Smart City Control Room Dashboards Exploiting Big Data Infrastructure

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Abstract: Smart City Control Rooms are mainly focused on Dashboards which are in turn created by using the so called Dashboard Builders tools or generated custom. For a city the production of Dashboards is not something that is performed once forever, but is a continuous working task for improving city monitoring, to follow special events and/or works, to monitor critical conditions and cases. Thus, relevant complexities are due to the data aggregation architecture and to the identification of modalities to present data and their identification, prediction, etc. In this paper, the architecture of a Smart City Control Room Dashboard Builder is presented. As a validation and test, it has been adopted for generating the dashboard in Florence city and other in Tuscany area. The solution proposed has been developed in the context of REPLICATE H2020 European Commission Flagship project on Smart City and Communities. **Keywords**: smart city dashboard, decision support system, widget, control room.

1. Introduction

In the development of a Smart City there is a great emphasis to the set-up of the so called Smart City Control Room, SCCR. A SCCR is an area (of one of more rooms) in which all the data are collected and high-level data/results are summarized and made accessible for the decision makers and for the city operators. In large metropolitan cities, the SCCR includes large panels/monitors (even covering large walls) in which the status of the city is reported presenting the view of the city with some synthesis, predictions, alert of data regarding: mobility, energy, social activities, environment, weather, public transportation, people flow, health, water, security, ICT, governmental, first aid, civil protection, police (118/112/911), fire brigade, hospital triage, and thus almost all the city resources expressed via KPI (Key Performance Indicator). Most of the KPI are representative of the status of resources deployed in the city. Some of the city monitored resources are critical infrastructures for the city functionality and life of city users such as: transportation, energy, security, health, water, civil protection, ICT, etc. In medium sized cities, the daily management of city resources is performed by a set of *separated city operators.* They autonomously manage their control rooms, accessing and rendering their own data to take their own decisions which may be limited in scope. For example, when the energy network has a problem in an area of the city the energy is rerouted to reach the all possible subareas via a different path; when the water network has a problem on major distribution tubes when possible the water is provided in other means; in presence of traffic congestion the red-light timing is acted to facilitate the flow and bus paths may be changed/rescheduled.

Once identified and understood the needs of having an integrated SCCR, immediately growth up the issue regarding what has to be shown on (i) the panels on walls and what on (ii) computers of the operators, (iii) how the data are collected and computed (in the case of prediction and early warning). These processes are very complex to be managed since the amount of information is heterogeneous and large and has to be easily understood by the observers of the panels on the wall and of the computers. It is not only a problem of usability is a problem of understandability, a problem of data representation, a problem of competence of the observers/operators, and of the decision makers. In most cases, they have to be trained to understand the data and graphics representations. They have to become confident on what they see to understand in deep all the single details represented on the screen. For example, we are used to understand: (i) a traffic representation observing the city map with red, orange, yellow, and green segments on the streets; (ii) a temperature and the humidity percentage, etc., while it is more difficult to read the tables of pollution, pollination, traffic flow trends by numbers, etc. Alarm signals in red, blinking signal, etc., may help on learning and understanding [Few 2006].

From the technical point of view, the tools for rendering information on SCCR are typically called Dashboards and are supported by big data aggregation tools [Badii et al., 2017]. The Dashboards should be capable to present real time data in several different manners with real time updates on screen autonomously H24 7/7 days, according to the refresh time of each data source.

Dashboards for control rooms should not be confused with business intelligence tools that produce graphics from the combination of data extracted from some sources (database, files, API, etc.). In most cases, business intelligent tools may access to data with faceted indexing and search, for example in SOLR or ElasticSearch. Those kind of Dashboards are focused on single view of data, filtering the drilling down on data, rather that representing the city KPI and status for example by using Apache Banana, or HUE.

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Moreover, the concept of Dashboard for SCCR is also often confused with the data aggregator tool that is a fundamental tool for the Control Room and city control in general, and can be regarded as the back office of the Control Room. Many solutions for control rooms and their backoffices, has been proposed such as IBM [IBM 2013] on services for citizens, business, transport, communication, water and energy; [Alcatel 2013] on governmental, educational, e-health, safety, energy, transport and utilities; etc. Most of these solutions present a multi-tier architecture ranging from 3 to 6 layers [Anthopoulos et al., 2014], [Filipponi et al., 2010], [Chourabi et al., 2012].

In this document, the Dashboard solution developed in the context of REPLICATE research and development projects of the European Commission, it is an SCC1 project of the European Commission on H2020 (http://www.replicate-project.org). The solution proposed is been based on Km4City Smart City Ontology Http://www.km4city.org [Badii et al., 2017], [Bellini et al., 2014]. Please note that the Dashboard Management System of DISIT Lab is released as Open Source on GitHub, see DISIT lab page. The present solution is managing more than 1.2 million of complex events/data per day.

The paper is structured as follows. In Section 22, the requirements of smart city control room are discussed. Section 3 presents the adopted smart city architecture. In Section 4, the dashboard system for the smart city control room is presented with its architecture. Section 5 reports a set of experimental results and lesson learnt. Conclusions are drawn in Section 6.

2. Smart City Control Room Requirements

In this section, the main requirements of Dashboards for SCCR are summarized. The have been collected during the research project by interviewing a number of operators and decisions makers belonging to several cities and nationalities.

A SCCR dashboard is substantially a decision support system tool, DSS, since it provides evidence of critical conditions, and may offer solutions. On this regard, it may integrate/exploit artificial intelligence algorithms, for example, reporting prediction, early warning, providing relationships among entities exploiting inference geospatial reasoning about what is located in the city: resources, structure, people, areas, critical infrastructures, etc. [Bellini et al., 2014], [Suakanto, 2013], [Gavin et al., 2016], [DeMarco et al., 2015].

According to our analysis, a Dashboard system for smart city has to be capable to:

- show data on widgets according to several graphic paradigms (tables, graphs, histograms, maps, kiviat, lists, tv camera, heatmaps, weather, critical city events, etc.) with a level of interactivity and animation;
- show data on autonomous and connected/ synchronized widgets;
- collect, show and keep update on screen data with automated refresh for each views;
- collect and show data coming from different big data and classic data sources (SQL, NoSQL, RDF, P2P, API, SOLR, etc.) also in aggregated manner;
- compose the Dashboard as a set of graphic and integrated widgets that can be separately set up assigning a number of parameters: data source, size, colors, shape, etc.;
- work with large amount of data providing high performances, as short response time;
- support by a flexible notification systems computing alarms and sending alerts, activating tickets for maintenance, automatizing actuators, etc.;
- provide actuators widgets together with showing graphs;

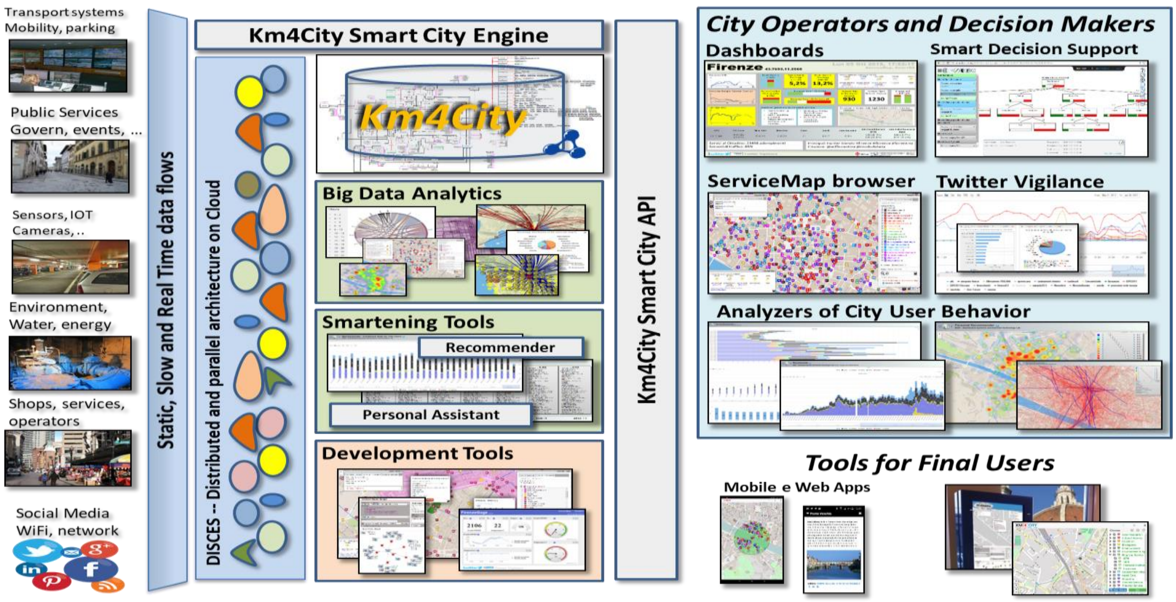

Figure 1: Km4City Architecture for Smart City.

- provide support for collaborative production of dashboards and for co-working;
- provide support for embedding dashboard into third party web pages;
- provide data engine for collecting connection response time on different protocols, and for verifying the consistency of web pages via HTTP;
- integrating with IOT Applications by managing real time data and connecting its actuators to real time IOT applications;
- integrate dashboards in more complex dashboards;
- support authentication and authorization with the most general approaches such as LDAP, Kerberos, etc.;
- collect and get data from batch resources and in real time.

This means that each Dashboard should be composed by a number of configurable Widgets, each of them can collect data coming from several data sources. On each data stream, one or more criteria as firing conditions should be set up for the notification of alerts, intervention, etc.

In small cities of at least 100.000 inhabitants the number of sources to be integrated by the aggregator and represented in Dashboard can be in order of 10-20 while in larger cities they can rapidly grow for the presence of multiple operators for each utility. Thus, the complexity is also greater as the actors to be involved in.

Therefore, before starting with the development of the proposed Dashboard solution, a number of state of the art solutions and proposals have been analyzed. As nonfunctional requirements, the Dashboard system has to be scalable, interoperable with several tools, open source, usable, secure in protecting data views, and flexible.

To this and, a number of commercial and noncommercial solutions have been analyzed to identify a viable functional platform to be adopted, and then we decided to start the development of the solution since they have not satisfied all the requested functional and functional aspects. Most of the solutions which are proposed on the state of the arts derive from business intelligence solutions (e.g., SpagoBI, Tableux, OpenDataSoft, etc.), in which the tools provide some data mart (data virtualization) tool to access data sources and thus have powerful tools in this sense while provide poor tools on rendering and dashboard for control rooms that have to stay H24/7, rendering specific kind of structured data. For this reasons, a number of specific custom solutions have been proposed by many cities such as: London, Amsterdam, Dublin, etc.

3. Smart City Architecture

This section presents the overview of the Smart City architecture which is presently in place in the Tuscany area. With the aim of producing a smart city infrastructure for stimulating sustainable mobility, smart energy, and smart utility in the city, a data aggregator has been developed. It presents a front end layer for the City Dashboard and control room, Smart City API for web and mobile App, decision support tools, personal assistants, participative portals, crowd sourcing, etc. The data aggregation also support Data Analytics and Data Intelligence based on integrated data collected from public administrations open data, private data from operators, and personal data coming from social media and city users. In this paper, the architecture enabling the construction of the Control Room in terms of Dashboard and Data Aggregator is reported.

In the Km4City solution, **City Operators and Data Brokers** provide data which are collected by using streams or ETL processes which are scheduled on the Big Data processing back office based on DISCES (Distributed Smart City Engine Scheduler) tool. Among the data collected those provided in Open Data from the municipalities, Tuscany region (Observatory of mobility), LAMMA weather agency, ARPAT environmental agency, etc., and several private data coming from City/Regionals Operators: mobility, energy, health, cultural heritage, services, tourism, wine and food services, education, wellness, environment, civil protection, weather forecast, etc. Once the data are collected, the back office activates a number of processes for improving data quality, reconciliating data and converting data into triples for the RDF store of the Knowledge Base [Bellini et al., 2014], [Badii, et al., 2017], implemented by using a Virtuoso triple store. DISCES is allocating processes on a number of virtual machines allocated on the cloud according to their schedule.

For semantic aggregation of data and service, it has been decided to exploit and improve the Km4City Ontology (http://www.km4city.org) [Bellini et al., 2014], as the main ontological model. Km4City is modeling multiple domain aspects related to mobility, services, Wi-Fi, cultural services, energy, structure (streets, civic numbers, green areas, sensors, busses, smart sensors, public structures, parking, city services, transportation, events, geographic locations, pharmacies, hospital and real time data of first aid, environment (with pollution and pollination, weather forecast, and private mobility with fuel prices.

In the smart city architecture in addition to the RDF store for the knowledge base, a number of noSQL Stores (namely: HBase and MongoDB) are adopted for storing tabular data as those arriving from sensors and user profiles.

4. Dashboard System Architecture

In Figure 2, the general architecture of the Dashboard solution is presented. The main components of the architecture are described in the following.

- **Data Aggregator** is a set of tools for collecting data from the field and from external services and reconciling them to the same city entities. To this

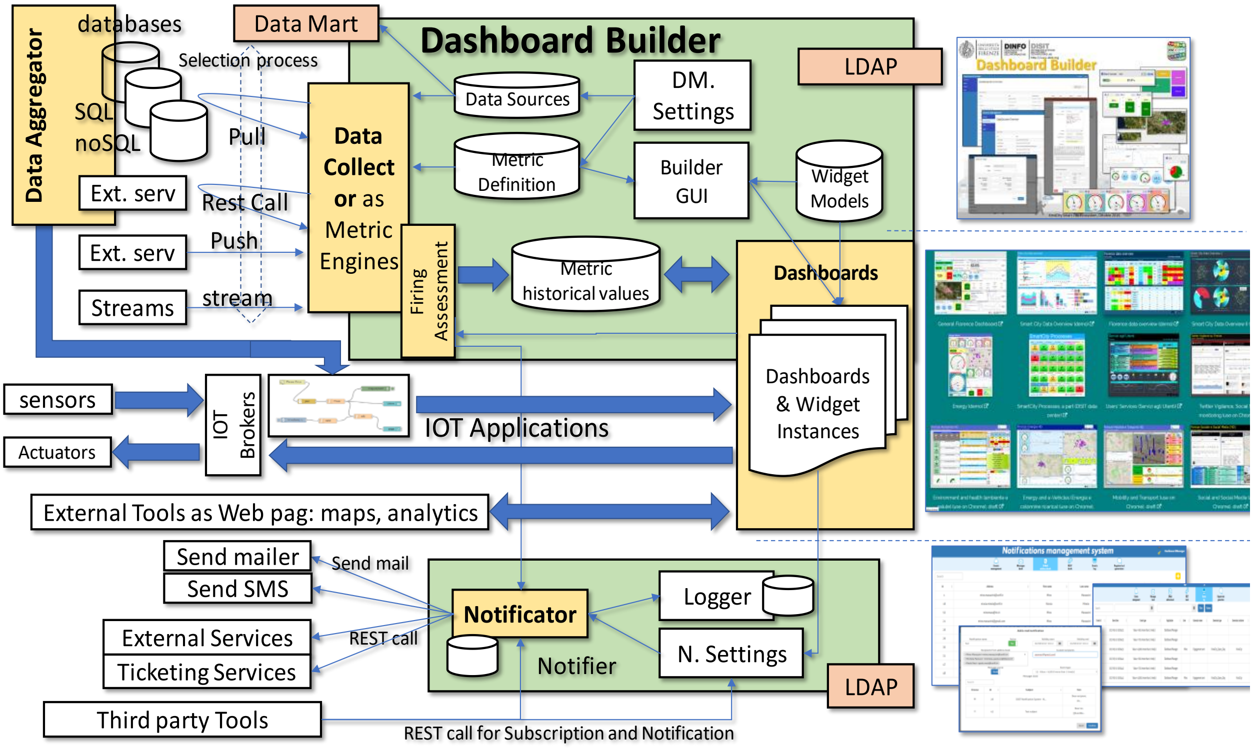

Figure 2: Architecture for Smart City Dashboard Management System integrated with IOT

end in the proposed architecture the Km4City Aggregation has been adopted to have all data fit into the Km4City Ontological model [Bellini et al., 2014]. Thus. Data are provided from the Aggregator with Smart City API (rest CALL), SPARQL, SOLR and/or SQL queries.

- **Data Collector** is a multi-process engine (also called Dashboard Engine) for acquiring data from multiple data sources: SQL, noSQL, RDF/SPARQL, API, SOLR, etc., by using multiple protocols: HTTP, HTTPS, ODBC, etc. The Data Collector needs to have a configuration for each acquisition process, which produce a result, also named **Metric** or Measure. Some of these **Metrics** may be saved into a local data base for historical reason. In order to finalize the queries to be performed for collecting Metrics, specific tools may be used for **Data Mart** such as database browsers and drilling down into Data Sources. The collected data can be (i) saved into a data base of **Metric Historical Values**, or can be (ii) directly accessed from Widget/Dashboard for their visualization. The Data Collector, with its processes to acquire Metrics, is also capable to perform the real time Firing Conditions Assessment.
- **Firing Assessment** allows to compute the firing conditions on all the data. In the case in which a Firing Condition becomes true, a message event is sent to the Notificator service. Conditions can be estimated:
  - on Metric Historical Values taken in Push from the data base of the builder,
  - on the streams directly arriving from the Data Collector;
  - from the data stream arriving directly from outside,
  - From the external tools embedded as IFRAME into widget if there is some integration.
- **Dashboard Builder** is the core tool for creating dashboards. In the tool the user can set up **Data Sources**: IP address, protocol, user name and password for accessing at each specific the data source. Once the data sources are identified a number of **Metrics** can be defined. Then new Dashboards can be created taking interested **Metrics** and associating them to one or more **Widget.** A Widget may render/exploit the same Metric by means of different graphic models. For example, a temperature read every 5 minutes, can be visualized as current value on a thermometer, while the trend in the last 24 hour, last week, last month, etc. can be show on a graph. Therefore, composing a **Dashboard consists of** placing and configuring a set of Widgets into the Dashboard frame. The Dashboards are created by using the visual interface of the **Dashboard Builder**.
- **Integration with IOT.** This feature has been covered by (i) producing special MicroServices as blocks that can be used into IOT applications developed in NodeRED, (ii) connecting NodeRED applications with a number of IOT brokers. Point (i) implied the development of a layer that allowed the traditional

Dashboard Widget to be connected to IOT applications by using IOT Brokers (for example in NGSI and/or MQTT) and/or WebSockets. To this end, the most suitable IOT broker has been the Fi-Ware Orion Broker.

Dashboards are typically adopted for reporting KPI of the city and thus of specific infrastructures and services. This means that specific alerts and notifications have to be activated and managed at level of single Metric. On the other hand, the same Metric can be used on different dashboards and widgets for different purposes. So that, for each Widget of each Dashboard specific alerts and firing conditions can be set up. For example, when Metric M is adopted in Widget W of Dashboard D, the certain criterion C is saved and computed for firing (M, W, D, C). One or more Criteria can be defined (M, W, D, C1….Cc), each of them may produce multiple Notifications,
N: (M, W, D, C1 (N1,…….., Nn),…., Cc(…)).
Therefore, the solution has been to design and develop a **Notifier** to

- Accept registrations of possible touples <m,w,d,c>, to enable the reception of *Notification Requests*, that are used to send Notifications according to different approaches.
- Accept registration by third-party tools, in addition to those of the Dashboard Builder, to send alarms about the firing of the registered conditions.
- Produce emails and REST calls, that can be used for calling SMS, as well as for the activation of maintenance ticketing system on OpenMaint tool for example.
- Log all the registrations and Notification Requests for further analysis and security evidence.
- Maintain and use a list of Notification recipients, that are the users which are going to receive the notifications. This list of uses is just listed as: name, surname, email, telephone (if any), role, organization.

To this end we suggest using specifically development tools, Such as the ServiceMap (http://servicemap.disit.org) which is used for knowledge base browsing over the city data as Km4City knowledge base, which is RDF store as well, exploiting geospatial reasoning and inference [Bellini et al., 2014]. In addition, the technical browsing on the RDF Graph Store may be needed to discover relationships. To this end, the LOG (http://log.disit.org) tool for browsing into any RDF store by using SPARQL and visual interface has been developed in the past and now used. This tool allows you to browse all the RDF stores accessible in the world which provide a public end point for SPARQL queries, from dbPedia, to Europeana, Geonames, Km4City, Camera, Senato, Getty, etc. [Bellini et al., 2014b].

As a conclusion, **Dashboard Instances** are available for view and activate corresponding widgets according to their Settings. The saving of data into the database of **Metric Historical Values**, allows keeping track of what has been visualized/monitored and thus enabling the replay of data logged. On the other hand, it is also possible to adopt widgets that (i) directly show/provide the data from in/out streams, respectively (for example, Civil protection alert status, etc.); (ii) directly render/visualize web page segments into the Dashboard (for example for showing social media analytics, traffic flow reconstruction tools).

5. Experimental Results and Validation

The solution proposed in this paper has been developed in REPLICATE flagship project SCC1 H2020 of European Commission for Florence City. It is also used in other large projects as Sii-Mobility Smart City Nazionale on Mobility and Transport of MIUR, RESOLUTE H2020 project for critical infrastructure and resilience of transport systems, and GHOST MIUR for Cagliari smart city experimentation. The proposed Dashboard solution is strictly connected with a number of tools of the Sii-Mobility/Km4City suite of tools which are used to perform smart city analytics, semantic browsing, and decision support, etc., such as: ServiceMap (http://Servicemap.km4city.org), smartDS, system thinking decision support based on Bayesian models (http://smartds.disit.org [Bellini et al., 2016]), Wi-Fi monitoring and predictions, smart parking prediction, traffic flow reconstruction and prediction, energy metering, first aid monitoring, environmental monitoring, social media monitoring and alerting, weather forecast, etc.; most of them based on clustering, machine learning, etc. [Badii et al., 2017].

In general, the decision makers in the city are politicians, assessors, and director of units. Some of the units have already adopted a high level of technology, for example, the mobility and transport, the civil protection, etc. In other units, the level of control is low since the technical activity is mainly delegated to City Operators such as: energy operators, public transportation, water management, health care hospitals, environmental agency, waste management, police and alert (112, 118, 911), etc. All of them have their own monitoring system, that is tuned to vertical control their own information and status. In some cases, the general information about weather forecasts and status is shared among the different operators. The dashboard can organize data according to different views/paradigms: vertical and horizontal view.

5.1 Example of Vertical thematic oriented

public transportation: position of busses, number of active busses, average delay at the bus stops, number of active taxis with respect to the plan, number of recharging stations for public vehicles, number of people on busses, percentage of busses with respect to the plan, number of events/incidents on traffic, status of the underpasses, status of the bridges, number of tickets, number of free lots in parking, events in the city, etc.

private mobility: level of traffic flow, traffic flow reconstruction, number of free lots in parking, number of cycling people on paths, number of vehicles entered into the RTZ, number of vehicles entered in the city, number of truck on the main streets, number of shared bikes in percentage, events in the city, etc.

Energy: KW/h or MW/h consumed in the last hour for public services, KW/h or MW/h consumed in the last hour for recharge stations, KW/h or MW/h saved by public services since the usage of renewable energy production, KW/h or MW/h saved in the store and available for consumption, number of monitored meters grid, saved energy by following suggestion provided by Apps, etc.

Environmental data referring to different area of the city: temperature, humidity, PM10, PM2, CO2, wind, pollination, etc.; weather forecast; level of water in the rivers; level of drinkable water; Tons of collected garbage; Tons of collected garbage differentiated; earthquake monitoring; etc.

Social: status and stream of the social media; the most cited users on Tweet; the most mentioned hashtags on Tweet; the sentiment analysis on Tweets connected to the city; number of people moving the main area; number of people arrived by train in the City; TV cameras about the main points of interest in the city; number and list of the major entertainments, political, and sport events in the city; etc.

Security: data also presented on the Social Dashboard describing the presences in the city of people; any kind of event in the city from entertainment, sport, political, religious, etc.; eventual paths and area of the events; TV cameras observing the areas of the events; number of resources available for controlling the city and their deploy on the city map (cop, ambulances, 118, 911); aspects related to the environmental data; aspects related to mobility for planning the evacuations; aspects related to the public transportation for eventual change the paths.

Health: data reporting the status of the triage in the major hospitals; position of the emergency stations; number and position of the ambulances; environmental data for hot waves, temperature, etc., which can increase the risk of stroke.

5.2 Examples of Horizontal User Oriented

Event oriented: a dashboard for controlling the status of city with respect to a large event (such as the visit of Pope, or US President). In that case, the dashboard would be dedicated to monitor the paths that would be probably used, the status of traffic in those area, the number of police and security resources in those area, the Tv cameras, the hospitals, the other events and micro-events (accidents, crashes, fights), etc.

Tourism oriented: a dashboard reporting the major events in the city, the number of arrivals in the city, the number of people in the major points of the city, the number of accesses to the museums, etc.

As a conclusion, after the production of a set of Dashboards some of them where selected for trial and are reported in the web site for your public access from Http://www.km4city.org where most of them are presenting data that can be rendered on screen to public. This does not mean that the published data are open and that can be downloaded to be reused and published/exploited for other purpose. Moreover, the Dashboard can also contain data that cannot be visualized by public, for safety reasons, and thus are protected by some conditional access solution. For instance, since they are sensitive data describing the city status in real time or by predictions. Many examples of dashboards produced by the presented tool can be accessed from Http://www.km4city.org Presently about 10 qualified users have developed a total of 153 dashboards that have been accessed by thousands of viewing users per month.

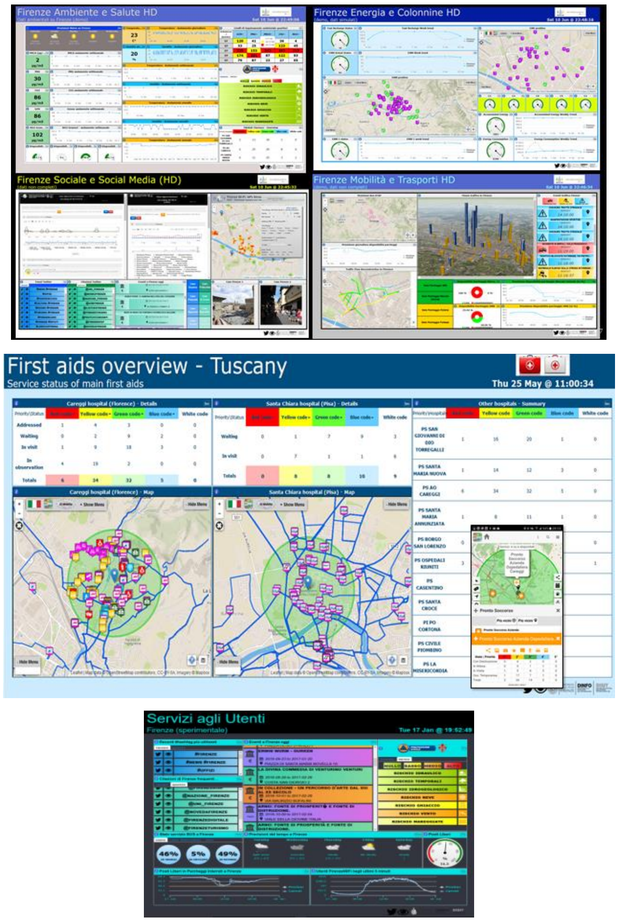

Figure 3: Florence Smart City Dashboards, dashboard reporting first aid status, and a final user dashboard for hotels

6. Conclusions

Smart City Control Rooms are focused on Dashboards. The dashboard production is a continuous working for improving city monitoring, adding more data, focusing on critical issues that may have seasonal aspects, follow special events, and/or works for city improvement and maintenance. Complexity is due to the needs of data aggregation and to the identification of modalities to present data, their prediction, early warning, etc., and corresponding notifications. In this paper, the architecture and principles of the Dashboard Builder has been presented. As a validation, the tool has been adopted for generating the dashboards in Florence city and Tuscany area and accepted. An analysis of the possible views has been also provided. The solutions proposed have been developed in the context of REPLICATE H2020 European Commission Flagship project on Smart City and Community, and it has been validated during the usage with real city users. The dashboards produced and considered are all accessible online, and the Dashboard Builder is released in Open Source on github/disit.

7. Acknowledgements

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