 3.2 Elements of traffic theory

First of all we would give a reader's guide about the most frequently used terms and their meaning in traffic engineering.

As it is well known to practitioners, the saturation flow (here referred as S) is a fundamental parameter of traffic description. On one side S (defined as Vehicle/hour of green) can be derived from lanes layout geometry and width. This yields a standard values which would be tuned to real case by means of several correction factors. Alternatively S could be estimated on site recording and processing queue lengths at the beginning of cycle and queue clearing times.

Once S has been obtained, we are interested in the fraction of S allowed to flow during effective green time part of the cycle.

Given this fraction is λ , thus we have $C= \lambda S$.

From traffic theory model we know the demand parameter which feeds the system. We call it Q or volume or rate of arrivals (vehicle/hour).

Q and C describe the arrival and departure process at the intersection. As far as the ratio Q/C is less than 1.0 the system is in a equilibrium state, known as steady state or time independent state. When

Q/C is greater than 1.0 the system leaves from steady state, that means queue and waiting times build up, cycle-by-cycle as a time-dependent variables.

For a fixed-time signal, capacity C is clearly a constant, as constant is any of the assigned green times. Where C could be adaptable to Q variations, a so-called traffic-actuated control would be in place to control queue and delay excess.

The simplest traffic-actuated strategy is known as “green extension”. Green extension assumes a minimum green time exists on which the controller would add extra green “time unit”. This would supply, for a while, additional capacity to serve the increase of arrivals. Then green time extension is expected to produce a better LoS.

A 3.3 Validation programme

For the purpose of LoS evaluation several traffic record were acquired in the days 12, 18,19 and 20 of June 2012, for all approaches at intersections nr. 17 and 18 of ARCHIMEDES project corridor. These days has been recognised as a significant sample.

A record is containing for each movement:

- queue length , to say the count of vehicles arrived during red phase.
- queue clearing time (service time)
- the count of arrivals during green time
- the saturation flow (vehicles/hour green)

A typical traffic record is organised as in Table 4.

Intersection 18

Battisti-Brianza

Movement **1**

Date 18-19/06/2012

Brianza (from North, town of Vedano)

Cycle #	Queue clearing time[sec]	Initial Queue /arrivals by red time	arrivals by green time	Avg. headway sec/veh	Day time	Saturation flow[veh/hour]
1	30	22	0	1,67	09.23	2160,00
2	26	17	0	2,00	09.27	1800,00
3	32	28	0	1,33	09.29	2700,00
4	22	13	0	2,44	09.31	1472,73
5	38	24	-1	1,90	09.35	1894,74
6	37	21	-2	2,18	09.37	1654,05
7	26	19	0	1,73	09.40	2076,92
8	20	11	5	2,86	09.44	1260,00
9	29	18	0	2,07	09.46	1737,93
10	32	24	0	1,60	09.48	2250,00
11	33	22	0	1,83	09.50	1963,64
12	22	15	0	2,00	09.52	1800,00
13	13	10	0	2,17	09.54	1661,54
14	35	23	-26	1,84	08.50	1954,29
15	33	16	-20	2,75	08.52	1309,09
16	25	8	-22	6,25	08.54	576,00
17	28	22	-15	1,56	0.8.56	2314,29
18	16	17	-20	1,23	08.58	2925,00
19	25	21	-22	1,47	09.00	2448,00
20	36	22	-13	2,00	09.05	1800,00
21	32	22	0	1,78	09.08	2025,00
22	32	24	0	1,60	09.10	2250,00
						S_{avg}=1911

Table 4 - Example of traffic record [two different days of collection]

"Arrivals by green time" are labelled with + if were served in the current cycle or – if they were served in a later cycle. Saturation flow S, capacity C, expected waiting time W and queue length D_q should be determined for the purpose of Level of Service successive calculation.

A3.4 Saturation flow

A movement related saturation figure S_{avg} should be computed. This is done by averaging individual cycle contribution S_{cycle} (please see Table 4). The headway is the reciprocal of saturation value. As headway is given in sec/vehicle it must be converted to a correspondent, hourly-based, value. The formula S_{cycle}=3600/headway does this properly. Finally the saturation figure S_{avg} is the average, over the number "N" of observations gathered in the record.

A 3.5 Evaluation of C, Q, X parameters

Once S_{avg} is known we would derive the remaining system parameters on which Level of Service calculation depends. Namely these are capacity C, volume Q, saturation index X=Q/C.

Capacity is proportional to saturation flow S_{avg} through a parameter λ, i.e the ratio of g/c [green time/cycle time]. In fixed time system λ is a constant, thus C as well. Q is the number of arrivals to the stop line, counted during the whole cycle time.

In Table 5 an example of model parameters is shown, as it was derived by signal timing and traffic records.

symbol		**description**	**Max**	**Min**
c	[sec]	Signal cycle	**150"**	132"
g_{Eff}	[sec]	Green time	**43"**	25"
S	[veh/h green]	Saturation flow	Mean **1911**	std dev 507
λ		= g_{Eff} /c ratio	**0,29**	0,17
C	[veh/h]	Capacity = λ x S	**548**	318
Q	[veh/ h]	flow or volume	**616**	616
X		Saturation index	**1,13**	1,94

Table 5 - Battisti-Brianza lane #1 parameters

In the example factor λ is affected by minimum-maximum green time variations. This is known as green time extension mechanism, whose purpose is to fit, as far as possible, capacity to demand. Green extension is sustained by inter-arrival time gap of traffic flow. As soon as the gap drops under a predefined time threshold, minimum green is restored.

Q_i is the arrival rate (the demand) of a lane. We observed and recorded samples in each cycle.

A cumulated Q value is obtained by progressively summing contributes over successive cycles. The terminal sum, scaled to one hour time, is the lane averaged volume. In the example this value is of 616 vehicles/hour.

The volume/capacity ratio of a lane, Q/C, is the indicator of the current saturation level.

Q/C, usually called X_{sat}, indicates whether the equilibrium between arrivals and departures is stationary. This condition is possible when $X \leq 1.0$.

When X_{sat} is greater than 1.0 the control is driven into an oversaturated region. Former assumptions on the equilibrium are not any longer valid. The arrivals begin to accumulate while service delay and queue progressively grow.

In Figure 26 a diagram is derived from data record of June 18th and 19th, where arrivals, departures and waiting times are represented as time series. Capacity of lane #1 is about 23 vehicles/cycle, can be regarded as constant in both day records.

As far as arrivals dwell around this rate (June 18th and the tail of June 19th), the control condition is stationary with small random fluctuations. Oversaturation begins when arrivals-departures equilibrium breaks up, as it appears in June 19th record.

Averaged delays have been estimated in both uniform and random arrival components. Uniform arrival mostly affects w_{unif} through g/c [eq.1] while random arrival mostly affects w_{random} delay through X [eq.2].

Arrivals, despite max green extension, can not any longer be served within the current cycle and, thus, would be awaiting for any next to get clearance. Clearance of queue hence would happen after a delay, according to saturation ratio. Oversaturation is a temporary peak hour condition.

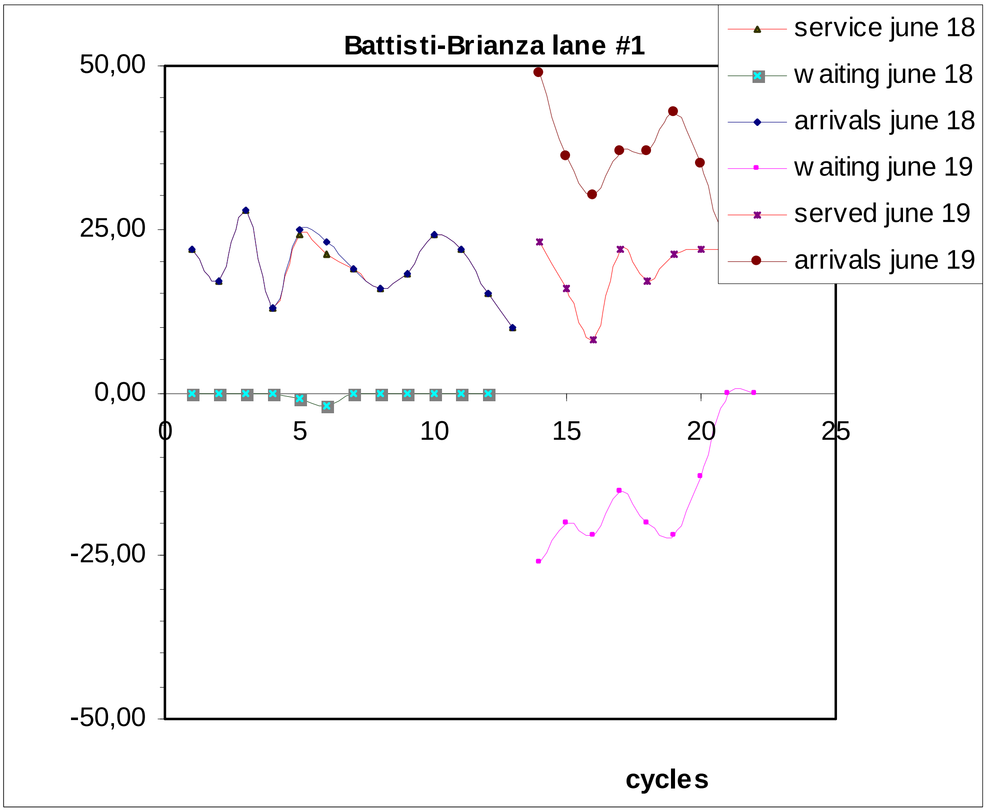

Figure 26 - Arrivals and service process by june 18th and 19th records

A 3.6 Control delay evaluation

“Waiting time” is a prime parameter for signal performance evaluation. Arrival-departure is a process governed by statistical distribution. Traffic engineers usually look for reliable models and simple calculation tool.

Webster’s original model (1958) is the most known. Webster’s assumes a steady state condition with a probabilistic equilibrium between arrivals and departures. Webster’s assumption **holds when Q<C**, i.e capacity is larger than demand.

Under such an assumption Webster’s model yields two delay components, $W_{uniform}$ and W_{stoc}. The first is related to an hypothesis of uniform rate of arrival, the latter to the effect of a random arrivals distribution .Total delay is the sum of two terms:

$$W_{uniform} = \frac{c\,(1-g/c)^2}{2[1-(g/c)X]} \qquad 1)$$

$$W_{stoc} = \frac{X^2}{2Q(1-X)} \qquad 2)$$

where

c =cycle length

g =effective green time

Q = volume or arrivals

X =Saturation index or Q/C

Practitioners often resort to a modified version of Webster in which a corrective factor 0,9 accounts for green extension improvements.

Another well known formula is provided in HCM manual (2000), chapter 16. Also this model computes two terms as Webster's and a third accounting for oversaturation delay, if a queue was accumulated "initial queue"[i.e. unmet demand] in former cycles.

Uniform arrival delay was adjusted with calibration factor provided in HCM manual. This factor is known as PF, to say progression adjusting factor and caters for platooning effect. The figure depends on g/c ratio and was assumed according to HCM exhibit 16-12 clauses.

Incremental random delay was also adjusted according to HCM. The adjustment factor depends on signal controller type (pretimed or actuated). We deployed a default K=0.5 factor ,as per HCM Exhibit 16-13, which is equivalent to the worst possible factor.

We followed such a HCM delay calculator model for each of the lanes.

Furthermore, delays were also assessed with Akcelik time-dependent formula, under the assumption of a quarter of hour observation interval. Ackelik is usually overestimating delays while HCM underestimates total delays. That way Ackcelik and HCM could be thought as respectively upper and lower bounds.

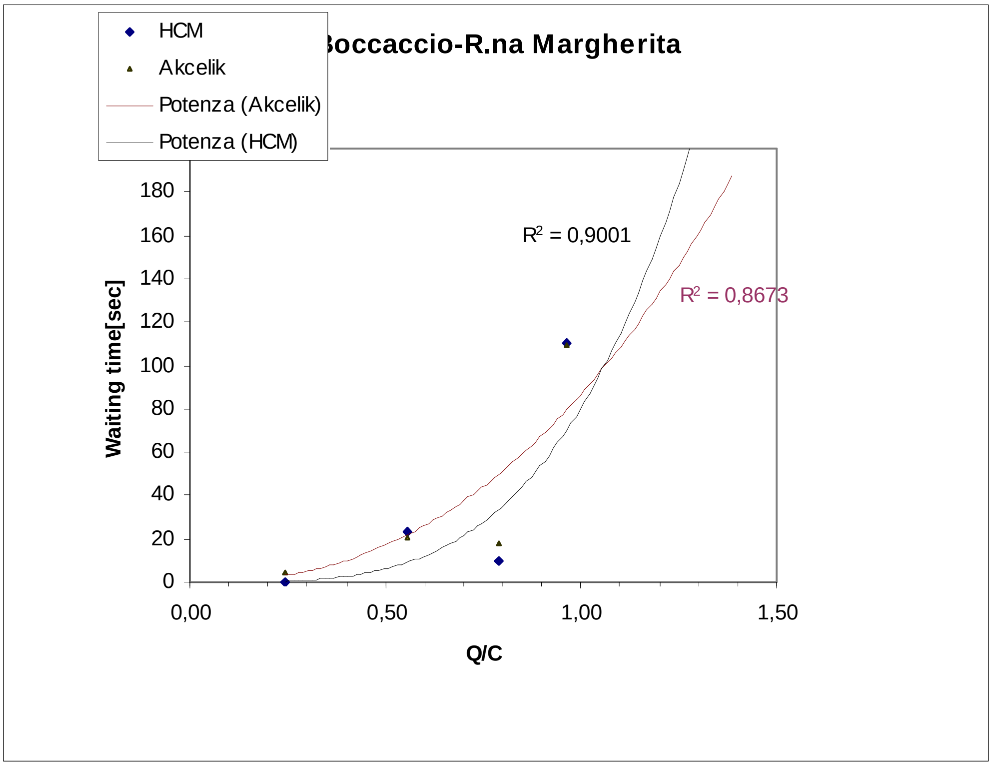

Figure 27 - delay vs. saturation index

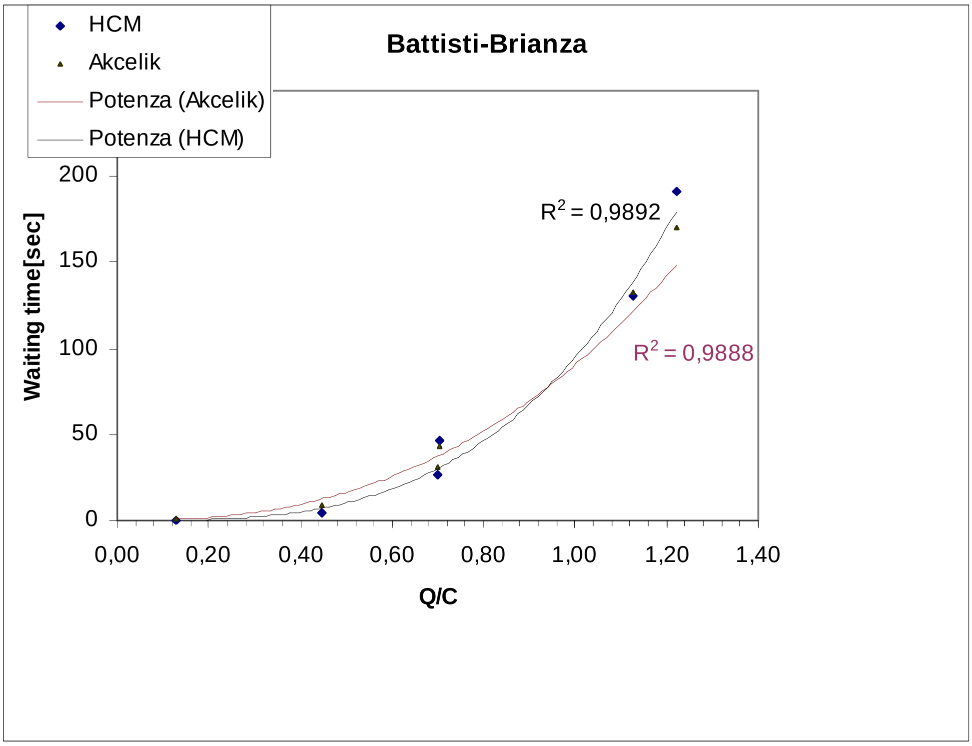

Figure 28 - delay vs. saturation index

Diagrams in Figure 27 and in Figure 28 are drawn to show the dependency of total delay W from saturation index Q/C. Delays grow when Q/C lies in the saturation region, i.e. Q/C>1.0. The delay process is described by its mean cumulated function which fits well in collected data records.

A 3.7 Queue length evaluation

Queue length is actually not recognised in LoS calculation by HCM model. Anyway practitioners commonly resort to it as a further indicator of cycle timing fitness. Queue length depends on Q/C saturation index or, to say, arrival-departure rates equilibrium. Queues in general are considered a sum of two terms, respectively due to uniform arrival and random arrival process models. HCM method as well is based on such a general assumption.

First we consider the HCM queue standard calculation. Fundamentals are available in appendix G of HCM manual.

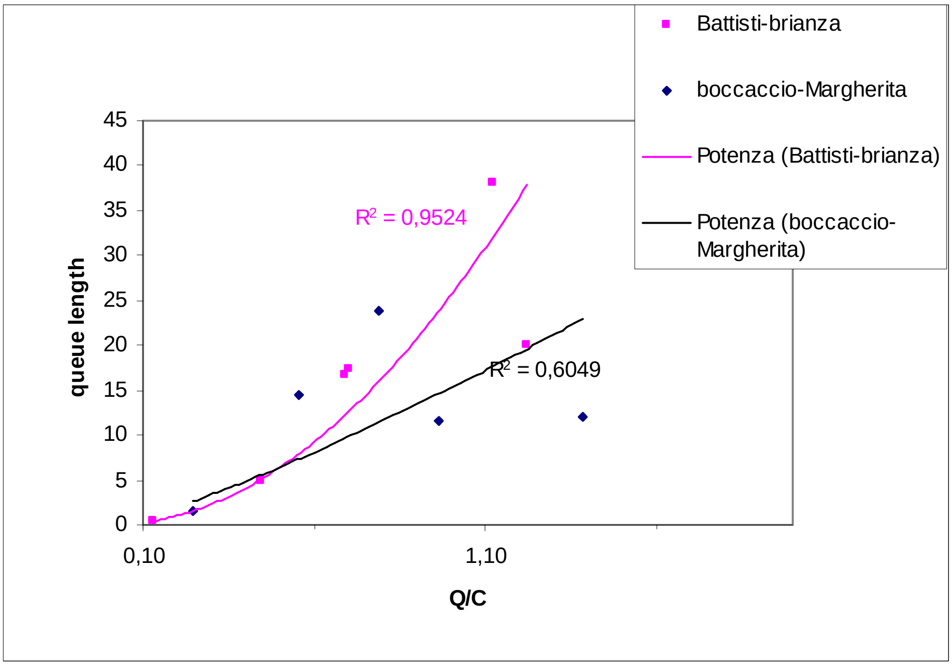

Figure 29 - averaged queue lengths [HCM standard method]

Results are displayed in Figure 29 for both intersections. Power law approximation is still exploited to model the process.

It should be of use to derive queues by an alternative way, in order to establish some evaluation bounds. Given W_{AVG} the averaged delay, q the rate of arrivals and R_{Eff} the red timing, we would consider two possible condition when red starts,i.e.:

Absence of an initial queue Q_o

Presence of an initial queue Q_o

In the first case the queue lower bound (at steady state equilibrium) is

$$qR_E$$

In the second case the queue upper bound is

$$0,5\ qR_E + qW_{AVG}$$

being the first term the, probability-weighted, queue due to arrivals during red signal time and the second term a random term dependent on signal delay. Figure 30 and Figure 31 show calculated queue bounds of both intersections. Queue displays are evidently in strong connection with delay correspondent displays. Power law, adopted for queue process model, fits rather acceptably with records, to say, all calculators provide a comparable order of magnitude.

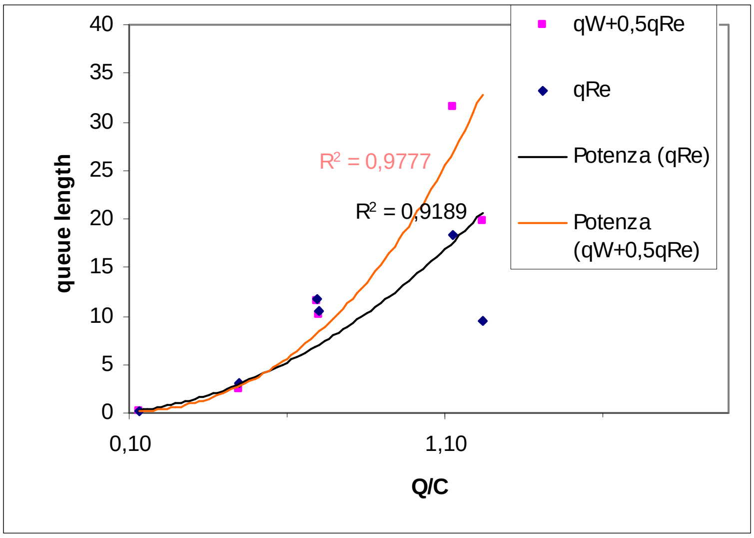

Figure 30 - Bounds of queue in Battisti- Brianza

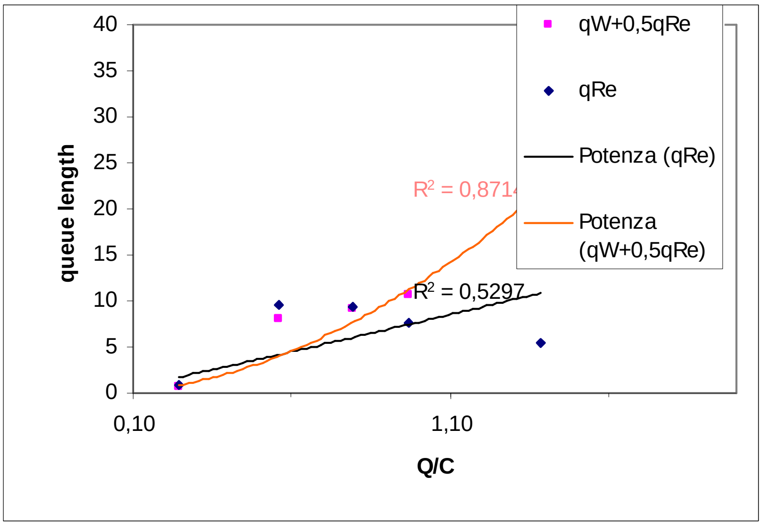

Figure 31 - Bounds of queue in Boccaccio-Regina M.

A 3.8 Level of Service evaluation

Level of Service, in Highway Capacity Manual [TRB 2000], is a performance figure based on the expected system "waiting time". This latter criterion is widespread in many application fields, from telecommunication & networking to transport network. Being grounded on "*Queueing Theory*", the criterion is applied to a traffic control process, which is inherently a probabilistic process. From the point of view of model validation, we are interested in averaged figures.

HCM manual provides the following evaluation scale, reminded in Table 6 for reader convenience:

LEVEL OF SERVICE	WAITING TIME[sec]	
A	< 10	negligible
B	>10 e < 20	acceptable
C	>20 e < 35	acceptable
D	>35 e < 55	acceptable
E	>55 e < 80	sensible
F	>80	untolerable

Table 6 - Level of Service definition (source: U.S.A. D.o.T, HCM)

HCM method conceives LoS either for "group of lanes", "approaches" or the "whole intersection". In the current case all lanes are independent then each of them is, by definition, a group on its own. The whole intersection LoS is a weighted sum of individual delays normalised to total flow.

Individual flows, delays and LoS are reported in columns of Table 7.

Movements	q_j	HCM w_j	Akcelik	LoS
A	225	111	161	F
B	146	288	832	F
C	819	10	53	B
D	528	23	48	B
E	463	0	4	A
1	616	131	308	F
2	246	0	1	A
3	266	5	30	A
4	451	46	68	C
5	520	27	60	C
6	283	192	502	F

Table 7 - Delay evaluation

The aggregated LoS index is:

$$LoS = \frac{\Sigma q_i w_i}{\Sigma q_i} \qquad 3)$$

With j = A, B, C, D, E for Boccaccio-Regina M. and J = 1, 2, 3, 4, 5, 6 for Battisti-Brianza

A 3.9 Outcomes of investigation

Aggregated signal delays and Level of Service of the two investigated intersections are reported in Table 8:

Traffic-actuated signal	Boccaccio-Regina M.	Battisti-Brianza
Signal Delay [sec]	40	72
LoS	D	E

Table 8 - Aggregated L.o.S. values for intersections 17 and 18 ("Villa Reale")

As a general comment, aggregated LoS are both within an acceptable HCM class. Nonetheless we should remind individual LoS depends on the saturation degree. Volumes are quite independent variables and capacity is affected by assigned g/c. To differently say it, delay depends on how much of the volume Q could be served, by design, with a correspondent capacity C. Thus performance is mostly matter of lane-allocated saturation.

HCM suggests, as a general rule, to set a threshold at X=q/C=0.80. Beyond this value, even marginal arrivals increments will produce sensible delays. Collected records in Figure 27 and Figure 28 confirm this trend.

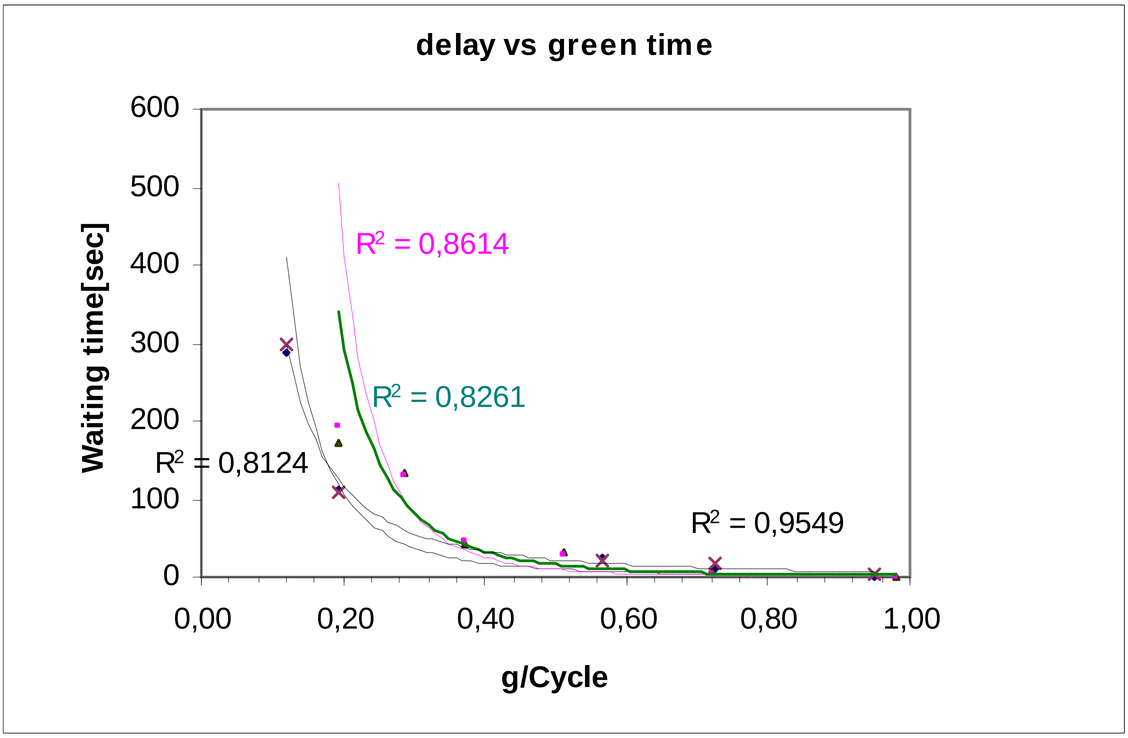

Figure 32 - delay sensitivity to g/c ratio

The investigation upon delay sensitivity to g/c is plotted in Figure 32. Delays minimisation, for given arrival rates, is matter of green allocation to the diverse movements. The g/c figures is such an information in a glimpse. g/c affects delays and, in turn, LoS of individual lanes as well the whole system's LoS. The search for optimal allocation is often a search constrained by cycle length and saturation choices, which can not be defined independently one from each other.

In the next paragraph an investigation among different options of green allocation is provided for the purpose of benchmarking.

A 3.10 Benchmark

As a final benchmark, a comparison would be conducted among a traffic-actuated and a fixed-time signal option.

The purpose is to provide an assessment of signal performance against a baseline even theoretical example. This analysis is done according to HCM equations and assumptions.

We based once more on a comparative delay evaluation and consequent calculation of LoS.

First of all we produced cycle length options for a target saturation index and time loss, by means of HCM equation:

$$\text{Cycle planned} = L\ X/(X-\Sigma q/s)_{ic} \qquad 4)$$

where suffix "ic" meant the most critical movements in the phases of signal.

Then a green distribution, equalised among movements, was provided according to HCM equation

$$g_i=(q/s)_i\ c/X_i \qquad 5\ )$$

where X_i are saturation indexes to be assigned during an optimisation search for a set of g_i.

Assessment procedure assumes the green time distribution is equalised with respect to each movement weight, indicated with q/s.

g_i /c and X figures in eq.5) are fed to delay calculator. Then the aggregated delay is turned in a overall LoS score.

Under the already described assumptions we concluded that:

- in Boccaccio-Regina M. intersection a time-actuated signal LoS turns out a little worse than theoretical fixed-time/green-equalised baseline model. It matters with a "D" score against a "C". On the other hand major movements C and D, right and left turns from Boccaccio with their considerable volumes, are targeted to get more green than others. With traffic-actuated choice this is provided together with very less delay than fixed time could do.
- In Battisti-Brianza intersection with a time-actuated signal the score was the same class "E" than fixed-time's. To say, no penalisation comes from a not equalised green allocation among the movements.

Critical movements have been considered those in conflict among them, i.e 1, 4 and 6 or a straight current from Vedano and the two left-turns which are in. Given q/S indexes of those movements a saturation-equalised approach would produce individual delay and an aggregated delay within E zone of LoS table. By deploying a actuated signal there is a great beneficial for left-turn movement #4 as well for right turn #5.

lane	S	g/c	C	q	Xs	q/S	Cycle Lost time [sec]
A	1204	0,19	233	225	0,97	0,19	18
B	879	0,12	105	146	1,39	0,17	
C	1428	0,73	1038	819	0,79	0,57	
D	1674	0,57	949	528	0,56	0,32	
E	1900	0,95	1900	463	0,24	0,24	
1	1911	0,29	548	616	1,13	0,32	25
2	1900	0,98	1900	246	0,13	0,13	
3	828	0,72	596	266	0,45	0,32	
4	1745	0,37	651	458	0,70	0,26	
5	1443	0,51	741	520	0,70	0,36	
6	1201	0,19	232	283	1,22	0,24	

Table 9 - movement general parameters

Table 9 summarises all major parameters which had a part in traffic-actuated benchmark against fixed time signal. Individual benchmark outcomes are then, separately, displayed in Table 10 and in Table 11.

movement	Traffic actuated	Fixed time/ saturation equalised
A from city centre	82	111
B left turn from Boccaccio to centre	288	94
C right turn from Boccaccio	10	19
D left turn from Regina M. to Boccaccio	23	55
E straight to city centre	-	-
	Aggregated LoS D	Aggregated LoS C

Table 10 - Boccaccio-Regina M. comparative delays [in sec]

movement	Traffic actuated	Fixed time/ saturation equalised
1 from Vedano to centre	131	71
2 right turn to Battisti	0	-
3 from centre to Vedano	5	90
4 left turn to Battisti	46	93
5 right turn from Battisti	27	68
6 left turn from Battisti to Vedano	192	106
	Aggregated LoS E	Aggregated LoS E

Table 11 - Battisti –Brianza comparative delays [in sec]

A further processing of traffic data, for the specific corridor from Battisti to Boccaccio, results in a Origin-Destination performance of "C" in LoS level terms. This score, substantially obtained for both travel directions, proves the goodness of a joint approach the two intersections, as shown in Table 12.

O-D Joint delays and LoS

delay	25"		23"
LoS	C		C

Table 12 – Joint Battisti –Boccaccio (Inters. 17 and 18) performances

Detailed Excel sheets used to carry out all the computations so far presented are available.