A Introduction

The measure 6.11 focuses on establishing an innovative control system for boats entering the Grand Canal, the main artery for traffic in the historical city of Venice. The proposed action is part of a large-scale initiative launched by the City of Venice to enforce regulations in force, provide continuous monitoring of waterborne traffic density and flows and contribute to the development of new traffic management policies.

A1 Objectives

The main measure objective is to implement a Grand Canal automatic control and data management system (ARGOS) which supports enforcement of regulations in force and provides continuous monitoring and data which can contribute to the development of new traffic management policies.

Objectives through ARGOS are therefore:

- to enforce city regulations previously emanated regarding access and speed limits in the Grand Canal limited traffic zone;
- to enforce city regulations on other traffic management issues in the Grand Canal limited traffic zone (parking, timetable, wrong way circulation, etc.);
- to provide accurate, systematic and continuous measurement of traffic density and flow. The system provides information on the exact number, types and speed of boats navigating in the Grand Canal. This will allow for the development of traffic management policies through instruments such as the water traffic management-modelling tool, which is a MOBILIS initiative (measure 12.6): “Management decision support system for waterborne traffic in Venice”;
- to complement other traffic management instruments such as that in measure 12.5 “Satellite control (GPS-GPRS) for water PT services in Venice”.

A2 Description

The ARGOS system (Automatic Remote Grand-Canal Observation System) has been designed for boat traffic monitoring, measurement and management along the Grand Canal of Venice. Based on automatic vision technologies such as those employed in robotics and unmanned space and aircraft missions, the ARGOS system is based on a number of Survey Cells, each using special cameras, deployed along the Grand Canal, disguised along the façades of ancient buildings. Providing real-time picture, the type and position of each boat circulating in the Grand canal can be determined by means of artificial vision techniques. In this way, not only the boats entering/exiting the waterway system are detected, but also their behaviour (average and maximum speed, number of starts/stops, congestion, compliancy towards the rules of navigation etc) is detected and measured all along the waterway network.
Description of activities:

1. **Concept Design Review**

Selection and proof-testing of the most appropriate optical sensors for remote traffic detection and classification and of the most appropriate software algorithms and techniques for image-based moving targets detection and classification.

Purchase and test in real operating conditions of samples of commercially available sensors based on CCD and CMOS technologies. Their performance are compared in terms of sensitivity in day and night conditions, resolution, image quality and expected lifetime in order to select the most appropriate hardware technology for the project purpose.

Comparison and choice of the suitable techniques for automated vision. Image processing candidate technologies include image rectification and re-projection, calibration vs. geographical coordinates, background/foreground separation, recognition and tracking of moving objects.

2. **ARGOS Prototype System Release**

Several optical sensors are assembled together with a local rugged computing unit in a small-size, low power consumption integrated unit suitable to be hanged outside the historical buildings leaning over the Grand Canal, with minimum impact on the buildings’ aesthetics. This unit, named “Survey Cell” includes a large-bandwidth radio data transmission equipment to send traffic and image data to the Control Centre.

3. **Demonstration and testing final review**

A computing and processing centre is equipped with suitable hardware and software components. The Control Centre provides specific functions addressed to:

- the Public Security Officers, for the identification of any possible risk or offence to the law, including boat driving misbehaviour;
- the City Planning Officers, for the definition of the best boat traffic monitoring system, through the management of the total number of boats navigating along the Grand Canal, boats position, speed, trajectories, density and flow and all the relevant functions related to Grand Canal access control and management.

4. **Training and dissemination events**

This set of activities includes:

- training of the City Planning Officers and Public Security Officers for the optimum use of ARGOS functionalities;
- workshops to inform the local community about the system and demonstrations for the executives and potential users from other cities, in order to promote the diffusion of the ARGOS concepts in other cities and regions.

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**B Measure implementation**

**B1 Innovative aspects**

Use of new technology/ITS - New policy instrument

For water traffic management purposes, a complete real-time view of all the Grand Canal is required. Therefore a completely new approach has been devised. Based on automatic vision technologies such as those employed in robotics and unmanned space and aircraft missions, the new ARGOS system is based on a set of Survey Cells, each using special cameras, deployed along the Grand Canal. The fields of view of all the cameras is joined together – by means of advanced image rectification and
processing techniques – in a single real-time picture of the whole waterway system. Based on this real-time picture, the type and position of each boat can determined by means of artificial vision techniques. In this way, not only the boats entering/exiting the waterway system are detected, but also their behaviour (average and maximum speed, number of starts/stops, congestion, compliancy towards the rules of navigation etc) is detected and measured all along the waterway network.

These innovative features, together with the GPS-GPRS Satellite control system (MOBILIS measure 12.5), the model for water traffic management (MOBILIS measure 12.6) and other systems such as the logistics management and water parking management (MOBILIS measure 10.2) represent a unique integration of unprecedented capabilities and flexibility.

B2 Situation before CIVITAS

First, we provide some background information on the measure context in order to better present the before CIVITAS situation.

Venice (historical centre and the lagoon islands) has a unique traffic system in that the primary means of vehicular transportation is boats. Throughout Venice’s history, waterborne transportation has been a critical and integral part of city’s transportation system. Venice is interwoven with nearly 150 canals through which boats travel daily. The most important waterborne traffic artery in Venice is the Canal Grande (Grand Canal) that with its shape of a reverse “S” divides the city centre in two distinct parts (see photo). The Grand Canal is 3.800 metres long and has a width ranging from 30 to 70 metres. This however, does not exempt Venice from some of the same problems that the average major city faces. Like other cities, Venice is subject to traffic-related noise pollution and congestion. Unique to Venice, though, is Moto Ondoso, otherwise known as wake pollution caused by boat traffic. A thorough understanding of this boat traffic can lead to vast improvements throughout the city. The City of Venice has mainly the management responsibility of all inner urban canal of the Venice historical centre, of Murano and Lido islands. Lagoon canals defined as outer to urban centres are generally managed by the Venice Water authority.

Daily about 30,000 boats pass in the Venice Lagoon of which 4,000-5,000 in the Grand Canal leading to some traffic-related noise, pollution and congestion. To face this phenomenon the City of Venice has emanated a series of regulations regarding access to and traffic rules for navigation in Venice waterways and, in particular, in the Grand Canal, which have the overarching aims of:

- creating Limited Traffic Zones (LTZ) in which access is permitted only on the basis of the typology of boat (waterbuses, water taxi, gondola, etc.) typology of service (transport of goods, public transport, residents’ private boats etc.) and at certain times of day;
- controlling and limiting speed in order to reduce wave action and consequently protect the natural environment and basement structures of historical buildings;

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1 “Magistrato alle Acque”, that is a national body
- regulating and controlling traffic flows in order to reduce the number of boats entering in the Grand Canal;
- monitoring traffic flows in order to minimise traffic congestion;
- facilitating and guaranteeing public transport transit;
- rationalising boat transit for the transport of goods;
- improving traffic safety and emergency management in case of accidents.

In order to regulate navigation in the City of Venice all the national and regional laws in the matter (such as the “navigation code”) are enforced. Comparing to the rest of the country, though, the Venice lagoon, due to its peculiarity, deals with particular problems that need to be managed through specific regulations. In particular, intensive wave action the so-called “Moto Ondoso” has been recognized as one of the major causes of damage to the basement structures of historical buildings in Venice since the early 1960’s, with the increase in boat mass and speed consequent to the diffusion of large diesel engines.

Figure 1: Competencies of the Venice canals - green: City of Venice, blue: Venice harbour, blue-grey: Venice Water Authority

Since then, the City of Venice has drawn up and implemented regulations suitable for the need to transport goods, inhabitants and tourists on the one hand, and the need to preserve historical heritage on the other hand. The main regulation in operation is the “Regulation for waterborne transport circulation” enacted by the City of Venice in 1997 in order to:
- establish the maximum speed limit;
- foster boat transport according to criteria of compatibility between social needs and the historical, urban and environmental context;
- minimize harmful effects caused by propellers and boat induced waves;
- prevent air, water and noise pollution;
- privilege the scheduled public transport services, the transport of goods, and other public transport of persons;
- safeguard services and activities run with typical Venetian rowing boats;
- minimize inconvenience linked to canal closure maintenance works.
Furthermore, in order to face the “wave action” emergency caused by the intense waterborne traffic, the national government decided on December 2001 to appoint the CDG TALV\(^2\). Till the end of its mandate (December 2006) the CDG TALV was responsible for all waterborne traffic and navigation management activities in the Venice city and its lagoon\(^3\) and enacted a set of norms to regulate navigation and mooring.

The most recent and important CDG TALV orders which are currently in force and concern specifically the limited traffic zone in the Grand canal are the following:

- Ordinance n. 9 of February 2002 that modifies and collects in one single measure all the norms related to navigation safety in the Lagoon, driving issues and speed limits;
- Ordinance n. 31 of September 2002 that identifies areas with particularly sensitive ecosystems to the effect of boat-induced waves, instituting specific zones named “blue areas” with further limitations to the navigation;
- Ordinance n. 19 of 14 May 2002 that sets out the obligation for pleasure craft with motors exceeding 10 horsepower to have a registration number;
- Ordinance n. 25 of 24 June 2002, that sets out limited traffic zones and the following updating norms and modifications.

Further orders in force recently enacted by the City of Venice are the following:

- Managerial ordinance n. 310 and n. 311 of 3 July 2007 that disciplines the navigation in the lagoon areas under the city of Venice competences, setting out limitations according to boat typology, dimensions and timetable in the Canal Grande and in other rii and inner city canals.
- n. 3 of 10 May 2006 and Managerial ordinance n. 421 of September 2006 that sets out the obligation for private transport or private crafts to have a registration number.

The control of waterborne traffic and more in general, curbing the problem of wave action can take place in three complementary ways: administrative control, vigilance and through the respect of technical protocols regarding vessel specifications.

Administrative control regards controls carried out when authorisations are given by the City of Venice.

Technical protocols are being drawn up and proposed by a special Commission for different types of boats circulating.

With regards to vigilance, stationary municipal police control points at the most critical parts of the Grand Canal and the use of mobile municipal police officers are core parts of the enforcement system. However, as with all traffic management systems, support is needed from technology for autonomous traffic monitoring.

Prior to ARGOS, however, measures such as speed limits were proven to be only partly effective, due to the lack of continuous and autonomous traffic monitoring systems.

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\(^2\) Commissario del Governo Delegato al Traffico Acqueo nella Laguna di Venezia

\(^3\) that is to say that the City of Venice competences on the canals has been extended to the whole lagoon to better manage the “emergency”.
Boat traffic congestion in the Canal Grande

Enforcement of regulations in the Grand Canal before ARGOS took place in the following manner. Circa 45 municipal police officers circulate in the Venice inner canals. They are equipped with 15 boats and communicate with each other and with the Municipal Police control centre via radio and mobile phone. In order to catch offenders such as boats entering the Grand Canal without authorisation to do so (non residents for example) or speeding, the municipal police officers have to be in the right place at the right time.

Another relevant aspect of ARGOS is that regarding the provision of accurate, systematic and continuous data on traffic in the Grand Canal. Without such a system, traffic data is collected in Venice in the following manner.

Since 1986, waterborne traffic has been surveyed for the City by COSES. Since 2000, a Waterborne Traffic Observatory has been set up in COSES. Data is collected twice a year, once in spring and once in late summer. There are 26 monitoring stations and data is collected regarding the time boats pass, the direction in which they are travelling, type of boat, registration number, name or company name of boat, presence of goods on board and estimation of quantity, permits displayed. Data is collected from 7:00 until 19:00. In addition, special monitoring projects have been set up, one of which concerns the Grand Canal and collects data such as total traffic flows, determines carrying capacity, use of docks etc.

Data collected through the ARGOS system is obviously more complete, although at present only concerning the Grand Canal. The data which is automatically processed and stored by the system and therefore available for future study and development of policies include the following:

- traffic flows and density: number of boats during different periods of time and in a limited area;
- boat direction;
- boat speed;
- boat dimensions.

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4 Consorzio per la Ricerca e la Formazione
Venice Municipal police control boat

B3 Actual implementation of the measure

1 Concept Design Review

A thorough review of the available image analysis software algorithms and techniques was carried out in collaboration with an outstanding scientific partner (University of Rome “La Sapienza”, Dept. of Information Science and Technology). A set of candidate image analysis techniques were identified (Automated Vision techniques for Robot autonomous action). A set of preliminary tests was made on real images of the Grand Canal.

2 ARGOS Prototype System Release

An exhaustive survey was carried out in order to select the most appropriate locations to install the Survey Cells. A preliminary optical coverage map was elaborated in order to define the minimum number of Survey Cells to be installed.

The 14 Survey Cells were installed on following locations on Venice Grand Canal (Table 1 and Figure 2):

<table>
<thead>
<tr>
<th>Survey Cells number</th>
<th>Building / Palace name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Convento S. Chiara</td>
</tr>
<tr>
<td>2</td>
<td>Sede ex Compartimentale FF.SS.</td>
</tr>
<tr>
<td>3</td>
<td>Sede ex Compartimentale FF.SS.</td>
</tr>
<tr>
<td>4</td>
<td>Hotel Principe</td>
</tr>
<tr>
<td>5</td>
<td>Ca’ Vendramin Calergi</td>
</tr>
<tr>
<td>6</td>
<td>Palazzetto delle Pescherie (loggiato)</td>
</tr>
<tr>
<td>7</td>
<td>Palazzo Civran</td>
</tr>
<tr>
<td>8</td>
<td>Palazzo Dolfi MANIN</td>
</tr>
<tr>
<td>9</td>
<td>Palazzo Grimani</td>
</tr>
<tr>
<td>10</td>
<td>Hotel Manin</td>
</tr>
<tr>
<td>11</td>
<td>Palazzo Balbi</td>
</tr>
<tr>
<td>12</td>
<td>Palazzo Moro-BARBINI</td>
</tr>
<tr>
<td>13</td>
<td>Palazzo Ca’ Corner</td>
</tr>
<tr>
<td>14</td>
<td>Palazzo Giustinian</td>
</tr>
</tbody>
</table>

Table 1: Survey Cells location in the canal grande
Final analysis software algorithms and image analysis techniques have been finally defined in collaboration with an outstanding scientific partner (University of Rome “La Sapienza”, Dept. of Information Science and Technology).

3 Demonstration and testing Final Review

The control centre was installed and is fully operative and the testing of the system was completed in November 2007. The following Working documents were delivered: 6.11 V-1 “ARGOS System Requirements”, 6.11 V-2 “Scientific and technical feasibility analysis”, 6.11 V-3 ”ARGOS Architecture and Detailed Design”.

The system was presented at the VISAPP seminar held in Barcelona, and the related paper was submitted and published on the seminar proceedings “A distributed vision system for boat traffic monitoring in the Venice Grand Canal”.

4 Training and dissemination activities

The dissemination events to present the ARGOS system (workshops and seminars) were held in November 2007:

- 11.04.2007 – presentation of the ARGOS Project to the Chief Officer and to the security force (Workshops to inform the local community);
- 09.11.2007 – press conference;
- 19.11.2007 – Interview made by a German television (ZDF);
- 26.11.2007 – presentation to the Venice Municipal Council;
- 29.11.2007 – presentation to ACTV and to other professional associations.

The training activities of the City Planning Officers and Public Security Officers for the optimum use of ARGOS functionalities were concluded in March 2008, as originally foreseen.

B4 Deviations from the original plan

- There are no deviations from the original plan.
B5 Inter-relationships with other measures

The measure is related to other measures as follows:

- **Measure 1 no. – 10.2 V “Clean urban logistics in Venice”** because also in this measure traffic density and flow are tuned in accordance to the demand/availability of docking points & docking time;
- **Measure 2 no. – 12.5 V “Satellite Control (GPS-GPRS) for water PT services in Venice”** because it foresees a former traffic management system to be integrated with ARGOS;
- **Measure 3 no. – 12.6 V “Management decision support system for water borne traffic in Venice”** because ARGOS should provide real traffic figures (density, flow, avg speed) to the decision support system.

C Evaluation – methodology and results

C1 Measurement methodology

ARGOS is meant as an instrument to enforce city regulations on traffic management and to support Municipal Police. The evaluation methodology is mainly based on the evaluation of impact in terms of traffic management including the variation of traffic flows (ex ante and ex post) and the analysis of traffic offence (fines) trends in the Grand Canal. Traffic offences in the Grand Canal may include:

- speed limits exceeded;
- movements of boats in group;
- overlapping of boats that last longer than the time necessary for overtaking;
- parking in forbidden zones;
- transit in one-way canals in the wrong direction.

The evaluation methodology also includes functionality analysis: the Argos system is an innovative system and it is the first time an image-based waterway control system is applied in the Venice historical centre. Under the functionalities analysis technical characteristics and performance are described and analysed. The functionality analysis is important in order to describe how works the system and make clearer the traffic control system and rules enforcement.

C1.1 Impacts and Indicators

The selected indicators and the reference to the CIVITAS II Common Core Indicators categories are presented in Table 2.

<table>
<thead>
<tr>
<th>No</th>
<th>Category</th>
<th>Sub-category</th>
<th>Impact</th>
<th>Indicators</th>
<th>Measure Unit</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Transport</td>
<td>Transport System</td>
<td>Traffic flow</td>
<td>Boat Traffic flows in the Grand Canal - number of boats navigating in the limited access zone in Grand Canal</td>
<td>Traffic data from the manual COSES’ annual survey will be confronted to Argos data (in the same condition, and same typology).</td>
<td>COSES City of Venice - Municipal Police</td>
</tr>
</tbody>
</table>
Table 2: selected indicators for the impact evaluation

<table>
<thead>
<tr>
<th></th>
<th>Society</th>
<th>Acceptance</th>
<th>Traffic offences</th>
<th>Number of fines in the Grand Canal</th>
<th>Trend</th>
<th>Data from the Argos System - Municipal Police</th>
</tr>
</thead>
</table>

Detailed description of the indicator methodologies:

**Indicator 1 - Boat Traffic flows in the Grand Canal:**

This indicator contains an overview on the traffic flow trends in the Grand Canal. It is a trend indicator based on statistical data provided firstly by COSES\(^5\) and afterwards by the Venice municipal Police. COSES is a city organisation dedicated to research and advancement. Traffic count studies are undertaken semi-annually by COSES usually during the high tourist season (from April to October) - once in spring and once in late summer. There are 26 monitoring stations located in the inner Venice canals and collected data regards the time boats pass, the direction in which they are travelling, the type of boat etc. Traffic patterns are subject to change depending on the day of the week and depend heavily on environmental and seasonal conditions. In order to reduce fluctuations due to high and low tourist seasons, the same day typology is used. Data is usually collected a working Friday of early April and September from 7:00 until 19:00 and with similar weather conditions. For our purposes, we use COSES spring surveys from 2003 to 2005 (September traffic patterns are usually conditioned by high tourist events such as the international movie festival and the Art and Architecture biennale). In addition due to the high number of canals and survey stations, and to the intrinsic complexity of waterborne traffic patterns it is still not easy to extrapolate data only for the Grand Canal and to get coherent data series and trends. Data from COSES of the total number of boat in the Grand Canal and in some particular sections are confronted with 2008 Argos traffic data. In particular 5 Grand Canal stations with heavy boat traffic are analysed (Figure 3 and table 3).

In addition data of particular relevance and reliability are data about taxi flows. In fact due to the extremely high level of tourism in Venice, a significant portion of inner canal boat traffic and in particular in the Canal Grande is made up by taxis. Taxis belong to the public transportation class (called “transporto non di linea”). Over the years, Taxis represent a share of about 36-37% of the total traffic and is usually the main boat category\(^6\) (component) into the Grand Canal. For these categories good data sets are available for the Grand Canal from COSES from 2003 to 2008.

Under this indicator information on hourly peak and monthly evolution is provided along with the total number of boats transiting in the waterborne ZTL and the possible effect over time of the control system on the global volume of boats.

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\(^5\) Consorzio per la Ricerca e la Formazione

\(^6\) COSES classifies boats in Venice in 9 categories.
Figure 3: The five survey stations in the Grand Canal

<table>
<thead>
<tr>
<th>Number</th>
<th>Survey station name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rio Novo (Piazzale Roma)</td>
</tr>
<tr>
<td>2</td>
<td>Rio Marin</td>
</tr>
<tr>
<td>3</td>
<td>Erbaria (Rialto)</td>
</tr>
<tr>
<td>4</td>
<td>San Vio</td>
</tr>
<tr>
<td>5</td>
<td>Salute</td>
</tr>
</tbody>
</table>

Table 3: survey stations name

**Indicator 2 - Traffic offences - fines in the Grand Canal**

This indicator is a trend indicator based on traffic offences statistics provided by the Municipal Police. Data are monitored monthly and annually and classified according to the type of legislation infractions for the whole canal network (included in the Venice LTZ). Due to the complexity of the waterborne navigation legislation, only the total number of infractions and the boat speed infractions are considered within this indicator. To that end it is worth reminding the speed limit in the Venice as shown in table 4.

<table>
<thead>
<tr>
<th></th>
<th>ACTV boat</th>
<th>Other boat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grand Canal (Venice) / Grand Canal (Murano)</td>
<td>11 km/h</td>
<td>7 km/h</td>
</tr>
<tr>
<td>Rio Novo - Ca' Foscari</td>
<td>-</td>
<td>5 km/h</td>
</tr>
<tr>
<td>Cannaregio Canal</td>
<td>7 km/h</td>
<td>5 km/h</td>
</tr>
<tr>
<td>Other canal</td>
<td>7 km/h</td>
<td>5 km/h</td>
</tr>
</tbody>
</table>

Table 4: Boat speed limits in Venice
The indicator contains an overview of the total annual traffic offences data in all Venice from 2004 to 2008 and gives a more specific trend on the traffic offences data for the Grand Canal over the years 2007 and 2008. Data for 2008 have been available until the end of September. Sanctions data regarding only the Grand Canal and provided by the Municipal Police through the Argos system database are available only for the years 2007 and 2008.

The indicator also contains a relevant sub-indicator, the offence-controls ratio indicator (number of sanctions for 100 controls) to get rid off the annual fluctuation of the number of controls.

It is well known that the positioning and use of cameras and the application of sanctions work as an efficient deterrent to craft transit. A strengthening in the Grand Canal control system is expected firstly to bring an increase in sanctions, surely followed by a progressive decrease.

C1.2 Establishing a baseline

Baseline situation refers to the situation before ARGOS implementation in the Grand Canal and concerns the MOBILIS months 1 to 34. The MOBILIS scenario refers to the following period, that is to say, after Argos system implementation for the monitoring of waterborne traffic flows and traffic controls in the Grand Canal. The MOBILIS scenario concerns months 35 to 44 (September 2008 – end of evaluation activities).

C1.3 Building the business-as-usual scenario

The ARGOS measure in MOBILIS is part of a large project which the City of Venice intended to develop over 2007 and 2008. It became part of the MOBILIS project after the withdrawal of another measure concerning access management in Venice due to problems. The BAU scenario is therefore more or less the same as the MOBILIS scenario: the implementation of the ARGOS project. It has, however, received a great deal more visibility due to it being part of MOBILIS than it would have done without it. In addition, it could be said that MOBILIS has led to greater expectations of ARGOS than were originally foreseen. Originally seen by the City of Venice as a powerful tool for monitoring and as a support for the police in enforcing regulations on the Grand Canal, within MOBILIS much emphasis has been put on its potential to automatically fine and therefore enforce regulations once this is permitted through homologation of the system by the Ministry of Infrastructure and Transport.

C2 Measure results

C2.1 Functionality Analysis

The following section describes the main technical functionalities of the system. That is the first time that this kind of innovative system is applied within the Venice inner canals. The analysis describes the main technical features, functionalities and related performances.

In general, intelligent traffic management systems readily available are:

1) GPS-based satellite positioning receivers;
2) Radio-controlled identifier tags;
3) Camera & RADAR controlled gates.

However, water traffic management differs greatly from that on the land. None of these single technologies, taken alone, is able to give a comprehensive view and a satisfactory control over water traffic.

Systems 1) and 2) have the main problem of requiring special equipment to be installed on board. GPS systems for boat traffic control have been experimented in Venice since the mid 1990’s, but, due to the above problem, are operating on public service boats like waterbuses, police and local city boats, etc. but have encountered some opposition from private operators.
Systems 3) have the major drawback of providing a measurement of vehicle flow at a certain “gate” or “road section”, while for the specific aim of the project a complete real-time view of all the Grand Canal (and the minor waterways in a near future) is required. Therefore a new approach has been devised. ARGOS is a waterway control system by means of some observation posts or “Survey Cells”. The system is based on digital image processing collected by a group of IR/VIS sensors installed just below the roof of several buildings leaning over the Grand Canal (Table 1 and Figure 2). The fields of view of all the cameras are joined together – by means of advanced image rectification and processing techniques - in a single real-time picture of the whole waterway system.

The 14 locations are interconnected in a network structure converging in the Local Police Operative Centre, where the information received are coherently run and integrated with the navigation control systems already installed in the Centre itself (Figure 4). The system is able to supply a continuous control and real time boat traffic monitoring, to draw automatically useful information about flows and traffic density in any time interval, as well as to highlight any illicit behaviour held by craft pilots.

Each survey cell is composed of three sensors: one centre wide-angle (90°), orthogonal to the navigation axis, and two side deep-field cameras (50-60°), arranged all together (as shown on the Figure 5). The three sensors are connected to a local computer where the digital date are processed. The images are rectified and stitched together so as to generate a composite plain view, similar to a radar image. The resulting overall view field along the waterway could stretch over 250-300 meters end-to-end (Figure 4) and the camera covering represent 100% of Grand Canal area (Figure 9). The digital date are processed through a two-level analysis software: a module for image re-sampling, rectification and stitching of contiguous images which, in turn, feeds a second innovative software layer capable of detecting moving targets, delimiting them, finding their geometrical centre and filtering the time and position data by means of tracking algorithms to compute position, speed and direction of each target.

The fields of view of each camera shall slightly overlap so as to allow the software to continuously follow and track the motion of each target through the whole composite view field of the survey cell, keeping each target labelled by a unique identifier (Track ID). Each survey cell is also equipped with a pan-tilt-zoom camera, for the automatic tracking of selected targets.

Due to the impossibility of wiring the survey cells together, all the system data traffic shall be conveyed trough a private radio channel. As this gigahertz channel has a limited bandwidth, most of the computation load shall be borne by the survey cells themselves.

The system is designed for 24/7 all-weather day-night operation. The global system architecture is depicted in Figure 4. The system is mainly based on two processes: segmentation and tracking that computes tracks associated to the boats moving in the waterway.

The main ARGOS functionalities are:

1) optical detection and tracking of moving targets present in the FOV;
2) computing position, speed and heading of any moving target within the FOV of each camera;
3) elaboration at survey cell level of any event (target appears, exits, stops, starts within the cells FOV) and transmission of any event to the Control Centre;
4) connecting all the track segments related to the same target in the different cameras FOV into a unique trajectory and track ID;
5) recording all the video frames together with the graphical information related to track IDs and trajectories;
6) rectifying all the camera frames and stitching them into a composite plain image so as to show a plan view of the whole Grand Canal;
7) allowing the operator to graphically select any target detected by the system and automatically activating the nearest PTZ camera to track the selected target.
Measure title: Access and traffic management in the Grand Canal through ARGOS
City: Venice  Project: MOBILIS  Measure number: 6.11 V

Figure 4: position and covering of the three sensors

Figure 5: The survey cells
Figure 6: The system architecture - All the system data traffic is conveyed through a private radio channel.

The main control window shows a live global view of the Grand Canal, integrating a GIS map with live information about position and velocity of the boats currently in the canal (see Figure 7). More specifically, a coloured dot is plotted in the map location of each target with associated a few smaller dots representing its recent track. The colour denotes the speed of the vehicle and other icons may appear close by to indicate specific events (such as, moving in a wrong way, stopping in a forbidden area, etc.). In addition, flow and density analysis are performed and displayed in order to have a global view of the traffic present in the canal at every time (example in Figure 8).

In order to make available all the information gathered by the system in a useful way for the Venice Municipal Authorities, different modes of visualization of the results have been developed. The relevant extracted information can be divided into two groups: statistics measures and event detection.

Statistic information is necessary to continuously monitor the traffic in the Canal. In particular, we wanted to calculate the traffic of boats moving in each direction for each survey-cell at different times of the day, as well as the boat density in the different areas of the Canal. To this end track analysis has been performed in order to compute the quantities of interest. For example, for computing the flow of boats passing within the area monitored by a survey cell, we can define two virtual lines in the Canal and count the number of boats (i.e., tracks) passing these lines.
Figure 7: The main control window displays a global view of the Grand Canal with real-time information about position and velocity of the boats transiting in the canal.

Figure 8: Density analysis are performed and displayed in order to have a global view of the traffic present in the canal at every time.

Another important parameter is the velocity of the boats since it is the main factor of wave motion. The velocity is computed by analysis of the world coordinates of the tracks: in particular to increase robustness to noise we compute the length of the path done in the last n frames (e.g., n = 10) as the sum of the distances between consecutive points and divide this value for the time duration of the path.

Further parameter that are automatically detected are: speed limits, i.e., detecting boats going at a velocity greater than a given threshold; parallel travel, i.e., detecting boats that move parallel and close each other for long time wrong directions, i.e., detecting boats moving in the wrong direction in one-way pieces of the Canal; forbidden stops, i.e., detecting boats stopping in forbid-den areas.

Event detection is again based on specific analysis of the determined tracks. Speed limit is checked using two thresholds (that have been fixed to 5 Km/h and 7 Km/h) and each target is labelled with a colour: green for speed below 5 Km/h, yellow for speed between 5 and 7 Km/h and red for speed
above 7 Km/h. The visualization of coloured dots in the GIS map makes it possible to quickly detect speed limit violations. Moreover, the system automatically records the tracks moving at a velocity above 7 Km/h for some time, allowing for subsequent analysis and post-processing. Parallel travel is detected by track analysis, in which we first detect parallel motion (by projecting the position of one boat to the direction line of the other) and then computing the distance between the two direction lines. A pair of parallel boats that maintain this distance below a given threshold for more than a given amount of time generates an automatic alert.

Also in this case automatic recording allows subsequent analysis. Finally, the other events are detected by defining zones in the canal that activate the corresponding checking procedures: for wrong direction we simply check that boats move in the right direction, for stops detection we monitor the time in which a boat remains within a limited area.

**Performance of the system:**

- Number of cells installed: 14
- Area covered by cameras – camera covering: 100% of Grand Canal area (figure 7)
- Sensitivity of telecameras (CMOS image sensor): each telecameras is made up of two optic sensor, one for the day and one for the night (infrared sensitive). The CMOS sensor has a 0,005 lux sensitivity (1 sec integration time) and a 0,1 lux sensitivity (1/60 integration time). Each telecamera is connected to a local computer able to produce 6-7 images per second whereas the transfer to the control centre is done by 2 images per second. The telecamera throughput is about 3 Mbit/sec.
- Image resolution: real-time image resolution is 1Mpixel (1280*960 pixel).
- Zoom capacity: the PTZ telecamera has a zoom capacity of 35. Each sensor cover a maximum lateral area of 150 m long. The sensor is then able to identify a
- Number of boats (boat licence plates) that can be identified: Each telecamera is able to track a maximum of 40 targets at the same time
- Functionalities in diverse situations – variation of solar radiation, light, fog, night shadows: The image parameters (light, contrast) are controlled automatically by the software. In that way variation of solar radiation and light do not interfere with the target detection. However fog conditions may be a relevant filter that increases with fog intensity. During the night thanks to the infrared sensitive CMOS image sensors and to the public lighting in the Grand Canal Capacity, the success of boat tracking is in the order of 75-80% .
- Measure of craft speed (precision): in accordance with the municipal Police, if an speed boat exceeds 10 km/h for more than 15 seconds, it is identified as an infraction. The displayed symbol becomes then a red triangle. The precision of the craft speed estimate is around 0,2 km/h (negligible when tracking the target for 15 seconds).

**Evaluation test**

The following evaluation tests have been performed to measure the performance of the system in counting and short-term tracking of passing boats. The test was carried out with the same configuration of the software (i.e., with no specific optimisation for a given functionality) on real images taken from a survey cell installed in Venice.

Counting evaluation test: The evaluation test has been set as follows. A virtual line has been put across the Canal in the field of view of a survey cell, the number of boats passing this line has been counted automatically by the system $n$, and the same value is manually calculated by visually inspection $\hat{n}$. The average percentage error is then computed as $\varepsilon = \frac{|n - \hat{n}|}{\hat{n}}$. This error measures the general performance of the system, and it is useful to determine the general capabilities of the system of estimating traffic flow. However, this measure does not capture exactly all the errors made by the system. For example, if a boat is counted twice and another one is not detected, the error $\varepsilon$ is zero. An additional error measure is then calculated by considering the probability of making an error in counting a single boat passing the line.
where \( d(\cdot) \) is 0 when the argument is 0 and 1 otherwise. This experiment has been performed with three different videos of about 20 minutes each taken in different days. The results are shown in Table 5.

<table>
<thead>
<tr>
<th>Video 1</th>
<th>duration</th>
<th>( n )</th>
<th>( \hat{n} )</th>
<th>( \varepsilon )</th>
<th>( P(e) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video 1</td>
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<td>95</td>
<td>0.055</td>
<td>0.144</td>
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<tr>
<td>Video 2</td>
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<td>0.043</td>
<td>0.130</td>
</tr>
<tr>
<td>Video 3</td>
<td>25 min</td>
<td>62</td>
<td>67</td>
<td>0.081</td>
<td>0.129</td>
</tr>
</tbody>
</table>

Table 5: Counting errors.

With ARGOS, the police officers are equipped with hand held computers. Should an offence occur such as the entrance into the Grand Canal of a boat, which for reason of size or type is one of the boats not permitted in the limited traffic zone, the operations centre automatically communicates this to the hand held computers. The Police officers patrolling the Grand Canal are directed in real time to intercepting the offender. Other types of offences which the system can automatically indicate through a light signal to the handheld computers are the following:

- speed limits exceeded;
- movements of boats in group;
- overlapping of boats that last longer than the time necessary for overtaking;
- parking in forbidden zones;
- transit in one-way canals in the wrong direction.

Should an offence occur which cannot be automatically communicated by the system to the hand held computers the officers manning the operational centre can contact the patrolling officers and direct them to intercept the offender. It should be noted that ARGOS is not yet able to be used for the
automatic emission of fines, such as that which takes place with laser cameras on roads but this should be possible in the future after the homologation of the system by the Ministry of Infrastructure and Transport.

At the moment, ARGOS images cannot be used as the only evidence to prove that an offence has been committed but they can be used as proof of violations which have been intercepted by police officers. During the experimental phase images are kept for 48 hours, but after the authorization from the Privacy Authorities, it will be possible to keep them in the archives as long as needed to complete the verification of the offences. The rest of the data may be kept as long as necessary.

The technical solutions presented and the system functionalities are innovative, efficient and truly adapted to the specific characteristics of Venice waterways.

Further technical information may be found in the technical paper at the following link: [http://www.dis.uniroma1.it/~iocchi/ARGOS/docs/argos-visapp07.pdf](http://www.dis.uniroma1.it/~iocchi/ARGOS/docs/argos-visapp07.pdf)

### C2.2 Results

The results are presented under sub headings corresponding to the areas used for the selected indicators – transport and society.

#### C2.2.1 Transport

**Indicator 1 - Boat Traffic flows in the Grand Canal**

The Grand Canal has always been the main canal for transportation of goods and persons. According to the recent traffic surveys carried out by COSES it represents about 67-68% of the total Venice boat traffic.

Total traffic flows in the Grand Canal over years shows a sharp increase trend as shown in Figure 10. The 2008 data report a particularly high traffic increase with +27% respect to 2005. This increase rate far exceeds the 2004-2001 growth rate that was about +18.6%. 2008 data show a traffic peak with nearly 24,000 boats recorded in 12 hours survey (Figure 10).

Looking more specifically at the survey stations, traffic flow patterns show important differences between stations. The increase trend is confirmed but with a lower intensity. Apart for Rio Novo, all stations confirm a sharp traffic increase trend (Figure 11). In particular at Rio Marin, the 2005-2008 traffic increase exceeds +36%, and at Erbaria station +44%. However looking at a longer period of time - the whole survey period 2003-2008, the reported increase turns out to be lower. Traffic growth rate from 2003 to 2008 range from 10% in Rio Marin to 52% in Erbaria station. The Herbaria station located near by the Rialto bridge is one of the more strategic areas for commercial transport and tourism and shows the higher traffic increase. Rio Novo (Piazzale Roma) as one of the ingress point in the Grand Canal is also a strategic area characterised by high traffic intensity and the 34% drop in 2008 is probably due to day typology difference rather than a traffic trend shift.

The reported traffic flows increase may be attributed in part to the increase in the number of watertaxi boat typology circulating in the Grand Canal as shown in Figure 12. Recorded taxis flows are increasing steadily over years and in all survey stations. Watertaxis is an important component of the Grand Canal traffic that is continuously increasing despite traffic and boat speed restriction enforcement.

Furthermore as shown in Figure 13, daily traffic pattern shows a strong traffic boat concentration in the morning peak hours 08-12 am. That suggests that vigilance and main traffic controls should be concentrated in the morning hours that present higher risks of congestion, accidents and traffic offences.

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7 Including taxis and lance grand turismo
**Measure title:** Access and traffic management in the Grand Canal through ARGOS  
**City:** Venice  
**Project:** MOBILIS  
**Measure number:** 6.11 V

**Figure 10:** Traffic volume in the Grand Canal

**Figure 11:** Traffic flow trends in the 5 Grand Canal stations
C2.2.2 Society

Indicator 2 - Traffic offences - fines in the Grand Canal

The indicator contains firstly an overview on traffic offences trends in the waterborne ZTL – that is to say in all the city inner canals - including the Grand Canal. Over the period 2004-2008 (until the 31-08-2008) the total number of traffic offences in the Venice canals amounts to 28,485 with an annual average of 5,517 (Figure 14). From 2004 the number of reported sanctions increased steadily reaching a peak in 2007 with 7,158 and this figure will surely be exceeded by the end of 2008. 2007 is characterised by a sharp increase in the total number of traffic offences with 22.6% increase respect to 2006 while between 2005 and 2006 the increase was only about 5%.

Including all type of traffic infractions (speed limit infractions, administrative infractions, illegal access, parking infractions, etc.)
One factor that may have influenced the reported increase in the number of traffic offences is the number of controls. The offence-controls ratio indicator has been developed to get an overview of the increase in absolute value of the number of traffic offences. In these cases, data are available only for the waterborne ZTL and are presented in Figure 15. Controls are made up of telelaser controls and onboard controls. Between 2004 and 2005, traffic controls with telelaser became more systematic in the Venice canals and the total number of controls rose considerably (+267% increase in the number of telelaser controls from 2004 and 2005). 2004 is then characterised by a high number of reported offences respect to the number of controls and then a peak offence-controls ratio (Figure 15). The offence-controls ratio drops strongly from 2004 to 2005 and increases steadily afterward to reach a ratio of 2.2 offences per 100 controls in 2008. The apparent strong rise in traffic sanctions in 2007 is then also correlated to a rise in the number of controls of the waterborne traffic. The offence-controls ratio shows then a light and steadily increase rate from 2005 to 2008 with a ratio ranging from 0.015 to 0.022.

Looking at the monthly number of traffic offences between January 2006 and December 2007, the trend shows an evident seasonal pattern (figure 16) corresponding to tourist seasons. High traffic offence period corresponds to the higher tourist season from May to October. In this period waterborne traffic and the related infraction increases drastically.

In the Grand Canal the number of sanctions amounts to 1.745 in 2007 and represents about 24.4% of the total number of sanctions for all Venice LTZ. For the nine first months of 2008 the reported number of traffic offences is 1.372 and corresponds to 22% of the total number. Monthly trend patterns of both years are quite similar with a sharp increase in the high tourist season (Figure 17). From August 2008 the number of sanctions seems to start decreasing slightly respect to 2007 and September 2008 shows a drop of about 28% respect to 2007. By the end of year the total number of reported sanctions for 2008 will surely be lower than 2007 levels confirming this positive trend.

![Figure 14: Traffic offences trends over 2004-2008 in the city of Venice canals](image-url)
Figure 15: Offence – control ratio in the waterborne LTZ over 2004-2008 period

Figure 16: Monthly trend in the traffic offence number (2006-2007)
C3  Achievement of quantifiable targets

<table>
<thead>
<tr>
<th>Target</th>
<th>Rating</th>
</tr>
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<tbody>
<tr>
<td>The main measure targets are qualitative based targets:</td>
<td></td>
</tr>
<tr>
<td>1. To give to the City of Venice the instruments needed to enforce and</td>
<td>**</td>
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<tr>
<td>implement the regulations, traffic schemes and restrictions for the</td>
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<tr>
<td>boats navigating in the limited access zone in Grand Canal.</td>
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<tr>
<td>2. The implementation of ARGOS should result in a first period of</td>
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<tr>
<td>increased number of sanctions and corresponding reduction in flows in</td>
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<tr>
<td>the Grand Canal as compared to the scenario before ARGOS.</td>
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<tr>
<td>3. Setting up of continuous and autonomous traffic monitoring system.</td>
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</tbody>
</table>

NA = Not Assessed  * = Not achieved  ** = Achieved in full  *** = Exceeded

C4  Up-scaling of results

The Venice urban space is defined and can not be extended. In this context it is clearly not possible to change the physical structure of the urban channel network. Canals may only be restored or reorganized in order to improve physical conditions and traffic. The logic scale for the up-scaling of results is the whole Venice island city and the whole city canal network under the City responsibility. However not all canals have the same characteristics in terms of viability, and traffic issues. Venice is interwoven with nearly 150 canals through which boats travel daily and in which the Canal Grande is the primary one.

The most important waterborne traffic arteries in Venice can be represented by two rings (red lines on the left figure): one outer ring including the Fondamente Nuove canal, Tronchetto, Giudecca canal,
and the San Marco basin, and one inner ring including the central part of the Grand Canal and the Rio Nuovo that connects both rings. The presence of the lagoon, which encircles the city with wide and deep navigation channels, acts as a travel system of around Venice.

The smaller canals are usually forbidden to engine powered boats. Areas and canals of main concern in terms of traffic and congestion have then to be controlled and monitored in priority.

The objectives of the City of Venice in order to improve boat traffic monitoring in the inner city includes to extend the electronic control system to 6 areas of main concern (figure 18):

1. The Tronchetto area which is the main arrival and departure terminal of tourist flows coming with tourist coaches from the road or with tourist launches from the lagoon;
2. Riva degli schiavoni – main disembark area of “Gran Turismo” boats coming from the Tronchetto, the cruising port, Fusina and Punta Sabbioni;
3. Fondamente Nuove area in the Northern part of the city in order to monitor flows from and to the Marco Polo airport;
4. Rio di Cannaregio – connecting canal from north-West to the Canal Grande;
5. Rio Nuovo, inner connecting canal of two important sections of the Canal Grande from Piazzale Roma to Cà Foscari;
6. Rio di Noale, crossing canal from North to the Canal Grande.

Figure 18: Future extension of the Argos system

**C5 Appraisal of evaluation approach**

The evaluation methodology takes into account the main aspects of the set-up of waterborne automatic control system in the Grand Canal including technical characteristics and performance, legal issues linked to the enforcement of regulations in force and acceptance of the system in terms of traffic offences and fines.
C6 Summary of evaluation results

ARGOS (Automatic & Remote Grand Canal Observation System) is an innovative water traffic navigation control system on the Grand Canal able to implement an efficient automatic navigation monitoring and an effective operative deterrent for all those circumstances that require Police intervention, while rationalizing the Local Police presence, in terms of human resources. It also gives an important contribution to the reduction of wave motion in the crucial points of the city of Venice.

This system based on digital image processing collected by sensors installed along the Grand Canal is able to supply a continuous control and real time boat traffic monitoring to draw automatically useful information about flows and traffic density in any time interval as well as to highlight any illicit behaviour held by craft pilots.

The key results are as follows:

- Fully running instrument which supports the municipal police in the enforcement and implementation of the regulations, traffic schemes and restrictions for the boats navigating in the limited access zone in Grand Canal;
- A continuous and autonomous traffic monitoring system is running and can be see online and in real time at the following address: [http://www.argos.venezia.it/](http://www.argos.venezia.it/);
- According to the recent traffic surveys Grand Canal represents about 67–68% of the total Venice boat traffic. Total traffic flows in the Grand Canal over years shows a sharp increase trend. The 2008 data report a particularly high traffic increase with +27% respect to 2005. This increase rate far exceeds the 2004-2001 growth rate;
- The positive effect over time of the AROS control system on the global volume of boats transiting in the Grand Canal has not yet been perceived. A longer period of valuation would be necessary to see a reduction trend in the global boat volume and in the water-taxi flows particularly in the critical peak hours;
- The strengthening of the traffic control brought firstly to an increase in sanctions followed by a progressive decrease that started according to our assessment in August 2008. The reported trends in the monthly number of traffic offences in 2007 and 2008 show similar patterns that follows boat traffic seasonal patterns. However a light decrease in the number of traffic sanctions is reported from August and September 2008 respect to 2007 with a drop of about 28%. By the end of year the total number of reported sanctions for 2008 will surely be lower than 2007 levels confirming this positive trend;
- In the Canal Grande the number of sanctions amounts to 1.745 in 2007 and 1.372 for the nine first months of 2008 and represents respectively about 24,5% and 22% of the total sanctions number for all Venice LTZ.

D Lessons learned

D1 Barriers and drivers

D1.1 Barriers

No barrier within the implementation of this measure

D1.2 Drivers

1. The strong political support for this project.
2. Great attention to the system was paid by various City Administration Councils (Sozhou, Beijing and another cities in the south of Italy) interested in innovative ways to deal with security issues.
3. The system has been designed in a manner which is sensitive to the architecture and surroundings of historical Venice. In fact, the Bureau for the Preservation of Historical Architecture Heritage (“Soprintendenza ai beni Architettonici di Venezia”) approved the design of the Survey Cells and authorized the installation phase.

D2 Participation of stakeholders

The key stakeholders involved in the measure are:

- The Municipal Police;
- The city of Venice;
- ECOTEMA SPA
- ARCHIMEDES.

The closed and continuous collaboration between stakeholders was fundamentals for the success of the measure.

D3 Recommendations

ARGOS is an applications of advanced navigation and information processing technologies designed to improve the performance of the existing transport control system. A potential negative impact of this kind of system is that with the intensive surveillance and data collection nature of some applications, travellers and the public in general may become more concerned about their privacy. To avoid this concern, it is important to invest in communication. Communication and information diffusion though local medias that are generally very sensitive to new technology development may be a valuable possible opportunity.

D4 Future activities relating to the measure

The measure is part of a wider challenging project called “//venice >connected” based on information technologies and internet infrastructures for the city. The project foresees among other things the extension of the system to further inner-city canals under the City of Venice responsibilities (see C4).