Fostering Smart Mobility for Middle Sized Cities

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Abstract*— Urban Mobility systems play an increasingly important role in the way people move around their communities and how communities develop. Despite the significant benefits to using public transportation, many potential riders are reluctant to utilize public transportation. In this current situation, cities and communities are increasing efforts to provide multiple solutions for urban mobility and to promote it among their users. Although such an approach provides valuable alternatives to the citizenry, it also multiplies the information flow that users and service-providers must gather. Riders and commuters are, then, often confused or intimidated by the complexity and unpredictable nature of transit systems. In this paper, we present the results of the group discussions held in Trento at the IEEE-SC Workshop on December 2014 focusing on the topic of Smart Mobility. During this workshop, we analyzed in detail the current situation of Trento as a Smart City and the general requirements for transforming a good mobility plan into a smart mobility action. Our group contributions converged into five main priorities: 1) developing citizens' awareness regarding the adoption of alternative services; 2) engaging citizens themselves as an important and valuable source of input; 3) enhancing Localized Based Systems (LBS); 4) the creation of an open platform, with an advanced Dashboard, through which citizenry, administration, and businesses can easily develop civic apps and services by means of intelligent and aggregated information, even in real time; 5) last, but not least, increasing the communication network by leveraging the development of cooperative systems.

***Index Terms*—Smart City, Smart Mobility, Urban Mobility, Open Data, Big Data, Gamification, Crowdsourcing, Crowd-sensing, Dashboard, Cooperative Systems.**

I. Introduction

We all know the experience of having to wait for a commute, whether it is at a bus stop or sitting in a car at a traffic jam. It can feel like one is waiting forever! However, this experience is largely due to our perception of the events. In fact, in a study conducted at the University of Washington [1], the time transit riders waited at bus stops was measured, and then each of the riders was asked how long she/he had been waiting. Bus riders, on average, estimated their wait was 50 percent longer than it actually was. Several research results demonstrated that having the correct information makes public transit, suddenly, an agony-free journey, thereby enhancing the lives of citizens.

In addition, a survey report shows that more than 90% of users were more satisfied with public transit as a result of obtaining real-time information on public transportation (as depicted in Figure 1). Additionally, in an era of cash-strapped transit agencies, this means these agencies could provide better service without literally providing a better service at all. This situation also means that they could significantly improve their product by focusing not just on the travel experience itself but also on what happens before we board the relevant public transportation vehicle.

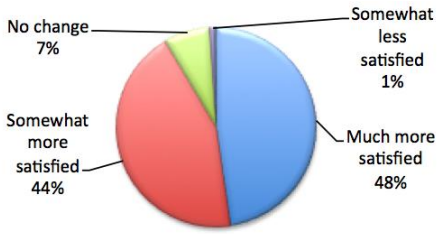

Figure 1- Overwhelmingly positive change in overall satisfaction with public transit by providing users with organized real-time public transportation information (from [1])

However, mobility is not only provided by public transport. The term of mobility includes the way in which citizens use the city: it implies using cars, parking facilities, bikes, sidewalks, as well as the manner in which the citizens move through the events and how simple and unified the access to service payments is. Mobility can occur within outdoor and indoor scenarios (e.g., inside large shopping malls, when travelling by metro, etc.). In this context, it is deemed necessary to envision a mobility plan that is actually smart, able to interconnect the different aspects of the transportation realm and integrate the relevant information.

Clearly, our goal is not to force citizens spend more time using applications and portals, rather, to reduce the efforts

required for citizens to adopt a new service or understand a piece of information. The societal benefits derived from an increase of intelligent transportation accessibility are numerous. The case of an app providing real-time information on the status of urban means of transport has an impact on several levels. Less time spent waiting for transportation equals more time for personal and professional activities, i.e., **social and economic impact**. Making mobility a more predictable and accessible experience not only has a clear **impact on the environment** but also on the time that people use for their activities. A more responsible and smart use of transportation systems provides better mobility, thus improving the access to workplaces, municipal offices, education, and medical care as well as enhancing personal safety and security, i.e., a **community impact**. The provision of open application interfaces greatly facilitates the development of a new economy of medium and small companies that can specialize and provide customizable applications to its users, i.e., a **business impact**. In Trentino the mere publication of data regarding timetables and locations of bus-stops has enabled the creation, in a very short time-span, of seven applications available on mobile media, thus allowing for the development of quality users' applications. Encouraging multi-modal transportation, and more eco-friendly shared means of transport, reduces congestion, gasoline consumption and a nation's carbon footprint, i.e., a clear **ecological impact**. In 2007, public transportation spared 646 million hours of travel delay and 398 million gallons of fuel in the U.S. alone, resulting in savings of $13.7 billion in congestion costs [2], which also corresponds to a huge reduction of CO_2 emissions. Many similar scenarios could be built over the European landscape and Trentino as well. Furthermore, while eventual hybrid and electric-vehicle technologies can reduce the carbon-footprint of single occupancy vehicles, they cannot compete with public transit in terms of traffic reduction and in promoting compact, sustainable communities rather than low-density urban sprawls. Last, but not least, the reduction of road traffic is the only viable way to provide a responsible use of transportation systems with a consequent reduction of road accidents and litigation, all unpleasant situations for the community, i.e., **people's serendipity**.

Although most of the data are already available in the Public Administration's (PA) information system, such data are still heterogeneous and often not completely appropriate for being used "as is." Thus, a first objective should be preparing an environment that allows the collection of required raw data and the creation of a platform that integrates the data to produce meaningful information readily usable by application services.

Empowering the sharing among urban mobility stakeholders and the access to PA's Open Data with enriched information is a straightforward means to guarantee a viable and successful Smart Mobility plan.

In this paper, we consider some of the topics that are characteristic and essential for building a Smart City, targeting middle sized towns such as Trento. More specifically, the document is organized as follows. Section II analyzes the current situation regarding Smart Mobility worldwide, highlighting the main concepts and requirements for building a smart urban mobility plan. Section III focuses on the current situation in Trento, how it is now and where it is going in terms of Urban Mobility needs and choices. Section IV evaluates priorities in terms of smart development, delving into five main aspects that are considered fundamental to succeed when building a Smart Mobility plan. These priorities consider both a shorter term plan, which is required to quickly improve the situation with a minimal cost, and longer-term plans involving advanced communication systems, which require an incremental integration based on innovative aspects still under research. Section V concludes the paper.

II. State-of-the-art and trendset

a) Current situation

The development of Smart Cities is now one of the main topics in the agenda of the European Commission and of several countries worldwide, aiming at creating an urban model that can guarantee a high quality of life for individuals and businesses alike, optimizing resources and space for sustainability, making it easy to move around, minimizing the time and energy required for transportation, thus increasing opportunities for personal and social growth.

The starting point for this development is the projection that by the year 2030, 60% of the global population will live in cities, consuming 73% of the world's total energy supply [3]. This trend shall primarily impact bigger cities, but even small- and medium-sized cities, such as Trento, will be affected by this urbanization trend, which increasingly challenges in the organization of urban mobility.

The future of urban mobility obviously depends on the current status of transportation systems and management applications. Indeed, there are completely different situations all around the world influencing the potential adoption of a technical solution targeting mobility optimization because of the dimensions, the specific geographical conformation, or structural characteristics of the transportation systems. For example, a city such as Venice should be almost exclusively pedestrian, with just sea-side mobility connections. Larger American cities, such as Los Angeles, or large urban centers in the Middle East, such as Abu Dhabi, are quite entirely dependent on individual means of transport, typically cars, while other cities represent a sort of a middle-of-the road model. In addition, when living within these cities, we spend approximately 90% of our time indoors, often in unknown environments (e.g., airports, train stations, etc.).

In this configuration, we primarily find the same modes of moving people and freight, with the possibility of different regulations and strategies, but most of all, there are different technologies that could be applied to monitor and to control behaviors, system components, mobility stakeholders and players to provide such information to both the local public and travelers. Some examples of these technologies are smart cameras that can automatically read the license-

plates of those vehicles entering historical urban centers (no thru traffic) or unified multifunctional smart cards usable for accessing public transport and other services, such as parking. This information can be further used for computing city-related statistics to be then redistributed to citizens.

b) Smart Mobility concepts

The mobility aspect of a city should also look beyond its own internal needs and must also be connected to the external environment at a regional, national and even international level, which implies that local transportation networks must also be well connected with all other infrastructures (railways, roads, streets, highways) and means of transport (trains, vehicles). The requirements are summarized below:

- Properly integrated and interacting effectively with the territory.
- Without non-homogeneous segments.
- Able to offer conditions of real competition among the different users of the network.
- Able to guarantee modal inter-exchangeable processes.

The new paradigm of mobility is "Better Moving for Better Living", and Smart Mobility is the new approach to conceive it, meeting the transportation needs of goods and people in an effective and sustainable way, thereby elevating the quality of life. With respect to this definition [3], the main points of impact by the adoption of a Smart Mobility are:

- Reduced CO_2 emissions.
- Increased safety of the whole transportation system.
- Optimized solutions for transport planning and management, with relevant support for multimodality.
- Reduced mobility needs for both individuals and goods.
- Optimized interoperability enabling for more efficient transport networks.
- Provide citizenry/users with mobility-related, value added information through open data platforms and correlation algorithms.

To address this last point, one of the core actions consists in opening and making data and information available to support smart mobility services, enabling and encouraging ICT platforms and creating the conditions for the interoperability of systems and cooperative informational exchange among all the actors involved; to this aim, wide open data platforms have been developed, for example, in Toronto and New York City, to provide citizens with information concerning traffic restrictions or speed detection. With the same purpose, the World Bank is sponsoring a similar project in Saint Petersburg [4].

c) Telematics for Mobility: some best practices

The set of technologies that can be applied to manage mobility within smart city contexts belongs to the broader set of Intelligent Transport Systems (ITS).

ITS are Information Technology and telematics platforms that support urban policy goals in areas such as travel information, traffic and demand management, smart ticketing or urban logistics. An integrated approach is even more required in urban areas due to the particular issues in such areas, including the various means of transportation and the combination of both technical and policy issues, for example, the introduction of "park and ride" monitored areas where people can safely leave their own vehicles and use public transportation. Several technical benefits are possible due to the introduction of an **Integrated Smart Mobility** (ISM) concept.

ISM implies a combination of Systems and ICT Infrastructures (Access Control and Enforcement Systems, Traffic Lights Coordination, Traffic Sensors Networks, Public Transport Management, Integrated Parking Management, Variable Message Signs, Integrated Payment and e-Ticketing solutions), Infomobility Services (pre and on-travel), Qualification and Differentiation of Public Transport Services (BRT, Demand Responsive, …), Urban Logistics Services, Integration of Different Modalities, and Additional Green Measures (e.g., collective taxing or carpooling).

Some middle-sized important cities, such as Florence or Verona, have experienced the integration of traffic data collection, traffic lights dynamic centralization, public transport management and coordination, together with the development of an integrated platform for traffic-related information and its monitoring and coordination. This type of approach has led, for example, to the possibility of prioritizing public transport and emergency vehicles at intersections and to the possibility of actually implementing a coordinated transport management strategy in those interested areas, as all ITS applications can operate collaboratively.

Such an integrated approach also allows for a comprehensive network monitoring process, the possibility of computing efficient traffic forecasts and performing real-time status monitoring.

The combination of technologies and measures can lead to (figures from actual experiences in Italian cities):

- Reduction of travel times in public and private transport of up to 30%.
- Reduction of fuel consumption of up to 15%.
- Reduction of traffic-related pollution (emissions) of up to 20%.

Those are very important impacts that can significantly improve the livable standards of large and middle-sized cities.

d) Social benefits for the public and government

Apart from the pure technical benefits, such as the reduction of queues/jams at intersections due to traffic-light centralization algorithms, integrated Smart Mobility platforms can also lead to social benefits, both for governments and the public alike. For governments, there is improvement in the level of information management and efficiency of information usage, improvement in the level of macro decision-making and improvement in the overall level of management and services. For the public, positive impacts could arise from the fact that information services make traveling more convenient, that travel-times can be reduced/spared, and traffic congestion can also be reduced,

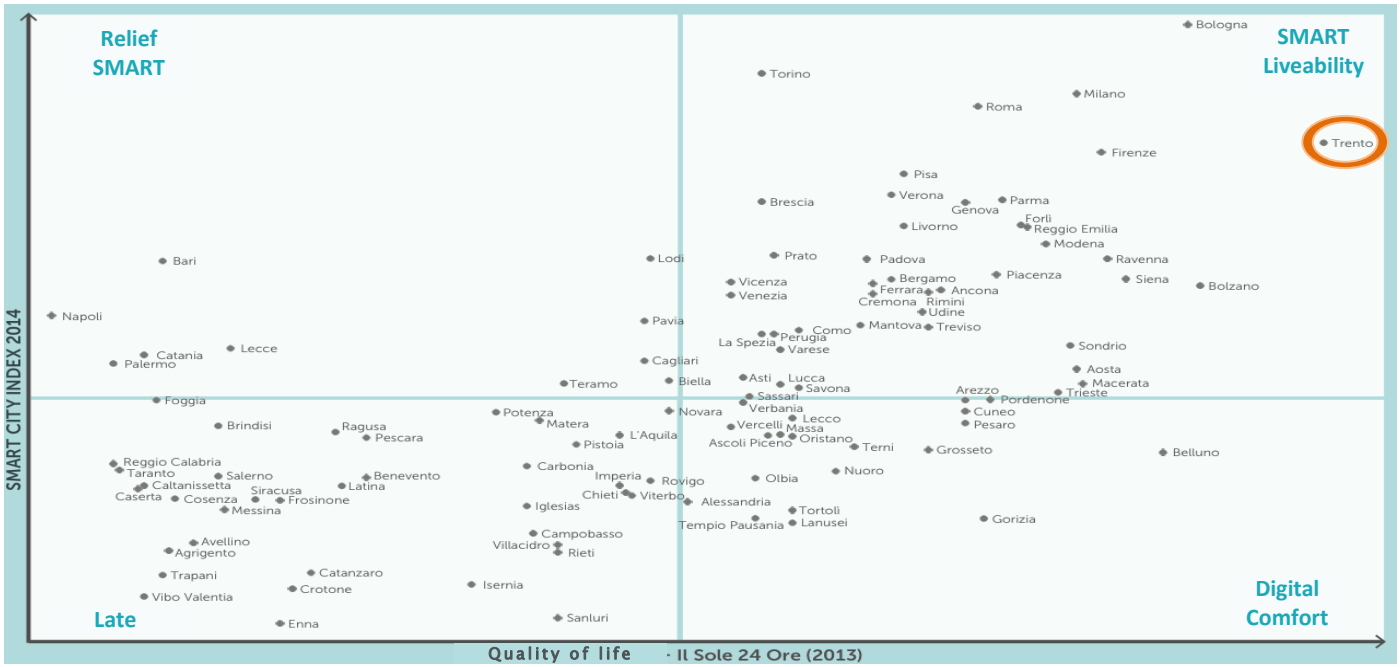

Figure 2 - Forum PA Smart City evaluation index correlated to the quality of life index for Italian cities [6]

as well as saving energy consumption, decreasing environmental pollution and saving travel costs. Further positive side effects are the generation of higher comfort for drivers and the improvement of traffic safety. With a harmonized traffic flow, the instances of road accidents should decrease significantly.

More specifically related to improvements in the Public Transport Service, there should be an increase in regularity and commercial speed together with a reduction of operational costs.

III. Current Situation in Trento

Trento is considered to be the Italian city with the best quality of life and is at the top of the national rankings on Smart City rates, such as the rankings realized by independent parties like Forum PA [6] and Between [7]. A representative picture of this situation is portrayed in Figure 2, which shows the distribution of all main Italian cities with respect to their quality of life in correlation to the Smart City index (as reported by the Sole 24 ore evaluation[1]).

This condition is made possible by the context that characterizes Trento: its size, its attention to inclusion and especially its centrality in a territorial system that sees the presence of the University, and many research and innovation institutions that collaborate with the Public Administration for the evolution of the territory. In fact, Trento is well regarded today as a center of excellence, recognized at the national, European and international levels in the field of Smart Cities, and, regardless of how such recognition has been achieved, Trento and its entire province are now under the media spotlight. Although the spotlight entails having a responsibility to progress as a smart territory, it also provides the opportunity to leverage this reputation by combining innovation with the capacity of creating new business opportunities.

As mentioned in Section II, an important aspect for evaluating the potential development of urban mobility directly depends on the specific geographic conformation and the structural characteristics of the town itself. With respect to this aspect, Trento is characterized by a very long and narrow valley-floor conformation with a rather difficult urban communication infrastructure. Indeed, the city of Trento is approximately 16 km long and is partly distributed on the valley area and partly on the surrounding hills, posing high difficulties when having to cross the city from east to west on its narrow side because of the presence of the railway, the river and the main traffic lanes. Trento is the capital city of the province, with 110000 inhabitants, and represents the main traffic attractor [5]. Figure 3 depicts the average vehicle traffic level in Trento that, with its 358700 units on average for a normal weekday, is already at a level of saturation for the area. An adequate improvement of the current public and shared transportation service would be a suitable solution.

Figure 3- Daily average automobile traffic in Trento

[1] http://www.ilsole24ore.com/speciali/qvita_2013/home.shtml

In fact, the peculiar geographic conformation of Trento, added to the situation presented, is the cause of useless, enormous traffic, excessive fuel consumption, air-pollution and noise, avoidable road accidents, and, of course a decreased quality of living. A rational improvement of public and shared means of transport would make the entire city more attractive, thus avoiding the ever increasing development of private vehicles/cars.

A first step for building and improving the mobility situation has been implemented by considering citizens' views regarding the current situation of urban mobility. As highlighted from the survey performed in Trento[2] (results shown in Figure 4), the main priorities for the citizenry requiring particular attention are: commute time, improved level of the transportation service, and an increase in comfort.

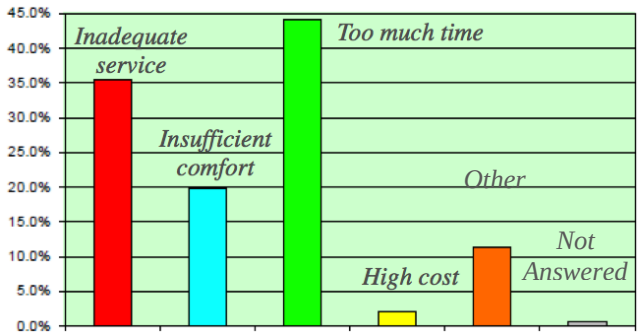

Figure 4 - Urban Mobility survey

In response to the need for a smarter mobility service, the municipality of Trento has already implemented a development plan favoring the increase of multi-modality service by allowing for the creation, in the past five years, of a shared modality of transportation, such as car and bike sharing, dedicated parking systems, and, bootstrapping carpooling services. However, although the adoption of such solutions already improves most of the inadequacies highlighted by the survey, as mentioned above, the bespoken experiment conducted by the University of Washington proves that users who are able to access real-time information completely change their views about the service [1], with users expressing satisfaction without any real change in the service itself, thus providing an adequate response with minimal financial investment. Following this line, the PA is also increasing the possibility of accessing data and empowering the dissemination of useful information to commuters, thereby enhancing the efforts of collaboratively sharing the information with all the stakeholders, public and private, of the local urban mobility.

The next section considers some of the priorities that (in addition to the priorities already implemented by the current administration) have been highlighted by the IEEE-SC Mobility working group to improve urban mobility in the city of Trento.

[2] Presentation of the Urban Mobility Plan: http://www.comune.trento.it/content/download/547107/5282543/file/Presentazione%20PUM%20TN%202010%20CComunale%2013-04-10.pdf

IV. Priorities

It isn't possible to discuss Smart Mobility without first identifying priorities and guidelines for an effective development of transportation systems and iterations with the services. Developing mobility, in fact, involves not only planning and improving the transport of people and assets but also the actions and services useful in making easier, safer and informative the displacement of people and the fruition of a territory.

Looking at the current state of transportation in and from town, certainly the development of a strong inter-modality is the starting point of a smart mobility management practice. This term sounds a bit abstract, but conceals the basis for rationalization of the transport systems active in the territory (e.g., train + car or bus + bike + walks). The inter-modality and its corollary multimodality are being implemented in cities around the world, and Trento in this context has all the opportunities to develop new processes in this area. This new way of organizing mobility requires the involvement of many players (public and private sectors acting together for the management of transport and its coordination and the entire citizenry with their sensing capabilities) to share information useful for all subjects involved in the planning process.

Starting from these considerations, the development of solutions for car sharing or pooling is a priority. It is inevitable, in fact, for public transport not to fully serve a territory, so it becomes necessary to satisfy the needs by using private vehicles; however, in a perspective of scale economy and emissions reduction, the sharing of vehicles and travel-paths becomes an opportunity both for developing new services and for growth. This approach is the direction in which cities such as Trento want to move, through increasing the available infrastructures and the sharing of information.

Infrastructure, at this point, is the heart of a smart mobility process. This process involves not only the transport-related infrastructure but also infrastructure related to communication and information sharing and those having to do with sensing (real or crowd) the effects and obstacles encountered in an efficient mobility scheme. All of these types of infrastructure play an increasingly central role in the use of intelligent traffic lights and street lights, as well as reconfigurable indicators for traffic information in network monitoring by means of cameras that can recognize vehicles and events from the perspective of planning as well as pricing/ticketing and sanctioning. In addition, in this scenario, cooperative systems together with a real Citizen Engagement could drive Trento into becoming a smarter city, especially if new services and apps are designed and implemented.

Furthermore, new mobility modes should consider that people spend a large share of the day in indoor spaces. A series of studies in different continents at different times indicate that people spend approximately 90% (on average) of their time indoors. IT support for indoor location applications has to date lagged well behind outdoor space

applications using GPS and GIS technologies. In addition, the spaces themselves (e.g., public buildings, museums, and hospitals) have become increasingly complex; the data are now slowly becoming more readily available. Additionally, an increasingly aging population requires more assistance indoors.

Importantly, today's smart mobility also must improve the fruition of the city for disabled and disadvantaged groups, such as the elderly and children, who must be able to benefit from the possibility of moving in times and ways that are best suited and easier for all. Among the categories to which special attention is required include the occasional city-dwellers, such as tourists or commuters, who must obtain information useful to their mobility, including smart charging systems for payment of mobility services (buses, bike sharing, parking and so on).

Among the possibilities to be further developed applying smart solutions for the displacement of people and goods over the territory, we must not forget the improvement of the infrastructure for hybrid and electric vehicles in addition to the solutions for the management and optimization of delivery vehicles. The experience drawn from many cities in the world teaches us that mobility is not only for those who travel for business or leisure but also, above all, for those who work daily "on the move", as is the case with van/truck drivers.

All of the above-described considerations must be planned by means of effective actions, as described in the following section. However, one point must be made clear: on one hand, in our search of smart environments, by no means are we to ***technocrize*** our cities; on the other hand, we should instead render the entire system user friendly, open, and of easy access for the layperson, particularly on behalf of those citizens that fall into categories like "PC illiterates" and/or "tech novices" (as it may be the case with senior citizens, or the elderly in general, children, sensory handicapped people, and other so related groups).
We must bear in mind that "*a fancy technology doesn't make a city any smarter, but just more complex, cumbersome, and unlivable instead*".

A. Citizen Engagement

There is no smart city without **smart citizens** inhabiting it. In addition, when we consider urban mobility, the concept of being "smart" depends on several factors.

A citizen is smart if she/he has an **easy and real-time access** to mobility information and if she/he can use/exploit in a **personalized** and **dynamic** way the mobility resources that best fit her/his needs. Regardless if she/he is a student cycling to the University with her/his own bike, a daily worker using public buses, a tourist walking around the city center, or a van-driver delivering goods, this person must access the appropriate mobility resources, when and where she/he needs them.

Another key characteristic of a smart citizen is **being aware of the impact** of one's choices (e.g., in terms of traffic, carbon emissions, social costs) and **actively contributing** to the improvement of the mobility situation in one's own city (e.g., adopting more sustainable behaviors, providing crowd-sourced/sensed mobility information, providing mobility-related shared-economy services).

Given this situation, it is clear that the challenge we are facing is not only technological but also concerns the **redefinition of the culture of urban mobility**.

Innovative and often costly programs introduced by cities to promote sustainable behaviors are liable to fail if not combined with initiatives aimed at changing citizens' attitude and at increasing their awareness towards the problem.

Daily transportation choices of citizens are mainly driven by habits and proximity. Most car drivers still believe that a car is the fastest and most flexible way to get from A to B. Yet, considering the common traffic situation during rush hours and parking issues, in most cases, they simply do not know that a more convenient and faster connection might exist. As a result, a key aspect is the lack of awareness regarding the different available transportation alternatives on their real value in terms of time, cost, and carbon footprint, not to mention other even more important parameters for a better urban commutation, such as security, safety and serendipity of having a cleaner life environment.

Numerous grassroots-initiatives are being launched from the mainstream to provide more sustainable and collaborative mobility solutions (e.g., ride-sharing, walking, buses, park-sharing)[3]. However, most of these shared-economy initiatives struggle to scale up and often do not survive long after their bootstrapping. This difficulty is mainly due to the fragmentation and isolation of these initiatives, **lack of dynamicity and flexibility** (especially whenever time is a strong constraint for the user), and last, but not least, difficulty in breaking away from the existing ways of doing things.

In recent years, **gamification**, i.e., *the use of game design elements in non-game contexts* [8], has been successfully applied to many systems and apps in many sectors. Both practical experiences from the market and studies from literature sources confirm that gamification can be very useful in increasing citizens' participation and awareness, as well as in promoting sustainable mobility behaviors [9]. For example, gamification makes it possible to drastically reduce traffic congestion [11], reduce carbon emissions [12], or, by coupling gamification and crowdsourcing, to involve citizens in sharing information regarding city parking and to distribute the parking usage in an optimized way [10].

Harnessing the power of **transformative ICT technologies** (e.g., Future Internet, Cloud Computing), of ICT networks (networks of people, of things, of open data and open services), and of advanced participation and gamification techniques will significantly improve the current situation, enabling the creation of a collective and individual mobility intelligence, catalyzing the enthusiasm of citizens, and driving them to adopt virtuous behaviors.

[3] Park Circa: http://www.parkcirca.com, BlaBlaCar: http://www.blablacar.it,
Uber: https://www.uber.com, Jungo carpooling: http://www.jungo.it

B. Cooperative Systems

The concept of a smart city is tightly bound to cooperation, distributed intelligence, local peer-to-peer interaction and communication. This relationship is even more evident when applied to mobility, in which case, information, instead of being shared locally where it is generated and needed, is first centralized and then re-distributed because of the cost and cumbersome nature of infrastructure. In general, we should consider the use of peer-to-peer applications built on heterogeneous, volatile ad-hoc networks that can sometimes access the global Internet when it is useful/necessary to complement the local intelligence and information systems. This consideration applies both to systems related to traffic management and road safety, as well as community communications.

Focusing first on road safety and management, the presence of short-range communication devices on vehicles is becoming a "take-it-for-granted" feature. Vehicles can have on-board both systems dedicated to inter-vehicle communications (DSRC/WAVE/802.11p) [13] and general purpose devices (Smartphones with WiFi) that enable communications with pedestrians, bikes and other actors. Cooperation goes from the simple application helping drivers to perform the correct maneuver to let an emergency vehicle pass, to more complex applications, such as assisted emergency braking in the case of accidents or similar events, to anti-collision systems at crossroads. In addition, traffic management and re-routing passes through local ad-hoc, peer communications, although access to global information can, in some cases, be useful for a global system improvement ([14], [15], [16]). Coupling local direct communications between interacting mobile phones and vehicular networks can enhance safety and increase the scope of ad-hoc networking. Imagine a smart handheld device that autonomously knows (by way of localization and, e.g., self-learning techniques involving its owner's habits) that a pedestrian is going to cross a street. The device can start sending broadcast beacons to approaching cars; these cars and the respective drivers can use the messages to slow down and prevent accidents. Such a scenario is of particular importance in streets with low visibility or under weather conditions that drastically decrease the available reaction time for drivers.

Community communications include a vast set of scenarios and applications, all of which are best supported by ad-hoc networks with peer-to-peer applications, for example, the creation of a platform for sharing local content among mobile phones in situations in which it is difficult to access other communication networks (4G or Wi-Fi). Imagine crowded places, such as stadiums or fairs, in which thousands of people are crowded into a very small area. In such situations, in which the communication infrastructure cannot guarantee even basic connectivity, ad-hoc networks can be a viable instrument to spread messages of any type that can be helpful for the efficient exiting of people, such as emergency messages and information about traffic. Many of the technologies required to achieve these systems are already available, and some of them are even present on today's cars and mobile terminals. For example, recent smartphones support direct mobile-to-mobile communications using Wi-Fi (such as its peer-to-peer variant Wi-Fi Direct) or Bluetooth technologies. The currently available technologies indicate that the development of smart cities also passes through systems that make the urban environment a communication plaza that is not mediated by arbitrage positions, and re-empowers people with the control of their communications [17].

Ad-hoc networks of mobile nodes can be created to interact with smart objects, sensors, and actuators and can be a valuable instrument for public administrations and commons-based organizations. As a mobility-related application, imagine that the Province of Trento develops a mobile app, capable of direct Wi-Fi communication among terminals, and uses it to spread critical information about mobility, such as: weather forecasts when the weather is expected to heavily impact on traffic and updates on interruptions of public transport due to failures, strikes, or other reasons.

Currently, such information is spread using standard, conventional media; however, the information could be delivered, at no cost, on ad-hoc networks to reach the majority of citizens as fast as possible or to make the dissemination process more focused, thereby increasing its impact. Such information can be coupled with local information in the mobile device to achieve a higher impact of the presentation, exploiting only the pieces of information that are relevant to the specific user. For example, the mobile terminal can be aware of the fact that the user is currently in his car and is not interested in train-related updates. Similarly, the decision about propagating the information can be taken locally at the mobile terminal, benefiting from the knowledge of the current geographical position of the terminal to deliver only information relevant to a certain area of interest. Stressing the importance of location is also fundamental to preserve users' privacy: decisions can be taken at the terminal without the need of sharing private data with a cloud-based remote service that might not even be available.

For non-critical applications, the technology is already available; in fact, it is even already deployed in certain cases, for example, the FireChat mobile app was the first app reported to be able to create networks of people using their mobile phones without the need of any network infrastructure. For critical applications, much development is still required, both in terms of research and information management. One key issue is data and network protection, and, consequently the interaction with the existing infrastructure. When a false alarm is shared within a crowd, this information can spread panic and create chaos. Similarly, if a non-existent alarm is generated on a highway, this could lead to accidents, instead of preventing them.

The validation of data and the protection of the ad-hoc network are critical issues that must be faced to guarantee that distributed platforms cannot be misused; this not only

applies to emergency applications or critical situations but also to the entire framework, keeping in mind the interactions with completely distributed networks and peer-to-peer protocols, which prevent the application of standard techniques, such as firewalling [18].

C. Location-Based Services

After several years of missed expectations, the Location-Based Service (LBS) domain is now expanding significantly. In particular, the market relevance of indoor location and mapping applications is extremely significant for new mobility concepts. In fact, because 3D and turn-by-turn directions are now a commodity within most navigation systems, indoor localization is regarded as the next big market opportunity, or, as stated by IndoorLBS (http://www.indoorlbs.com), *"indoors is the last mile and the next frontier for the location services market"*.

In recent times, several companies are investing significant resources to create indoor mapping databases, which are essential to be able to provide advanced indoor location based services. Nokia has already acquired thousands of locations for their Destination Map products, while Microsoft has already mapped thousands of indoor locations for their Bing maps suite. Google has already collected tens of thousands of floor plans from companies that want to be included within their mapping solutions. Google is also promoting crowdsourcing of indoor mapping data through Android smartphones. As result of this trend, according to recent forecasts made by IMS Research (www.imsresearch.com/), by 2016, up to 120,000 indoor venues will be mapped and will be available to consumer applications. Even more optimistic figures are foreseen by ABI Research, which have recently predicted that by 2017 the number of indoor maps available will increase to 500,000 venues.

However, as noted by several analysts, the "closed" approach to indoor data may not be winning in the medium-to-long term. Potential data owners, in fact, would have no control over the data regarding their premises. In this case, open indoor geographical data could indeed provide a more successful option. This assumption is driving the development of the www.i-locate.eu project, funded by the European Commission; Trento hosts one of the project's pilot sites promoting different examples of brand new smart mobility services for personalized door-to-door navigation services using public transportation.

From an infrastructural point of view, this development is achieved through a set of interoperable services that build on top of the existing data layer, ensuring provision of routing and navigation features based on open standards.

D. Data Layer

The Data Layer, in its broader sense, is surely one of the cornerstones of Smart Mobility infrastructure. The Data Layer must be included as an integral part so that all data can be intelligently collected, integrated, validated, and shared responsibly with authorized people and institutions and be open to the degree that addresses the concerns of **data privacy** and **protection** policies. Without such an infrastructure, even much smarter data-dependent applications would fail to perform at their full potential [19]. Figure 5 highlights most of the technical components of the architecture necessary to adequately respond to the requirements of the Data Layer infrastructure.

Without delving into technical details of the proposed architecture, which is outside of the scope of this document, we highlight the most important components. The **Import** component involves the data collection process as the task of bringing data from the myriad of **data sources** to a repository, which is accessible by citizens, businesses and the local government as well. The Import component forms the basis of data population for the data infrastructure.

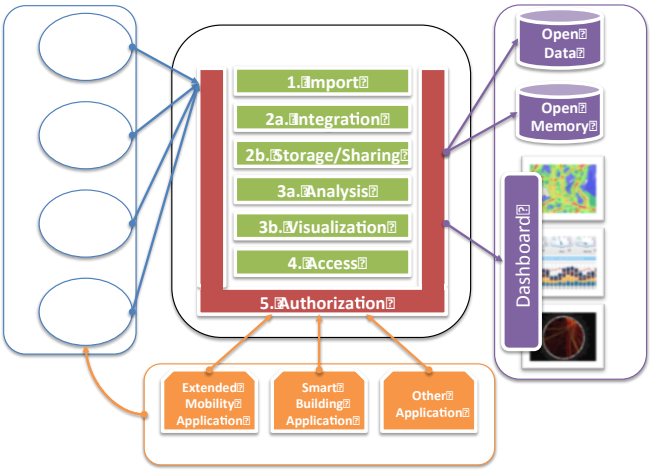

Figure 5 - Architectural overview of the Data Layer Infrastructure

The more well-structured, organized, and methodological the process is, the more complete, error free, and cleaned the datasets are. However, it is difficult to define a process that can overcoming all of the issues. Nevertheless, the approach followed by the data hunting team of the Open Data Trentino project (ODT) is worth mentioning. Basically, they identified the appropriate authority (e.g., a provincial department or an office) to ask for a dataset, run the data collection iteratively in multiple phases (as shown in Figure 6), and continued the process as long as the quality and quantity reached was at an optimal level [20]. Each phase was executed adding some new requirements to enrich the dataset and also to release the related new dataset whenever needed and applicable.

As argued in Section IV.a **crowd sourcing** mechanism can help maintain the collected data improved directly by the users, updated, annotate entities (e.g., a restaurant, a ski resort) with the new services they provide and the offers they give and add new entities that were previously unavailable on the data repository. Crowd sensing and crowdsourcing can go hand-in-hand in the context of a Smart City because the former can enable smart mobile devices to sense an uncanny amount of data, including the geographic position of an entity, the temperature of a location and the speed of a vehicle. Such data originating from crowd sensing devices can be matched automatically against the ones that are

already available on the data repository and can be brought to the attention of the human user if an anomaly is uncovered or a missing data element is found. In addition, the user can further verify the finding, and in turn, if she/he thinks it necessary, can crowdsource the newly found data to fix the error or increase the coverage. The Data Layer must also be connected to the city through a wide network of **sensors** required to obtain the input-senses from the real world and able to provide the appropriate feedback to decision makers, businesses and citizens.

A particular focus must be placed on the **Integration** component. Indeed, while various datasets are reporting the same entity from a multitude of directions (for example, the entity Trento is codified in both weather and statistical datasets), users should be able to perform any query targeted towards obtaining knowledge about any of the exemplified aspects of this entity seamlessly through an integrated view of datasets.

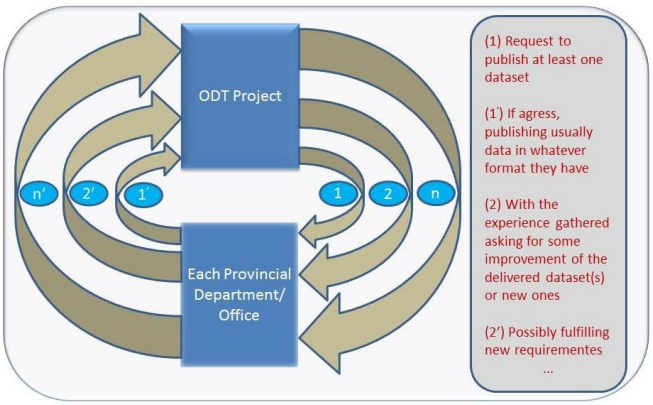

Figure 6 - Multiphasic data collection

To meet this requirement, there are some practical challenges that must be addressed. For example, the same entity is represented with multiple names (*synonymy*), or different entities are represented with the same name (*polysemy*), e.g., Trento (*the province*) and Trento (*the municipality*). Entity matching techniques can be used to identify the fact that, although appearing in multiple datasets possibly with alternative names, these variations are in fact different representations of the same entity [21].

The return of the information is provided by the **Data Exposure** layer, which gathers all integrated information and provides it in different forms, such as a **Dashboard** (see for example the ones from Dublin[4] or London[5]), used to instantaneously monitor the status of the city, which can merge together real time data with historical data and dedicated analysis and visualizations. In the specific domain of urban mobility, the Data Exposure layer can provide an efficient complete view of the traffic situation in the city. We also consider the exposure of data through existing **Open Data** catalogues and storage services of historical data with open access, a service that we refer to as **Open Memory**.

[4] http://www.dublindashboard.ie
[5] http://citydashboard.org/london

The **Access** to all collected data and generated information is achieved by means of application interfaces (APIs) allowing third party applications to develop their own environment and businesses, always with the aim of providing useful civic applications that leverage the access of data by all means to the citizens.

Last, but not least, the data layer for Smart Mobility requires substantial work for **standardizing** the content collection and exposure, which is still inadequate and results in primarily ad-hoc efforts implemented for each solution.

E. Services & Apps

Innovative services and applications, especially mobile, are the new frontier for achieving Smart Mobility. New apps can turn a smart phone into a collaborative sensor, a car into a rolling data platform, and all of the above into a safer, more cost-efficient, and socially connected means of mobility. Whether these services and applications are focused on gamification, crowdsourcing, or cooperative systems, all services require high levels of personalization, targeting a wide and heterogeneous consumer data: daily commuters, tourists, third party businesses, local and worldwide businesses, and, of course, PA service providers and maintainers. All of the above represent an important but not impossible challenge for the city.

In Trento, the effort was focused on meeting this challenge. On one hand, the municipality has decided to provide as much information as possible and to promote the effort on raw data availability that, after appropriate cleaning and protection, can be openly accessed. Increasingly, where possible, data are going to be published as Open Data to enable the creation of dedicated and smart services. Raw data as real time data are freely provided, but with care, because imprecise information can produce unpredictable results, with a high potential of unsatisfied [data] consumers.

On the other hand, much effort is implemented over the possibility of collecting data, bearing in mind the user perspective of the service. For example, it is useless telling a citizen that the next bus is late if we are not able to let her/him know that there is also another public service in proximity deserving the same spot, merely because the information comes from different service providers, such as bus and metro or train systems.

Dozens of apps are developed by specialized businesses worldwide, making available their services on smart phones after a few days from the publication of the dataset. Recently, real-time data regarding the available number of bicycles for each spot in Trento and Rovereto was openly published and accessible only two days after a few new mobile apps were already available.

The higher is the level of effort on delivering quality data, the greater is the number of services that are offered to citizens and businesses alike. Allowing people and businesses to create their own apps in their specialized field, eventually leading to the PA to focus on the validation and certification of the results, should produce the best value for the money.

V. Conclusions

Achieving Smart Mobility in a Smart City is a path that begins with a shared vision and requires the executive ability of the political leadership of the city. The effort to implement Smart Mobility is not the contribution of a single person but rather of a community of persons, who must design and create the path for improvement of their city, starting with the history and culture that characterize it.

Moreover, the already valuable improvements of the current Urban Mobility plan provided by the city of Trento during the IEEE-SC Smart Mobility task-group have led to the identification of five priorities of a Smart Mobility plan for the city of Trento, which can be a replicable model for other mid-sized towns. The first priority is the transformation of simple passive citizens into responsible and collaborative participants, increasing their level of awareness of the correct usage of mobility services and letting them take active part in their improvement by furnishing useful and guided data information through gamification. The second and third priorities are strictly connected and applied to the capacity of the city to provide, even through strong political actions, useful connected and complete information regarding all forms of mobility data available in town. Implementing the data layer is indeed the cornerstone action to empower the ability of businesses to provide useful and dedicated applications and information service to lower the barrier for access to urban mobility situations for all citizens and the government. Additionally, the improvement of LBS systems must be further improved, especially in the indoor context, and leveraged to improve contextual geo-localized information to the users. Last but not least, we must focus on the progressive introduction of cooperative systems as an important communication platform and resource, which we believe will be of high impact for the realization of a Smart City plan in the years to come, despite requiring improvement to be widely usable.

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