Research for Development

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Electric Vehicle Sharing Services for Smarter Cities

The Green Move Project for Milan: From Service Design to Technology Deployment

Fondazione Politecnico di Milano

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Foreword to the Book

Social and geopolitical transformations are modifying urban policies, metropolitan scenarios, and mobility systems, let alone the way people relate and interact. New and sustainable proposals are necessary to meet the continuing need for primary resources, health and well-being, culture, education, and vocational training. We are now witnessing one of the fastest and most disruptive technological developments of all time.

In a modern, multiethnic, and multicultural city, such as Milan, a public technical and scientific university has to guarantee a central role, a vision that includes the ability to drive great technological challenges, to cope with economic, social, and cultural transformations, to act as a leading institution in training, research, and innovation. Milan is working hard to be a "smart city," to integrate information and communication, to improve the efficiency of services and infrastructures, to work for and together with the community.

The mobility service described in the project Green Move is an example of the way Politecnico di Milano reflects this approach, a paradigm that counts on the interaction of diverse competences—like the ones represented here in terms of technology, services, and design—and the active involvement of citizens and end users. This is a pioneering initiative that moved its first steps in 2011 and that is now considered and acclaimed as a best practice.

I thank the former rector, Giovanni Azzone, for having promoted and actively contributed to this project, together with Regione Lombardia and all the partners involved in the project, Politecnico di Milano's departments, Poliedra Consortium, and our Foundation.

Milan, Italy

Ferrucio Resta
Rector, Politecnico di Milano

Foreword to the Project

Green Move is a project developed by several structures of Politecnico di Milano and co-financed by Regione Lombardia (Lombardy Region), with the aim of conceiving and experimenting a new car sharing system for the city of Milan by means of electric vehicles. A demanding task accomplished by qualified research and innovation teams representing specific competences and various approaches to the same topic: smart mobility.

Fondazione Politecnico di Milano, which I have the honor and the duty to lead as President, has supported this multidisciplinary and articulated project and worked side by side with the Department of Electronics, Information and Bioengineering (DEIB); the Department of Architecture and Urban Studies (DAStU); the Department of Design; the Department of Civil and Environmental Engineering (DICA); the Department of Management, Economics and Industrial Engineering (DIG); the Department of Mathematic Francesco Brioschi (DMAT) and Poliedra, the consortium promoting and supporting research and training activities in the fields of environmental concerns and sustainable mobility.

Environmental sustainability, a significant reduction in traffic and pollution, together with economic and social benefits for both citizens and the public administration are some of the ambitious goals that Green Move aims to achieve through the improvement of urban circulation. What the project has proposed, and what it has finally come up with, is a flexible service that addresses different targets and offers customized solutions that can be taken into account as a case study for other urban contexts. In fact, as the former mayor of New York Michael Bloomberg said, we are living in the "century of cities." For the first time in history, cities are more populated than the countryside. It is estimated that in 2050 more than 70% of the world's population will move into town. This process has been radically changing the way that millions of people interact with the environment as well as the socioeconomic model of reference.

Green Move has promoted and introduced elements of social innovation, the awareness and the acceptance that smart choices will drive smart cities. Technology can actually and truly improve people's lives, if it is developed in a reliable and sensible manner and, most of all, if it is adopted consciously. That is why researchers and citizens have worked together in studying and testing different solutions without losing sight of the bigger picture, that of enhancing the potential and the well-being of future generations.

Green Move project is an example of how Fondazione Politecnico di Milano works to foster innovation and knowledge transfer enabling and favoring a firmer interaction among research activities and social and economic stakeholders.

Milan, Italy

Gianantonio Magnani
President, Fondazione Politecnico di Milano

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Introduction: Car-Sharing Evolution and Green Move Project

Daniele Fabrizio Bignami, Alberto Colorni, Alessandro Luè, Roberto Nocerino, Matteo Rossi and Sergio Matteo Savaresi

Abstract This introductory chapter briefly outlines the main characteristics of car-sharing services and the main assumptions that authors of this book took into account for designing the innovative service that was the outcome of Green Move project. The second part of the chapter illustrates the overall organization of the book, and the main contents of the three sections: the service, focused on the Green Move service design, the technology, illustrating the technologic solutions realized for the project, and the simulation model, implemented for estimating the performances of different alternatives of car-sharing.

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1 The Current State of Car-Sharing

Shared mobility is a rapidly developing domain; even though services such as bike sharing, ride hailing and flexible forms of public transport are growing rapidly, nowadays car-sharing is the most widespread form of shared mobility (Le Vine et al. 2014). A large number of car-sharing operators are present on the market, offering different forms of service, and several new mobility-related business models (and related services) are expanding their market (Shaheen et al. 2015).

Generally speaking, car-sharing is a service where a fleet of cars is shared by a group of people paying only for the actual use of the vehicles. The general idea of car-sharing is "pay-as-you-drive," which leads to a more convenient car usage for the drivers and optimized car usage for the car owners. Car-sharing fleets are usually organized by a private company or association, in certain cases subsidized by a local or regional government or public transport authority, and are generally offered to private users, and sometimes to corporate ones.

The wide variety of car-sharing services can be grouped in three main categories (Jorge and Correia 2013):

1. **Station-based car-sharing**: Cars can be picked up only at designated stations; usage can be round-trip (i.e., customers must return the car to the same place that it was accessed) or one-way. Examples: Cambio (Germany, Belgium), Co-Wheels (UK), Greenwheels (Netherlands, Germany), Guidami (Italy), Autolib (around 4000 electric vehicles in France), Zipcar (USA), Orix and Park24 (Japan), and EVCard (China).
2. **Free-floating car-sharing**: The service enables one-way journeys freely within a specified geographic zone, and usually, there are no dedicated parking lots (Firnkorn and Müller 2011). Examples of global operators are as follows: Car2Go (around 15,000 vehicles worldwide) and DriveNow (around 5500 vehicles in seven European countries), while examples of local operators are as follows: Enjoy and Share'ngo (Italy), GreenMobility (Denmark), EVO Carshare and Communauto (Canada, France).
3. **Peer-to-peer car-sharing**: The service operator offers a platform to bring private car owners in contact with passengers, matching supply and demand directly. The operator takes a certain percentage of the transaction cost between the car owner and passenger to provide appropriate insurance and cover their operating costs. Examples are as follows: Tamyca (Germany), Mywheels (Netherlands), Snappcar (Netherlands, Denmark, Sweden), CarUnity (Germany), Bluemove (Spain), Turo (USA), PPzuche (China).

Nowadays, new car-sharing schemes are going to appear, targeted to specific market niches, such as company car-sharing or community car-sharing, the so-called micro-car-sharing.

2 Reasons of a Growing Success

In Western countries, private transport models (essentially based on privately owned fossil fuel-driven vehicles) are well-established. Starting from the sixties, there has been a continuous increase of private cars, especially in the Western world: the cars owned in Italy, for example, rose from about 10 million in 1970 to over 37 million in 2011 (ACI 2012; Fig. 1).

This increase is essentially linked to socioeconomic factors, mainly the increase of the average wealth (Prettenthaler and Steininger 1999), but also to psychological characteristics of the users. The perception of a better comfort and flexibility of a private vehicle in comparison with the public transport is still well-established, even if often alternative options could have better performances.

Recently, the increase in the number of cars slowed down, and cars in the cities, which have been designed before the invention of motorized vehicles, are often seen as a threat more than an opportunity of mobility. The main reasons are as follows: Cars are polluting and noisy, and occupy a large amount of space in our cities. These elements are crucial variables to determine the quality of urban life in cities. The problem is exacerbated by other factors such as the difficult compromise between a safe vehicle and an environmentally friendly one, and the need to ease congestion in metropolitan areas and free areas of parked cars.

A further reason of the slowing down of car purchases is that the ownership of a car requires for many people a significant economic effort. Moreover, in many situations, a car is not the more efficient means of transport. Especially in cities, public transport, bikes, and walking are in many cases faster and more cost-efficient than cars.

But even if often bike, bus or metro are better mobility options, in some particular cases a car is the fastest, cheapest and more efficient transport alternative. Even if the ownership of a car is not the best choice for some city users, the availability of a car, when necessary, is still absolutely needed.

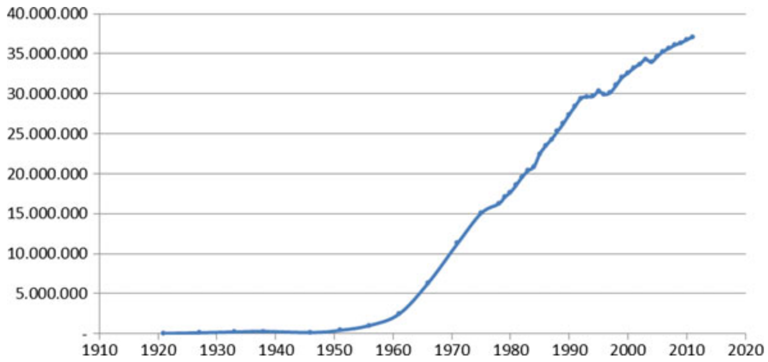

Fig. 1 Increase of private cars ownership in Italy (ACI 2012)

In this sense, cars will not disappear from our cities but their role will change in next decades; aside from autonomous vehicles, which will radically change the mobility scenario, three directions can be foreseen for the car industry:

- a reduction in weight and size of vehicles;
- a drastic reduction in the number of engines using carbon-based fuel and the consequent development of electric mobility;
- a change in the mobility model, moving from the traditional concept of privately owned vehicles to a model based on articulated mechanisms of vehicle sharing (Bert et al. 2016).

Small, electric, shared is probably the new scenario toward which models of urban and metropolitan mobility models will tend over the next decade.

Electric car-sharing can give a significant contribution to solve the threats and needs mentioned above. First of all, the replacement of the individually owned car with the availability of cars shared by many citizens and city users makes the overall space occupied by cars much smaller, which is a great benefit for many big cities. Furthermore, shared cars run much more frequently than private cars, which on average stay parked 23 h per day (Collaborative Fund 2012): that means that the life of shared cars is much shorter in time (assuming a constant distance run by a car in its lifetime) and the service has to replace the fleet with new cars more often than individual owners. Hence, with car-sharing, users drive cars that in general are newer than private cars. This means that, thanks to car-sharing, the vehicles traveling in the city are in general safer, less pollutant, and less noisy than before.

Summarizing, car-sharing produces three main categories of advantages: economic benefit, environmental sustainability, and flexibility for the user.

- **Economic benefit**: This point includes not only the choice to be a car-sharing user, but actually a wider range of choices. Becoming a car-sharing user has its highest economic benefit if it is part of a whole new mobility strategy, starting from the decision not to own a private car (or at least not to own the second family car). This decision frees many economic resources, since the yearly cost of a car includes purchase, insurance, maintenance, taxes, parking, cleaning. These resources can be partially used to purchase Local Public Transport (LPT) tickets, car-sharing subscriptions, and train tickets, to rent cars if necessary, and possibly to buy a bike. Many people would save money overall, depending on their mobility needs and routine: Users driving less than 4000 km per year would save about 40% of their expenses (Valenti and Mastretta 1999).
- **Environmental sustainability**: The process of switching from private cars to car-sharing is not immediate; buying or selling a car, or the decision not to buy a car, are long decisional processes that usually need time. This implies that the replacement of a car with a car-sharing subscription can occur with a certain delay (few years) since a car owner needs a period to adapt and trust the new service before taking the decision to sell his car or decide not to buy a new one. This has to be taken into account when monitoring the success of a new car-sharing service. It has been estimated that in a fully functioning system, each shared car can substitute

4–10 private cars in Europe and 9–13 private cars in North America (Shaheen et al. 2013). Moreover, shared cars have a short lifetime, meaning that more new cars, with low emission standards, are running. In case of electric car-sharing, the emission reduction is much higher. The lower usage rate of shared cars compared with private cars is due to an increase in LPT usage by car-sharing users. This means that with a fully functioning car-sharing system, the LPT will increase its volume of users and economical resources to invest in an increase of the level of service, with consequently environmental and mobility benefits. The main environmental effects are then a reduction of air pollution emitted by the car sector, a significant reduction in public space occupied by parked cars, and an overall reduction in traffic jams (Baptista et al. 2014).

- **Flexibility for the user**: This benefit is provided by those car-sharing companies offering different types of cars in their fleet (e.g., city car, sedan, minivan, or van). In this case, the user can choose the car fitting with his current need based on the number of people or baggage to carry, the length of the trip, the costs, etc. Flexibility can be increased through integration of car-sharing services provided by different operators, which in turn can be achieved thanks to standardized access systems.

Furthermore, car-sharing can produce benefits similar to those provided by a private car in terms of flexibility and comfort, but with significantly lower costs. Citizens that choose car-sharing services lower their mobility expense with a more rational choice among the available mobility options. Paying for the actual use makes the user wiser in his mobility choices, so cars become in many cases the last option, after public transport and bikes.

Figure 2 shows the best mobility options depending on the distance to be covered and the flexibility needed.

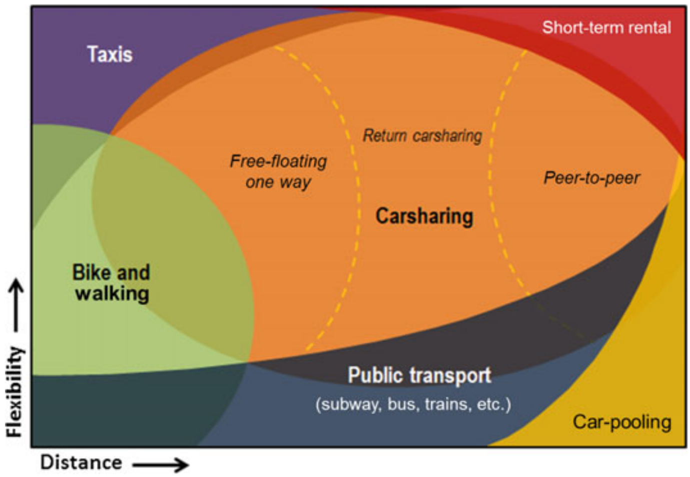

Fig. 2 Multimodality in large urban centers, excluding the private car (http://www.inov360.com/en/car-sharing-yes-but-whichone/)

Car rental is more efficient for long distances and high flexibility needs, whereas taxi provides the best flexibility, but only for short trips because of its high costs. Bikes and walking are the best choices that guarantee flexibility at a low/zero cost for short trips. When flexibility is not strictly required, the choice has to be made between public transport, for short-medium trips, and carpooling, for longer distances. Car-sharing appears as the right choice especially for medium distance trips and when medium-high flexibility is required, in comparison with the traditional means of transport.

Finally, a car-sharing is not a stand-alone service, but needs to be implemented in an environment equipped with a public transport network. In fact, car-sharing is a complementary service to public transport, which can fill those situational mobility needs that were covered by private cars, with overall higher cost, or by public transport, with a much lower level of service and flexibility (Millard-Ball et al. 2005).

3 History of Green Move Project

Green Move is a project co-financed by the Lombardia Region,[1] started in 2011 and concluded in 2013. The main idea behind Green Move was to create a flexible service of vehicle sharing, based on electric cars, and open to a wide range of different types of users. The system was designed to be easily accessible thanks to an add-on device, the Green e-Box, a bridge between the user, the vehicle, and the control center, allowing any vehicle to join the service network. For addressing the design of the innovative service envisaged, Green Move involved eight different departments and research centers of Politecnico di Milano:

- Department of Architecture and Urban Studies (DAStU) for demand analysis;
- Department of Civil and Environmental Engineering (DICA) for geographical information systems;
- Department of Design (DESIGN) for service design and communication;
- Department of Electronics Information and Bioengineering (DEIB) for information and communication technology;
- Department of Management, Economics and Industrial Engineering (DIG), for economic and stakeholder analysis;
- Department of Mathematics (DMAT) for mathematical models;
- Fondazione Politecnico for administrative management;
- Poliedra for evaluation and environmental analysis.

[1]Accordo istituzionale di R&S “GREEN MOVE” 11/02/2001—Decreti n. 5889 11/06/2010 e 1537 5/11/2010 Direzione Centrale Programmazione Integrata—Struttura Università e Ricerca di Regione Lombardia—Bando di invito a presentare proposte di accordi istituzionali per la realizzazione di programmi R&S nei settori energia, ambiente, agroalimentare, salute e manifatturiero avanzato—Fondo per la promozione di accordi istituzionali.

3.1 Working Hypothesis and Objectives

Green Move started from the following working hypotheses:

- **Multi-ownership**: Green Move worked on solutions able to allow single users, private companies, and associations to join the service both by using vehicles provided by the service itself and by sharing their personal electric cars or fleet;
- **Key-less-mobility**: The Green Move team, in their proposal in 2010, hypothesized that personal smartphones would be the access key to car-sharing services (and, more in general, to a wide range of services), avoiding the use of smart cards or physical keys;
- **Electric vehicles**: The engine technology chosen by the Green Move team was the Full Electric Vehicles (FEVs), as the most probable future solution for urban mobility.

A key element of the project was the planning and integrated development of an innovative vehicle-sharing system, based on light electric vehicles suitable for urban/metropolitan use. The main project objectives were the following:

- **Polluting-climate altering emissions and congestion**: Development of a solution able to drastically reduce not only the emission of pollutants and greenhouse gases, but also traffic congestion.
- **Use of renewable energy**: Proposal of a solution to the mobility problem integrating it with the evolution of renewable energy production systems with low environmental impact.
- **Monitoring and profiling**: The realization of methods and tools for effective capillary monitoring and profiling of users' behaviors.
- **Urban environment**: Activate an urban-level sustainable mobility system taking into account the need of a widespread recharging network.
- **Business model**: The project team worked looking at financial sustainability, exploiting ICT technologies, social networking, users' behavioral models.
- **Integrated approach**: Development of an integrated and complete solution that may have spin-offs in a number of directions, even beyond the solutions studied within the scope of the project.

4 Organization of the Handbook

Having in mind the car-sharing scenario described in the previous paragraphs, the Green Move project has been accurately structured by means of an approach aiming at taking into consideration both the *enabling technologies* and the *appropriate business model*. To pursue the three main categories of car-sharing benefits mentioned above (*economic advantages*, *environmental sustainability,* and *user flexibility*), the developments and related tests carried out within the Green Move project have targeted the three chosen strategic priorities "*small*, *electric,* and *shared,*"[2] which have guided the evolution of the project ideas.

The handbook is organized into *three* different parts, each aiming at investigating transversely and in depth the crucial aspects of our priorities (to be tested and verified). It is, however, important to underline that the project activities have been carried out following a multi-disciplinary and original research path in which the three main groups of activities have been developed jointly, partly in parallel, partly taking advantage of frequent and repeated exchanges of outputs/inputs among the research groups of the Green Move project team. Therefore, the three parts of the handbook can be seen as the final re-elaboration of the work.

The *first* part illustrates the activities related to the service, starting from the service design, the configuration of the vehicle-sharing model, the Milan mobility pattern. The section goes on presenting the peer-to-peer car-sharing local demand-and-supply estimation, the tests of the "condominium-based electric car-sharing" prototype model, and the communication design for social engagement through the chosen and assessed participatory process.

The *second* part explains the technological choices and developments made in the project. First, it illustrates the architecture of the Green Move system, then it presents the technology, based on the notion of "dynamic applications" developed to provide users with highly flexible and customizable services. These chapters also give a brief comparison of the technological platform developed in the Green Move project with commercially available ones.

The book proceeds by describing some specific technological achievements of the Green Move project: the *Information Management* mechanisms, which are based on a context-driven, pervasive, and personalized approach; the developed smartphone-based energy-oriented *driving assistance system*; the simulation of an automatic *fleet balancing system* via closed-loop dynamic pricing; and the real-time monitoring of the Green Move vehicles' positions through a dedicate *geo-referenced database*.

The *third* part starts by describing the model that has been developed to simulate different car-sharing configuration options and to estimate their related effects. Finally, a model to estimate the potential users of the car-sharing system (and related Origin/Destination matrices of the service) and a model for a full-scale electric car-sharing service planning for the city of Milan are presented, making use of decision-aiding methodologies (showing a multi-criteria and multi-stakeholder rating of the car-sharing configurations).

Acknowledgements In addition to the authors of this book, several people have contributed to the project and have provided useful suggestions and feedback on the chapters of the book. For this, we would like to thank Luciano Baresi, Gabriella Bergonzi, Alessio Campi, Gabriele Carbone, Lorenzo Carrara, Antonio Conte, Silvia Cortesi, Luca Di Natale, Elisabetta Di Nitto,

[2]Whereas the target vehicles considered in the Green Move project were all electric, in fact the technology developed in the project could be adapted also to other kinds of vehicles, including those with internal combustion of hybrid engines.

Maria Francolino, Gabriele Giussani, Raffaele Grimaldi, Monica Lancini, Paolo Liaci, Diego Longoni, Paolo Magni, Vincenzo Manzoni, Alessandro Margara, Davide Martinenghi, Gabriele Mellera, Emanuela Murari, Lucia Orbetegli, Giorgio Orsi, Giancarlo Piccinno, Marco Ponti, Elisa Quintarelli, Angelo Rauseo, Francesco Rizzi, Cecilia Rizzuto, Sante Rotondi, Dario Sigona, Alessandro Sivieri, Carlo Vezzoli, and Federico Zotti.

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References

ACI (2012) Serie storiche sullo sviluppo della motorizzazione e sull'incidentalità stradale in Italia negli anni 1921–2011. www.aci.it

Baptista P, Meloa S, Rolima C (2014) Energy, environmental and mobility impacts of car-sharing systems. Empirical results from Lisbon, Portugal. Procedia—Social and behavioural sciences 111 (2014) 28–37. EWGT2013—16th meeting of the EURO orking group on transportation

Bert J, Collie B, Gerrits M, Xu G (2016) What's ahead for car sharing? The new mobility and its impact on vehicle sales. The Boston Consulting Group

Collaborative Fund (2012) The bright future of car sharing. futureofcarsharing.com

Firnkorn J, Müller M (2011) What will be the environmental effects of new free-floating car sharing systems? The case of car2go in Ulm. Ecol Econ 70(8):1519–1528

Jorge D, Correia G (2013) Carsharing systems demand estimation and defined operations: a literature review. EJTIR

Le Vine S, Zolfaghari A, Polak J (2014) Carsharing: evolution, challenges and opportunities. 22th ACEA Scientific advisory group report

Millard-Ball A, ter Schure J, Fox C, Burkhardt J, Murray G (2005) Car sharing: where and how it succeeds. Transportation cooperative research program, Report 108

Prettenthaler FE, Steininger KW (1999) From ownership to service use lifestyle: the potential of car sharing. Ecol Econ 28(3):443–453

Shaheen SA, Cohen AP (2013) Carsharing and personal vehicle services: worldwide market developments and emerging trends. Int J Sustain Transp 7(1):5–34

Shaheen S, Chan N, Bansal A, Cohen A (2015) Shared mobility. A sustainability & technologies workshop. Definition, industry developments, and early understanding

Valenti G, Mastretta M(1999) Car sharing: evoluzione e prospettive. Studio ICS/ENEA

Part I
The Service

Service Idea: Creating Mobility Scenarios Through Service Design

Stefano Maffei and Beatrice Villari

Abstract The chapter discusses the initial stages of the development of the Green Move research. In particular, the authors focus on the generative phases developed in the early stage of the research process. The content mainly describes the different stages of the service idea development: (i) the research phase aimed at collecting examples of mobility solutions worldwide, (ii) the creative session aimed at sharing ideas among participants to identify design opportunities to be developed in the next steps of the process and (iii) the development of the service ideas in order to describe possible scenarios to support the implementation phase. Moreover, few considerations on challenges and opportunities to deliver the service are outlined. To describe the framework that influences the design choices, the chapter briefly introduces few concepts on service design approach used in the journey.

1 The Service Design Approach: Putting Users at the Centre of the Process

Nowadays service design is becoming a crucial element to differentiate businesses and public organization around the world. The first attempt of defining what a service is came from the service marketing and management field.

In this disciplinary area, some scholars have built the basis of service design starting from interpreting and defining new service development and delivery process (Shostack 1982, 1984; Scheuing and Johnson 1989; Gummesson 1990), service design still lacks a unique and common definition (Nisula 2012). Nevertheless, scholars and practitioners agree on considering service design as a multidisciplinary process characterized by a user-centric approach and by the

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interactions and the encounter between providers and users (Holmlid 2009; Stickdorn 2010; Meroni and Sangiorgi 2011). Negro (1992) describes the service as an interchange process aimed at solving problems for users through the reciprocal flow of information, knowledge, skills and work done in a period of time. Lovelock and Wirtz (2004, p. 9) define a service as an "act or performance offered by one party to another" that creates value for providers and customers.

Thus, service design discipline can be considered as a huge field of intervention that implies collaboration between different disciplines to propose, design, develop and deliver a holistic experience targeted to specific users or communities and provided by a system of stakeholders playing different roles.

Mager and Sung state

> … Service design aims at designing services that are useful, usable and desirable from the user perspective, and efficient, effective and different from the provider perspective. It is a strategic approach that helps providers to develop a clear strategic positioning for their service offerings. Services are systems that involve many different influential factors, so service design takes a holistic approach in order to get an understanding of the system and the different actors within the system… (Mager and Sung 2011, p. 1).

Service design is based on the idea that users are the core of the service design process, and it uses a great variety of tools and techniques to involve different stakeholders in the creative process. The collaborative processes are also supported by visualization methods and prototyping techniques that enable people to share ideas, define solutions and make concepts visible. In some cases, we can describe this journey as a real co-design processes where experts and non-experts work together in order to provide innovative solutions derived from the participation and representation of different perspectives (Jégou and Manzini 2008), like those of citizens, enterprises and institutions. This helps to share different types of diverse expectations and expertise that different stakeholders might have and stimulate a dialogue among different disciplines and group of people. Moreover, service design is a holistic approach (Stickdorn and Schneider 2010) that means that service touchpoints (such as digital interfaces, physical elements, people and places) and intangible elements (such us the user experience, the service values and people interactions) need to be coherent and well orchestrated in order to provide a performance that creates values both for providers and users.

The Green Move approach is based on these service design drivers: it is aimed at developing a mobility service using a collaborative approach, involving different stakeholders with different roles (such as public administration, researchers, firms, users) to envision and experiment a new mobility service able to fit with specific users' needs and based on electrical vehicles sharing (Villari and Luè 2013).

In particular, the service design process within its development has been focused on different levels: the creative phase, the service idea and the business model development, and the design of the system of touchpoints.

In the following paragraphs, we describe in detail the approaches and the tools used to frame it.

2 The Service Context: Sharing Economy and Collaborative Services

One of the main Green Move research hypotheses is based on the idea that collaborative and participatory approaches are fundamental to the development of innovative solutions for electrical vehicle sharing, in order to face urban challenges. This could be an innovative way to fuel new connections among social, environmental and economic issues. Accordingly, to orient the generative phase about service ideas, particular attention was given to define the concept of collaborative consumption and sharing economy (Botsman and Rogers 2010) and to include the social innovation and sustainability issues (Mulgan 2007) to create value for local communities and citizens. Since the beginning of the project, we put emphasis on the importance of peer-to-peer activities and the opportunities to adopt sharing concepts to orienteer mobility solutions. Another input to boost the idea of sharing was to consider the ICT as an enabler of people activities and as a way to create more tailored services.

The sharing economy models are generally based on the idea of access (especially using a pay-per-use approach) rather than ownership to promote a more efficient use of tools and resources. Since the past few years, the debate on sharing and collaborative economies has grown constantly (Pais and Provasi 2015) also due to the fact that some companies such as Airbnb, Uber, eBay or Etsy are climbing the market in a very fast way. But this has also shifted the focus on the possible critical issues about the sharing economy models, such as the IP regulation, the transformation of the labour market and the international tax regulations. Notwithstanding, many companies are investing in a sharing economy approach, and many start-ups are entering the market allowing consumers to play new roles and tasks that were normally conducted by businesses (Dervojeda et al. 2013).

In the mobility area, sharing economy has totally changed the way of accessing transport systems. We are progressively moving from owing a car (B2C model) to new business models and services based on rental or sharing (B2C services). Milan has led the way: in the past few years, the use of car sharing and bike sharing has rapidly grown. Hybrid and electric vehicles such as cars, motorbikes and bikes are offered by the municipality and by private companies to support urban mobility in accordance with the idea to offer even more citizen-centric services. This shift is especially true in the emergent area of the collaborative platforms, where P2P services are growing faster. Examples such as Uber and BlaBlaCar are interesting phenomena related to these new ways of using transports, based on peer-to-peer approach.

The main drivers related to sharing economy and shared mobility have influenced the Green Move service concepts. In particular, some aspects were considered as crucial ones:

- the central role of digital platforms as enabler of new user behaviours focused on matchmaking between demand and offering of mobility;
- the importance to have different service possibilities to access the service itself, i.e. renting, lending, subscribing, donating and so on;

- the change in consumption models based on collaborative social interaction;
- the value of a well-recognizable identity and process able to create trust and activate and maintain reliability and continuity in users' engagement.

The development of Green Move concept for an electrical vehicle sharing has been influenced from this emerging framework and from the holistic approach of service design putting together users' needs and perspective with value creation process of the enterprises.

3 Defining Service Design Scenarios for EV Mobility

One of the early stage activities of the Green Move development process has been dedicated to the service idea development. The process involved all the academic stakeholders and the external players such as experts, mobility companies and public administrations.

The ideation phase has been strictly connected since the initial steps to a literature review process and to a collection of best practices cases of mobility services to support the service ideas development phase. In particular, this phase supported the understanding of the most important design issues related to the technology choice, vehicle performance, service (user) experience and the nexus between the service offerings and the contexts of use. To structure the service ideas, some phases have been structured:

- Organizing and systematizing the best practices collected about mobility services (Sect. 3.1);
- Generating ideas of product-service systems through participatory workshops (Sect. 3.2);
- Developing mobility scenarios based on electric vehicles (Sect. 3.3).

In the following paragraphs, these activities (the design process and the tools used) are described.

3.1 Organizing and Systematizing the Best Practices Collected About Mobility Services

The research teams selected thirty-three existing cases of worldwide mobility services. These have been divided into four categories describing the main characteristics of the service offering and the mobility model: (i) services which use traditional vehicle sharing, (ii) services which use peer-to-peer approaches, (iii) services that use electrical vehicles and (iv) services that offer direct production of energy (Maffei et al. 2011). The first category includes mobility services that are characterized by innovative models in service or in business and use non-electrical vehicles; the second category encompasses that services characterized by a collaborative approach in experiencing or delivering the service; the third focuses on “green” vehicles; the last one considers some cases that include energy production as an element of the service system.

The analysis of best practices and the study of the literature have been useful to define the main design problems to be discussed during the creative phase and understand what are the current business models and the solutions adopted to make the services efficient and user-centred. In the following boxes, main characteristics of services analysed are presented.

Autolib (Paris)—The pioneer of electric car sharing
Autolib started in 2011 in the inner circle of Paris. In the recent years, the served area expanded so that now the whole Paris area plus some of the surrounding towns are included. The service aims to fulfil mobility needs for citizens, commuters and tourists. Today more than 2000 vehicles are shared in the city of Paris by more than 150,000 subscribers. The vehicles, named “blue cars”, are electric and have a 250 km range. The parking places are well spread in Paris and in the surrounded cities and are equipped with electric charge station, partially available also for private electric cars. With the registration, the user receives a smart card which is required to open the vehicles. The reservation of a vehicle can be performed 20 min in advance or in real time at a station, online or with a proper app. The car has to be returned to a station where the lot can be reserved in advance with a one-way approach. Autolib, a multi-nodal car sharing, is designed to foster the sharing concept, facilitating short and frequent uses of the cars. To pursue this objective, Autolib offers a quick and automatic system to reserve, unlock, drive and return cars. One-way trip is essential to allow an easy and instant use of the car sharing. Also a variety of subscription fees and fares help to wide potential users.

Car2Go—An easy replicable urban car sharing model
Car2Go started in 2009 in Ulm, Germany. After 6 years, the service is in more than 30 cities in Europe and North America. Since 2013, Car2Go is available also in the main Italian cities. Depending on the characteristic of each city, Car2Go offers either ICE or EV cars, while a mix of the two has not been set yet. The fast growth of Car2Go is mainly due to the successful, simple and innovative system that can be replicated in different urban environments. Car2Go does not have its own parking places, but it defines a wide area (e.g. the whole municipality area), called Home-Area, where the trips have to start and end. The one-way trip configuration guarantees a strong flexibility to users. The available cars can be searched on the map on the Website and on the app. Then the car can be reserved for half an hour. Once reached the parked car, the doors can be opened with a smartphone or with the Car2Go card. Car2Go fleet is made only by Smart cars models to facilitate the driving in the

city and the search for the parking. In the car, there is a touch screen that controls the communication user-vehicle-central station and helps the driver with a navigation system. It also evaluates the environmental sustainability of the driving style based on acceleration, constant pace and braking.

Enjoy—An integrated urban mobility model of car and scooter sharing
Enjoy is an Italian car sharing available in Milano, Roma, Firenze and Torino. This service is a joint venture between Fiat, Eni and Trenitalia, and this fact enhances the opportunities linked to car, fuel and train activities. Fiat can provide cars and the related system of services (e.g. maintenance stations), Eni can offer special price in its gas station for Enjoy cars, while Trenitalia can provide special offers for a combined use of trains and shared cars. The cars can be parked everywhere within the operating area, and one-way trip is allowed. The cars availability can be checked on the Website and on the app, and a reservation can be set. The fleet is composed by Fiat 500 and Fiat 500L, which is a car bigger than 500 and is useful for extra carriage. Moreover, Enjoy is the first scooter sharing in Italy with a fleet of 150 Piaggio scooters. Each scooter is equipped with two helmets and disposable cuffs for the driver and the passengers. The service covered a huge area of user needs that were not yet satisfied by the current car sharing and bike sharing services.

Hereafter, the cases were described through brief descriptions (cards) and clustered using some parameters such as the partnership characteristics, the pricing, the use of energy, the capillarity of the infrastructures, the community of users, the service accessibility, the quality of touchpoints and the presence of support assets.

The main characteristics of each case were described also through a scheme illustrating the customer journey (Fig. 1): this has pointed out the user interaction through the main touchpoints. Some elements were considered: (i) the access to the service and the vehicle (using desks, Web, smartphones, RFID), (ii) the service elements that support users while using the service and during the returning/leaving the vehicle in the station/parking (using internal/external drives, key box) and (iii) the infrastructure and parking areas (considering charging stations).

3.2 Generating Ideas of Product-Service Systems Through Participatory Workshops

The idea generation activity has been based mainly on the results of the context analysis (characteristics of the mobility system and electrical vehicle offering in Milan) and the best practice collection.

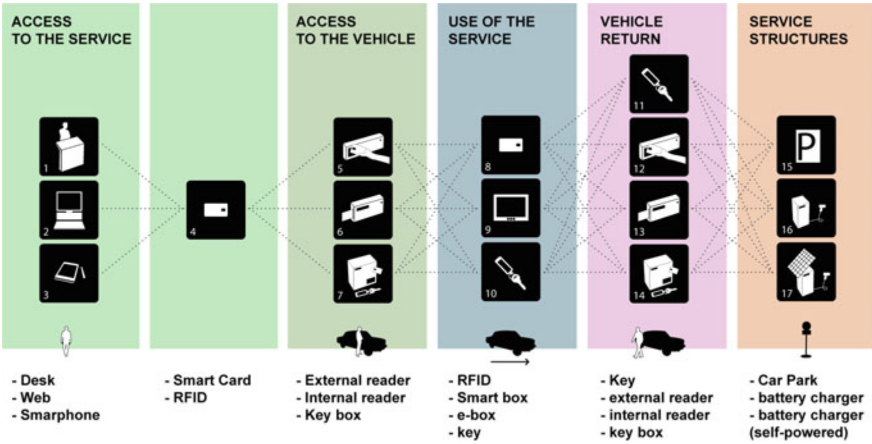

Fig. 1 Example of the general steps of customer journey derived from the case analysis

The concept generation has been developed through a participatory workshop that involved different stakeholders: the complete Green Move research teams together with some representatives of institutions and companies. This activity focused on sustainable urban mobility solutions describing the user experience, the use of technology and energy, the development of new business models and the possibility to include cooperative and participative models between users and user/service providers. Imagining new service solutions and new ways to structure service offer have an impact on vehicles design and performances, the whole service system and its organization, and the users' behaviours and experiences, moreover on the urban context and its mobility system.

For these reasons, the idea generation process has been structured in order to propose a large number of service ideas that consider future challenges for electrical mobility and urban sustainable mobility scenarios.

The creative phase of Green Move research involved, beyond some institutional and entrepreneurial stakeholders, a multidisciplinary team composed of designers, engineers, researchers and students that actively participated in brainstorming phase and in the subsequent reflection on service proposals. The brainstorming activities have been done during a design workshop to imagine—in a collaborative way—new service and new business models and new offering structures.

In order to facilitate the brainstorming activity, three cross schemes have been proposed each defining four design directions considering three main levers of innovation:

1. the user experience (active/passive users—community/single users);
2. the use of technology (relieving/enabling system—personal/shared technology);
3. the energy production/energy management (energy producers/consumers—B2B/B2C approach).

Participants were asked to propose different service ideas/mobility models for each of the cross schemes presented in order to obtain a large number of concepts. The collaboration between researchers with different backgrounds and external actors helped the creative process, the knowledge sharing and the discussion on different design perspectives and strategies considering, for example the users' experience, the technology and the technical issues related to the energy production.

3.3 Developing Mobility Scenarios Based on Electric Vehicles

The rough ideas generated during the brainstorming activity (total number of 67) were subsequently clustered into six design scenarios (areas of innovation). The description of the service scenarios considered the design challenges derived from the case study analysis and the heterogeneous stimuli derived from the concept generation.

In particular, the final six macro scenarios for mobility services are based on six innovation areas: (1) business model, (2) information management, (3) user interaction, (4) cooperation/peering, (5) co-production services, (6) energy infrastructure/energy management. These scenarios included the main design topics to be considered while defining the choice of a new electrical vehicle, coherent with the urban system and resources and the needs of users and communities involved.

For each scenario, some promising service concepts have been identified as starting point to be further developed in the next stages, these are:

- Pricing/incentives (adopting different fares for urban zones and trips);
- Fleets management (using external firm fleets to widen the service offering, for example during the night);
- Procurement/Consulting (defining specific offers for B2B services);
- Education (fostering education about the use of the EV sharing also through social technologies);
- Real time on the move (intercepting a wider demand connecting car pooling and car sharing);
- Feedback management (improving the idea of service community using the users' feedback);
- Customization/profiling (designing services for specific users'
- communities);
- Communities (adapting/scaling the service to particular communities such as co-housing models);
- Coop (proposing collaborative models for the service production, delivery and management using peer-to-peer approaches);
- Micro-entrepreneurship (expanding the service offering including other small companies—as co-producers—that can provide additional services).

The above-described ideas have been discussed within the different research teams (designers, engineers, managers) in order to select the most promising service concepts considering the complexity of the mobility service systems including infrastructures, vehicles, organization, interactions, capillarity, economic, social and environmental sustainability.

Successively the most promising scenario was clustered in order to define and select some interesting service concepts and configurations that are characterized by the aim of offering a service that is more tailored on users' needs. In the end, four service configurations have been structured according to different users' mobility behaviours and contexts of application (Arena et al. 2015). These are:

1. the condominium car sharing: the idea of a fleet of vehicles shared among people that share spaces and expenses and live in a small area like a neighbourhood or a condominium;
2. the network of services: a network that can be connected to other service providers in the vehicle sharing initiatives by positioning the stations of Green Move in key areas of the city;
3. the new business fleet: the idea to substitute the business fleets owned by local companies with a shared fleet receiving a mobility kit from Green Move;
4. the peer-to-peer car sharing: the idea to enable users to share their private cars with other members of the system through a Web platform.

All of these concepts are described more in depth in Sect. Vehicle sharing configurations (configurations 1, 2 and 3) and in chap. 5 (configuration 4).

4 Conclusions

Car sharing and electrical vehicle sharing are very interesting business areas and development areas where design can intervene at different levels: service design, interaction design, product design and communication design as well as strategic design.

We could define this as an intervention on a product-service system in which designers are not only rethinking the entire car mobility system (Pearce 2010) but also they are contributing in promoting an efficient way to use fewer resources and deliver sustainable services and platforms in order to change from a vehicle owner's perspective to a vehicle sharing one.

For the designers, these challenges do not concern only the classical design task about the improvement of the efficiency and the performance of the vehicle (e.g. reducing the energy consumption and the ecological footprint impact) but also the change of the whole mobility system. This means that the tasks are related to the behavioural changes (linked to the emergent lifestyle trends), the quality of users' interactions, the capacity to orchestrating new users' experiences.

The final Green Move design proposals can be considered as a possible suggested strategic solution that could help in finding complex answers to a wider problem (Luè et al. 2012).

These solutions should also face the difficult task of interacting with the macro-systemic levels—which are strongly linked with policy issues (e.g. urban policies, industrial strategies, sustainable development models) and design strategies (users' behaviours and consumption models)—and interrelated micro levels—such as the competitive scenario of new service and product solutions.

Thus, the design intervention has defined a sort of ideal process to which a service design mobility process should refer in terms of level and scale:

- the general mobility system (in terms of regulatory rules) in which new products and services will be delivered;
- the design strategies related to the general mobility system and their adoption/diffusion;
- the setting and the implementation process of the final solutions that need to be coherent to the macro problem setting and to the service industrialization perspective;
- the application of a complete suite of service design tools that need to be used to support the overall objectives of the design process and the related collaborative activities.

All these recommendations have been integrated in the subsequent steps of Green Move process, which involve the definition of a targeted value proposition.

References

Arena M, Azzone G, Colorni A, Conte A, Luè A, Nocerino R (2015) Service design in electric vehicle sharing: evidence from Italy. Intell Trans Sys, IET 9(2):145–155

Botsman R, Rogers R (2010) What's mine is yours. The rise of collaborative consumption. Harper, New York

Dervojeda K, Verzijl D, Nagtegaal F, Lengton M, Rouwmaat E, Monfardini E, Frideres L (2013) The sharing economy. Accessibility based business models for peer-to-peer markets, Case study no. 12, European Commission, Directorate-General for Enterprise and Industry, Brussels

Gummesson E (1990) Service design. Total Qual Manag 2(2):97–101

Holmlid S (2009) Participative, co-operative, emancipatory: from participatory design to service design. 1st Nordic conference on service design and service innovation, Oslo

Jégou F, Manzini E (2008) Collaborative services. Social innovation and design for sustainability. Edizioni POLI.design, Milan

Lovelock CH, Wirtz J (2004) Services marketing: people, technology, strategy. Pearson and Prentice Hall, Upper Saddle River, N.J.

Luè A, Colorni A, Nocerino R, Paruscio V (2012) Green Move: an innovative electric vehicle-sharing system. Proc Soc Behav Sci 48:2978–2987

Maffei S, Villari B, Liaci P, Longoni D (2011) Sintesi degli scenari. Green Move Workshop, 05 May 2011, (in Italian)

Mager B, Sung TJ (2011) Special issue editorial: designing for services. Int J Des 5(2):1–3

Meroni A, Sangiorgi D (eds) (2011) Design for services. Gower Publishing, Surrey

Mulgan G (2007) Social innovation: what it is, why it matters, and how It can be accelerated. Skoll centre for social entrepreneurship. Working Paper. www.sbs.ox.ac.uk/centres/skoll/research/documents/social/innovation.pdf. Accessed 4 Apr 2016

Negro G (1992) Organizzare la qualità nei servizi. II Sole 24 Ore, Milano

Nisula VJ (2012) Searching for Definitions for Service Design—What do we mean with Service Design? ServDes.2012 Conference proceedings co-creating services; The 3rd service design and service innovation conference; 8–10 February; Espoo; Finland

Pais I, Provasi G (2015) Sharing economy: a step towards the Re-embeddedness of the economy? Stato e Mercato 35(3):347–378

Pearce F (2010) What can you do on four wheels? The Guardian. www.guardian.co.uk/service-design/car-industry. Accessed 4 Apr 2016

Scheuing E, Johnson E (1989) Proposed model for new service development. J Serv Mark 3 (2):25–34

Shostack GL (1984) Designing services that deliver. Harv Bus Rev 1984(1–2):133–139

Shostack GL (1982) How to Design a Service. Eur J Mark 16(1):49–62

Stickdorn M (2010) 5 principles of service design thinking. In: Stickdorn M, Schneider J (eds) This is service design thinking. BIS Publishers, Amsterdam, p 24–45

Stickdorn M, Schneider J (2010) This is service design thinking: basics—tools—cases. BIS Publishers, Amsterdam

Villari B, Luè A (2013) Design research on sustainable mobility: an electric vehicle sharing service for Milano, Italy. In proceedings of the 10th European academy of design conference—crafting the future

Traditional and Innovative Vehicle-Sharing Models

Marika Arena, Giovanni Azzone and Irene Bengo

Abstract In recent years, car-sharing models have undergone relevant changes, leading to the emergence of different operational models, managerial and technological solutions, and more in general different vehicle-sharing configurations. These models are able to answer in different ways to potential mobility needs, put forth by both individual citizens and firms, leading to the idea that vehicle sharing should be not conceived as a standard service. In this context, this chapter outlines the evolution of different car-sharing models emerged from the literature review and discusses Green Move configurations with specific reference to the condominium car sharing, the network of services, and the new business fleet.

1 Introduction

Since its introduction in the late 1980s, the concept of car sharing has evolved in order to adapt its functioning to different changes that have been taking place in the social ecosystem. The core idea on which car sharing is based remained the same—i.e., replacing private ownership of cars with the access to a mobility service, coherently with the so-called access age (Rifkin 2000). However, the operational models whereby this idea can be enacted have changed significantly, leading to the rise of different service configurations.

This evolution has been determined by a mix of innovation impulses that can be related to both the development of the technology and the change in the market demand.

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The first relevant impulse to new car-sharing services was given by the diffusion of new technologies for the so-called smart mobility that according to Chun and Lee (2015) can be defined as "a concept of comprehensive and smarter future traffic service in combination with smart technology." In general terms, the concept of smart mobility is broad and refers to the idea of enhanced mobility, environmental sustainability, and inclusiveness. Hence, it depends on a plurality of factors ranging from an efficient means of public transport having a low environmental impact (reduced greenhouse gas emissions and energy consumption), a network of safe and continuous cycle lanes, interchange parking that avoids the city congestion, and also the availability of adequate car-sharing or more in general vehicle-sharing services (Garau et al. 2016).

In this context, two technological trajectories appear particularly relevant for explaining the evolution of car-sharing service configurations. First, several initiatives have highlighted how information and communication technologies (ICT) can be used to achieve smart mobility by modifying individual mobility behavior and lowering energy use and greenhouse gas emissions. In particular, the recent literature is converging on the idea that ICT is gradually enriching travelers' spatial and temporal practices (Aguiléra et al. 2012). From this perspective, ICT has opened up new opportunities in relationship to car-sharing configurations, facilitating a wide range of operations (such as reservation, vehicle localization, access) and enabling new services (Shaheen and Cohen 2007; May et al. 2008).

The second technological trajectory that is influencing the evolution of car-sharing configurations is represented by electric mobility. Indeed, there is a general expectation concerning a shift from internal combustion engine (ICE) to electric vehicles (EVs) in western countries' cities. This expectation is confirmed by the investments of the principal car producers, which are dedicating growing resources to develop hybrid and electric car models (e.g., Toyota, Peugeot, Nissan). In this context, several cities have introduced EV-sharing services as a means of dealing with the problem of congestion and urban pollution (e.g., Boyacy et al. 2015). The possibility of relying on a shared fleet of EVs has represented a means for dealing with some problems generally associated with e-mobility: higher costs compared to traditional ICE vehicles and the need of creating an adequate infrastructure for ensuring the possibility of recharging EVs.

In addition to the technological evolution, a further stimulus for the rise of new vehicle-sharing configurations came from the characteristics of the market demand—i.e., mobility demand of potential vehicle-sharing users. Roughly speaking, the attractiveness of car-sharing systems depends on two key factors (Boyaci et al. 2015):

- the level of service offered;
- the cost associated with the use of the system.

However, the level of service is a multidimensional construct that in turn depends on many different factors such as capillarity, flexibility, interoperability, multimodality, easiness of reservation, access and use, etc.. In recent years, mobility behaviors of private citizens have evolved and the expectations of car-sharing (potential) users toward this service reflect this change. From this point of view, a key issue is that different vehicle-sharing configurations answer in a different way—i.e., leveraging on different performance—to passenger demand for mobility (e.g., Efthymiou et al. 2013).

Against this consideration, this chapter aims to outline the evolution of different car-sharing service configurations based on a literature review and introduce the innovative configurations developed with the Green Move project highlighting how these configurations respond to different mobility profiles.

Accordingly, the rest of this chapter is articulated as follows: Section 2 presents a literature review of different car-sharing models; Sect. 3 identifies the key performance dimensions against which a car-sharing configuration can be assessed; Sect. 4 introduces the Green Move car-sharing configurations; Sect. 5 concludes with possible paths for future research.

2 The Evolution of Car-Sharing Models

In the literature, car-sharing models have been traditionally classified along two main axes (e.g., Boyaci et al. 2015), distinguishing between:

- "Two-way" versus "one-way" car-sharing systems;
- "Non-floating" systems versus "free-floating" car-sharing systems.

Moving from the first axis, two-way car-sharing systems rely on the idea that the users have to return the rented vehicle at the same location where they picked it up. Instead, in one-way car-sharing systems, the users have the possibility of returning the rented vehicle at a different station compared to where they picked it up.

Concerning the second axis, in non-floating systems, users can pick up and have to drop off vehicles in specific locations—i.e., designated parking spots. Instead, in free-floating systems, the users do not have any restriction in connection with parking spots. They can pick up or drop off vehicles in any parking spot within a predefined area.

Analyzing the evolution of the car sharing, we can distinguish four main car-sharing models:

- Neighborhood car sharing (two-way, non-floating);
- Stations cars (one-way, non-floating);
- Multinodal shared-use vehicles (one-way, non-floating);
- Free-floating car sharing (one-way, floating).

The neighborhood car sharing is the original car-sharing model. It is based on the two-way system, and it is characterized by a network of shared-use vehicles that are settled in strategic locations (Shaheen and Cohen 2007). Car-sharing users in this configuration typically reserve a vehicle in advance. At the time of the rental, the user gains access to the vehicle, carries out his trip, and returns the vehicle back to the same station he originally picked up it from (Shaheen and Cohen 2007, 2012).

Different car-sharing configurations were developed adapting this basic idea in order to answer to the mobility needs of a specific community—e.g., business car sharing, college/university car sharing, government and institutional car sharing, vacation/resort car sharing. In this way, some tailored car-sharing configurations started to emerge and were characterized by the either exclusive-use vehicles that are shared among clients belonging to a specific community—firms, students, public servants, tourist—or by shared-use vehicles where the clients access the vehicles as part of a larger car-sharing fleet.

The second basic model is represented by the station cars. In this configuration, parking stations are settled at public transport stations, and commuters can pick up vehicles for covering the trip between their home and the station or the station and their working place (Shaheen and Cohen 2007). This configuration was conceived in order to enhance transit connectivity and enable public transit to access to locations that are typically served by private vehicles. For this reason, it is often associated with providing "first and last mile connectivity" (Shaheen and Cohen 2007).

The third model is the multinodal shared-use vehicles. This is a one-way model with multiple stations that are placed at different points of interest (such as hotels, shopping malls, tourist attractions, firm, and university premises). Users are then free to pick up a vehicle from any point of interest and leave it at any station, without having to return it to the same location from which it was accessed (Shaheen and Cohen 2007). This model is clearly more complex than the previous one, because it entails a higher level of flexibility for the clients in terms of possible trips. It can also be integrated with some of the previous configurations; for instance, multinodal systems could also be directly linked to transit, when one station is placed in a relevant transit point. This possibility makes this configuration very interesting in terms of potential contribution to urban mobility, but also calls for advanced instruments for running the service (e.g., Boyaci et al. 2015).

Finally, the last model is the free-floating car sharing. In this configuration, traditionally fixed stations are substituted by extended areas where the car is allowed to be hired and left after the rental. The vehicles are distributed freely over that area and can be tracked by the customer via Internet or mobile phone applications together with information about their level of fuel as well as their inner and outer state of cleanliness (Firnkorn and Müller 2011). Obviously, this change has relevant implications on how free-floating car-sharing works and how users can access and use this service. This model aims to provide users more flexibility compared to other car-sharing models. Being a one-way system, one-way journeys are allowed. Booking a vehicle in advance is possible but not compulsory; thus, the cars may be taken spontaneously in the street (Firnkorn and Müller, 2011).

These conditions ensure the users much flexibility, but also lead to higher managerial complexity.

To conclude the analysis of the state-of-the-art literature concerning different car-sharing models, an emerging trend must be mentioned: the personal vehicle-sharing paradigm. This new paradigm cannot be brought back to the above taxonomy, because this practice is something quite different compared to car sharing itself, even if it is often cited as an emerging car-sharing operational model (e.g., Shaheen and Cohen 2012, 2013). Personal car sharing, also referred to as peer-to-peer car sharing, is a system in which car owners exploit their personal cars as shared vehicles and rent them to other drivers on a short-term basis (Hampshire and Gaites 2010, Shaheen et al. 2012; Shaheen and Cohen 2013). There are many different ways in which personal vehicle sharing can be deployed ; Shaheen and Cohen (2013) identify four sub-models of personal vehicle sharing: 1) fractional ownership, 2) hybrid peer-to-peer -traditional car sharing, 3) P2P car sharing, and 4) P2P marketplace (see Shaheen and Cohen 2013). P2P car-sharing sub-model is described in Chap. 5.

The review of the state-of-the-art literature has highlighted a wide variety of possible car-sharing configurations that can answer to user mobility needs in different ways. In the next paragraphs, the Green Move configurations will be discussed, pinpointing how they have been conceived, starting from the existing models, in order to answer to different mobility profile.

3 Mobility Profiles and Vehicle-Sharing Performance

The four service configurations have been analyzed taking care of:

- The potential mobility profiles to whom a vehicle-sharing service could answer and
- The mobility performance that is particularly relevant in connection with such profiles.

Since different performances often entail some trade-offs, a vehicle-sharing service should be configured focusing on those performances that are coherent with the mobility profiles it aims to privilege (see also Arena et al. 2015).

3.1 Mobility Profiles

Mobility profiles describe the basic characteristics of the trips performed by vehicle-sharing users. In other words, they represent the specific “need of mobility” to whom the vehicle-sharing service is aimed to answer (Millard-Ball 2005; EU Commission 2010; Sioui et al. 2013).

The literature review allowed to identify eight different mobility profiles:

1. Commuter: regular trips between the home and workplaces (or schools);
2. Shopping: recreational travel in the city center, generally characterized by multiple and unpredictable stops;
3. Neighborhood trip: travel focused in local areas for daily activities (e.g., shopping, driving children to school);
4. Tourist in the city: recreational travel aimed at visit different attractions;
5. Nightlife: recreational travel during evening and night;
6. Business trip: business travel between stations/airports and a meeting place;
7. Moving in the campus: travel limited in certain space (e.g., campus);
8. Business fleet: travel for business purposes performed by the employees using a vehicle-sharing fleet.

3.2 Vehicle-Sharing Performance

A vehicle-sharing performance represents the key characteristics that allow to answer to different mobility profiles. Based on the literature review, we identified ten performance dimensions (Barth and Shaheen 2002; Millard-Ball 2005; May et al. 2008; EU Commission 2010):

1. Capillarity: number and location of the stations. Higher capillarity reduces the access time to the system, making a vehicle-sharing service more similar to the car ownership and allows to capture a larger potential demand (Cohen et al. 2008);
2. Flexibility: lack of constraints in terms of choice of the release station and scheduling time. Flexibility can be related to two main dimensions:
   a) Space: the customer is allowed to release the vehicle in a station other than where the vehicle was picked up;
   b) Time: the customer is allowed to access the vehicle without reservation and/or to make an open-end reservation, without fixed time limits;
3. Intermodality: possibility to integrate the vehicle-sharing service with other public transport (underground, train, etc.). This concept can be declined into:
   a) Interoperability: the use of integrated access devices (e.g., a single smart card) valid for different types of transportation;
   b) Multimodality: location of parking stations near the public transport;
4. Rate: price charged to the customer for the vehicle’s usage. It consists of different components, such as subscription costs, kilometer and hour rate, penalties, that can be totally waved or incremented;
5. Availability of incentives: forms of facilitation to encourage service use; they include, for instance, access to free parking areas and limited traffic areas;

6. Vehicles: number and types of vehicles available; the vehicles must be adaptable to different needs in terms of interior (seats and luggage) and range distances;
7. Easiness of access and use: simplicity of the procedures to access and use a vehicle, so that it does not differ significantly from privately owned vehicles. It can be related to:

    a) Access time: opening/closing hours that determine when the vehicle can be accessed by users (the optimal situation is 24 h) and
    b) Lock/unlock system and driving style;

8. Easiness of the payment system: simplicity of the payment process that allows the customer to quickly access the service without lengthening the total journey time or creating barriers to the service use (e.g., mandatory request of the credit card);
9. Easiness of the reservation system: simplicity of the process required to reserve a vehicle and book the arrival station (in the multinodal service);
10. Additional services: ancillary services that complement the basic performances.

The analysis of performance dimensions has been used as starting point for the design of the Green Move simulation model (Sect. 3).

4 Vehicle-Sharing Configurations

This paragraph introduces the three vehicle-sharing configurations developed within the Green Move project:

- The condominium car sharing;
- The network of services; and
- The new business fleet.

4.1 Condominium Car Sharing

The basic idea of condominium car sharing consists in an EV-sharing service deployed on a condominium basis. It brings to the extreme the neighborhood operational model narrowing the sharing base to the condominium. In this way, the users have the possibility of booking and picking up the vehicle inside their own condominium and use them for two-way trips. Referring to the mobility profiles previously defined, this configuration aims to serve the mobility profiles connected to “neighborhood trip” and “nightlife.”

In the condominium car sharing, the capillarity is the main strength of the service. It helps to overcome one of the principal barriers that obstacle car-sharing

Table 1 Condominium car-sharing performances

Capillarity	Inside the condominiums
Flexibility—space	Two-way service
Flexibility—time	No reservation
Multimodality	There are no stations near the local public transport
Interoperability	No. The service is operated by a mobile application
Rate	Preliminary hypothesis of 5 €/h (7 a.m.–7 p.m.) and 3 €/h (7 p.m.–7 a.m.)
Availability of incentives	Area C and blue parking stripes "Sosta Milano" are free, and it is also possible to park on yellow lines for residents
Vehicles	2 different car models
Easiness of access and use	Cars are available 24 h on 24, every day of the year. Using a mobile application, it is possible to open the doors
Easiness of the payment system	Automatically by smartphone
Easiness of the reservation system	It is possible to book the car from the Web site or with the mobile application
Additional services	No additional services

use, i.e., the distance from the station of collecting/delivery of the vehicle. Other positive aspects concern the safety for both vehicles and users, as cars are kept within a protected area and the possibility to integrate peer-to-peer approaches due to the immediate community. On the other hand, the main weaknesses of this configuration consist in the rigidity of the system due to the possibility to perform two-way trips only and the difficulties to provide common areas for the vehicles parking, in existing condominium. Table 1 synthesizes the main performances of the service.

The condominium car-sharing configuration has been tested within Green Move activities, as depicted in Chap. 6.

4.2 *Network of Services*

The second configuration focuses on shopping and recreation profiles ("shopping," "tourist in the city," and "nightlife"). Based on the competitive analysis, a widespread mobility profile resulted to be linked to free time and shopping-related occasions. However, the existing services do not favor this travel pattern as they are not directly connected with recreational areas.

Hence, the second configuration bases on the multinodal operational model in which cars are driven among multiple stations or nodes to travel from one activity center to another and integrate the electric mobility service with other services offered in key areas of the city (e.g., shopping centers, cultural centers, health structures, city center, public transport stations, relaxation/fun centers, night

Table 2 Network of services performances

Capillarity	Stations located near the main city nodes
Flexibility—space	One-way service
Flexibility—time	No reservation
Multimodality	Stations located also near the local public transport
Interoperability	No. The service is operated by a mobile application
Rate	Preliminary hypothesis of 7 €/h
Availability of incentives	Area C and blue parking stripes "Sosta Milano" are free, and it is also possible to park on yellow lines for residents
Vehicles	Four different car models
Easiness of access and use	Cars are available 24 h on 24, every day of the year. Using a mobile application, it is possible to open the doors
Easiness of the payment system	Automatically by smartphone
Easiness of the reservation system	It is possible to book the car from the Web site or with the mobile application
Additional services	Service integration with main point of interest of the city

amusement sites). In this way, it is possible to improve the accessibility of vehicle-sharing users to key nodes, relying on the possibility of integrating vehicle sharing with the services offered by the nodes themselves. The basic idea of network of services is to involve other service providers in the vehicle-sharing initiative by:

- positioning the stations, the sites of these nodes to satisfy the needs of mobility of their users/visitors and
- integrating other mobility systems and services delivered by the node in a proper manner.

Key feature of this configuration is the possibility of performing one-way trips between nodes, i.e., releasing the vehicle in a parking station other than the departure one. To the users will be given the possibility to release the vehicle in the node more convenient to them and to interact with the service provider (for instance, by purchasing the museum access from the vehicle). In addition, including the main public transport stations among the key nodes, the "network of services" configuration could also support intermodal travels. Table 2 summarizes the main performances of the service.

4.3 *The New Business Fleet*

The business segment is an emerging market for vehicle-sharing initiatives; hence, the third configuration consists in an electric vehicle-sharing initiative targeting firms and public institutions. In this case, the main idea of the service is to both

Table 3 New business fleet performances

Capillarity	Inside the firms
Flexibility–space	One- and two-way services
Flexibility–time	Reservation is mandatory
Multimodality	There are no stations near the local public transport
Interoperability	No. The service is operated by a mobile application
Rate	Four different rate plans differentiated on the firm specificity
Availability of incentives	Area C and blue parking stripes "Sosta Milano" are free, and it is also possible to park on yellow lines for residents
Vehicles	Four different car models
Easiness of access and use	Cars are available 24 h on 24, every day of the year. Using a mobile application, it is possible to open the doors
Easiness of the payment system	Automatically by smartphone
Easiness of the reservation system	It is possible to book the car from the Web site or with the mobile application
Additional services	No additional services

substitute business fleets owned by local companies with a shared one (i.e., each firm can purchase a mobility package) and provide an alternative mobility service to the employees. Accordingly, this configuration aims to serve the "business fleet" and "commuter" profiles. The main characteristics of this configuration are:

- use of the vehicles from the companies on working time and from their employees for private use on spare time (evening and weekend);
- availability of parking lots for the vehicles inside company premises.

This configuration has several positive aspects such as the possibility to integrate peer-to-peer approaches. In fact, confidence in colleagues and the much time spent at the workplace help a possible sharing of the private car. Moreover, the service improves the transparency and traceability of employee travels. A weakness concerns the last mile problem, not solved by this configuration. In Table 3, the main performances of the service are summarized.

5 Conclusions

This chapter moved from the acknowledgment of the profound evolution that has characterized the operational models of vehicle sharing in the last decade. Though the core idea on which vehicle sharing is based remained the same—i.e., replacing private ownership of cars with the access to a mobility service—both the literature and the practice provide a very diversified picture of how this idea has been deployed in new services through the years. This evolution has been clearly informed by the emerging new technological opportunities, ICT and e-mobility in particular, and the change in the market demand, with users that are more sensible toward the issues of environmental protection, and also more used to the idea of really considering mobility as a service (i.e., not necessarily associating it with car ownership).

With this background, this chapter has drawn a picture of different car-sharing service configurations, first presenting the state-of-the-art literature and then introducing the innovative configurations developed with the Green Move project: the condominium car sharing; the network of services; and the new business fleet. These configurations have been designed based on the analysis of 1) the potential mobility profiles to whom a vehicle-sharing service could answer and 2) the mobility performance that is particularly relevant in connection with such profiles.

In conclusion, we discuss the main limitations of this work that open the way to future research. First, it is worthy of mentioning that the proposed configurations aim to answer to a potential demand for mobility that is associated with some specific mobility profiles. The identification of the mobility profiles and the relevant vehicle-sharing performance has been carried out based on the literature review. Hence, they are quite general in scope. Then, the Green Move configurations were developed posing particular attention to those mobility profiles that are somehow coherent with those expected in a large city. However, the same methodological approach could be adopted in order to develop different service configurations in areas that are characterized by a different mobility demand. The second aspect that is worthy of mentioning is that, in this chapter, limited attention has been given to peer-to-peer vehicle sharing. This is an interesting possible development that is coherent with the emerging paradigm of the sharing economy, and it is addressed in Chap. 5.

References

Aguiléra A, Guillot C, Rallet A (2012) Mobile ICTs and physical mobility: review and research agenda. Transp Res Part A Policy Pract 46(4):664–672

Arena M, Azzone G, Colorni A, Conte A, Luè A, Nocerino R (2015) Service design in electric vehicle sharing: evidence from Italy. Intell Transport Syst, IET 9(2):145–155

Barth M, Shaheen S (2002) Shared-use vehicle systems: framework for classifying carsharing, station cars, and combined approaches. Transp Res Rec J Transp Res Board 1791:105–112

Boyacı B, Zografos KG, Geroliminis N (2015) An optimization framework for the development of efficient one-way car sharing systems. Eur J Oper Res 240(3):718–733

Chun BT, Lee SH (2015) Review on ITS in Smart City. Adv Sci Technol Lett 98:52–54

Cohen AP, Shaheen S, McKenzie R (2008) Carsharing: a guide for local planners. Institute of Transportation Studies, Working Paper Series. Davis, California

Efthymiou D, Antoniou C, Waddell P (2013) Factors affecting the adoption of vehicle sharing systems by young drivers. Transp Policy 29:64–73

Firnkorn J, Müller M (2011) What will be the environmental effects of new free-floating car sharing systems? The case of car2go in Ulm. Ecol Econ 70(8):1519–1528

Garau C, Masala F, Pinna F (2016) Cagliari and smart urban mobility: analysis and comparison. Cities 56:35–46

Hampshire R, Gaites C (2011) Peer-to-peer carsharing: market analysis and potential growth. Transp Res Rec J Transp Res Board 2217:119–126
May A, Ross T, Grebert J, Segarra G (2008) User reaction to car share and lift share within a transport 'marketplace'. IET Intel Transp Syst 2(1):47
Millard-Ball A. (2005) Car sharing: where and how it succeeds. Transportation Research Board, Washington
Niches+, EU Commission (2010) Guidelines for implementers of electric cars in car share clubs. Retrieved at http://www.niches-transport.org/
Rifkin J, Saint-Upéry M (2000) L'âge de l'accès: la révolution de la nouvelle économie. La Découverte, Paris
Shaheen S, Cohen A (2007) Growth in worldwide carsharing: an international comparison. Transp Res Rec J Transp Res Board 1992:81–89
Shaheen SA, Mallery MA, Kingsley KJ (2012) Personal vehicle sharing services in North America. Res Transp Bus Manage 3:71–81
Shaheen SA, Cohen AP (2013) Carsharing and personal vehicle services: worldwide market developments and emerging trends. Int J Sustain Transp 7(1):5–34

Analysis of Mobile Phone Data for Deriving City Mobility Patterns

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Abstract A lot of processes affect lifestyle in an urban area, above all in a huge area that of Milan that represents, in terms of inhabitants, one of the biggest European metropolitan areas. In particular, working, residential, and mobility activities can be indicated as crucial for the well-being of the city. However, these processes are difficult to evaluate directly. Then, undirected instruments for the evaluation of these activities can be taken into account. In this chapter, we analyze a mobile phone network dataset in order to retrieve meaningful features of urban dynamics. These features can be exploited for urban planning procedures as, for instance, the implementation of a car sharing system. We perform a statistical analysis, based on Blind Source Separation techniques on a dataset that measures the intensity of mobile phone activity over the city of Milan varying along two weeks. Blind Source Separation techniques allow to extrapolate significant sources from raw data and to associate each source to a specific urban behavior.

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1 Introduction and Data Description

The disruptive diffusion of mobile phones in both developed and developing countries has made mobile phone data a rich source of information with respect to people movement in both densely populated urban areas and sparsely inhabited rural areas. These data have been indeed recently used to provide new real-time perspectives on several issues such as pollution, congestion, or even epidemic spread. This work focuses on the statistical exploration of mobile phone data provided by Telecom Italia which is currently the largest operator in Italy in this sector. In detail, our data refer to the mobile phone activity recorded in a period of two weeks (i.e., from March 18, 2009, 00:15, till March 31, 2009, 23:45) in a rectangular region of 757 km^2 (i.e., latitude 45.37° N—45.57° N and longitude 9.05° E—9.35° E). Row data were aggregated into 10,573 rectangular tiles of size 232 m $\times$ 309 m and 1308 intervals of 15 min for a total of nearly 14 million records collected. For each tile and each time interval, the corresponding record refers to the average number of mobile phones simultaneously connected to the network in that tile in that time interval.

This quantity is called Erlang and, at a first approximation, can be considered proportional to the number of active people in that site at that time, thus providing real-time information about people presence. These data reveal of course obvious global dynamics related to the day/night effect and working/weekend day effect which are not the focus on this work. We aim instead at identifying local and/or temporary dynamics possibly associated with specific subregions and/or with specific time periods. In detail, we focus on the comparison of four different state-of-the-art Blind Source Separation techniques (i.e., principal component analysis, independent component analysis, Treelet Analysis, and hierarchical independent component analysis) from the point of view of the practitioner.

These data have already been the object of two recently published papers in which another methodological issue is explored, i.e., possible spatial dependence between instances. In particular, in Secchi et al. (2015) a method based on the integration of Treelet Analysis (Lee et al. 2008) and Bagging Voronoi Analysis (Secchi et al. 2013) is proposed while in Zanini et al. (2016) a method based on the integration between independent component analysis and spatial Gaussian processes is proposed.

2 Data Preprocessing

All Blind Source Separation techniques are meant to deal with datasets containing stochastically independent instances (here univocally associated with 10,573 tiles) of a set of stochastically dependent random variables (here univocally associated with some time-instants). To make the raw data suitable for the analysis, we perform separately for each tile a standard Fourier filter based on least-squares approximation imposing a one-week periodicity to the observed phenomenon and removing the variability due to high-frequency components (i.e., only the first 100 harmonics are considered). This approach allows the estimation of missing data associated with discontinuities in information provided by the network antennas and enlarges the signal-to-noise ratio by removing the high-frequency fluctuations. On the other hand, it introduces some possible bias in the data for week-specific events (due to the averaging effect between the two weeks) and limits the temporal resolution to 1.68 h loosing events whose full dynamics evolve faster than this.

The number of harmonics to be used on the Fourier filtering is possibly case-specific and related to a bias-variance trade-off in the signal estimation. If too few harmonics are considered, we are likely to obtain very smooth data representations (i.e., low variance) in which some important dynamics might have been removed (i.e., high bias). On the contrary, if too many harmonics are considered, we are likely to obtain very rough data representation (i.e., high variance) in which also sudden peaks and oscillations are preserved (i.e., low bias). In this context, we have that the frequencies significantly contributing to the signal are the first seven harmonics describing low-frequency variations imputable to the differences between week days, and higher frequency harmonics with periods submultiple of the day describing the recurring within-day dynamics. Smoothed signals are finally evaluated on a uniform grid of 200 time instants, thus generating a data matrix of 200 rows and 10,573 columns. Further details about the preprocessing can be found in Secchi et al. (2015).

3 Data Analysis: Blind Source Separation Approach

We consider the following model:

$$X = AS$$

where X is the data matrix of dimension $p \times n$, A is a matrix of dimension $p \times K$ called mixing (or loadings) matrix, and S is the $K \times n$ source (or scores) matrix. Here, p represents the number of variable, n corresponds to the sample size, and $K < p$ is the number of supposed significant elements needed to describe the phenomenon gathered in X. According to the analysis of mobile phone data, p is the number of time instants (i.e., $p = 200$) and n is the number of pixels of the rectangular region (i.e., $n = 10{,}573$).

Our aim is to decompose the observed data matrix X in the product of two unobserved matrices A and S, describing a lower dimensional space with respect to the original p-dimensional space, and then to give an interpretation to the new K components according to the physic of the problem under study. From a geometrical point of view, we want to project the n observation of the original p-dimensional space in a K-dimensional space, with $K < p$. The columns of A represent the basis elements used to span the reduced space, while the rows of S gather the projections of the n observations. For the mobile phone application, we analyze here: Matrix S contains K spatial maps, and matrix A, its relative K temporal profiles. The idea is to associate each spatial map to a specific urban behavior related to working, residential, and mobility activities in the Milan area. Then, the relative temporal profile provides us information about when the specific urban activity is active or not.

This decomposition problem is often known in literature as Blind Source Separation. There are countless methods and techniques developed to approach this problem. Basically, they differ according to:

- the modeling assumption made on the matrices A and/or S;
- the constraints imposed on the matrices A and/or S; and
- the geometric characteristics of the reduced K-dimensional space where observations are projected.

Here, we consider four different approaches: principal component analysis, independent component analysis, Treelet Analysis, and hierarchical independent component analysis.

3.1 Methods

The first approach considered is the principal component analysis (PCA), one of the most widely known dimension reduction techniques in statistical literature. The great success of PCA is due to the fact that the K-dimensional spaced determined by PCA is the best approximation in terms of mean squared error. Furthermore, its solution is unique and exists in a closed form. Despite the nice geometrical property, PCA is not very suitable if the interest is focused on giving an interpretation to the identified components. Indeed, it provides an orthogonal basis matrix A. This means that the scalar product of the columns of A is identically zero. This constraint, even if could be useful from a mathematical point of view, is not necessarily related to any physical behavior. In our problem, this corresponds to find orthogonal temporal activation profiles of the urban activities, clearing showing how in this situation the orthogonal constraint cannot be directly interpreted.

To overcome this problem, we consider a second technique, named independent component analysis (ICA) (Comon and Jutten 2010). ICA relies only on the assumption of statistical independence of the K source variables, whose unobserved realizations are gathered in the rows of S. In our framework, this means that we look for urban activities whose realizations (i.e., the spatial maps) are independent. This technique is widely used in the decomposition of spatiotemporal datasets and, in general, it provides independent components (i.e., spatial maps in our case) and basis elements (i.e., temporal profiles) which are very meaningful with respect to the problem under study. However, a closed-form solution to the ICA problem does not exist in general situations. Hence, several algorithms have been developed along the last 20 years. Here, we exploit fastICA algorithm (Hyvarinen and Oja 2000).

Both PCA and fastICA approach are global methods, i.e., they provide full basis elements. This means that the matrix A is full. However, it would be interesting to introduce a sparsity assumption on the loadings matrix. In our framework, this means to find temporal profiles defined on a small set of instants. This allows us to identify urban activities localized in time. For this reason, we focus on a method, name Treelets (Lee et al. 2008), that, through a hierarchical procedure, provides a multi-resolution (i.e., providing both full and sparse elements) estimate of the matrix A. Treelets is a wavelet-inspired method, but data-driven. Indeed, it is a hierarchical procedure that at each step decomposes the two more correlated variables through a principal component decomposition. This provides an orthogonal data-driven multi-resolution basis.

Since the local decomposition at each step is based on PCA, Treelets maintains the same drawback due to the orthogonality constraint of basis elements. For this reason, as fourth method, we consider hierarchical independent component analysis (HICA) (Secchi et al. 2016). HICA follows the same principle of Treelets, but at each step it decomposes the two more dependent variables through an independent component decomposition. This allows to obtain a data-driven multi-resolution basis, as well as for Treelets, but non-orthogonal.

A schematic representation of the principal characteristics of the methods described above is provided in Fig. 1.

3.2 Results

In this subsection, we show the results obtained with the four methods considered. For every method, we performed a dimensional reduction with K = 15 elements. In this way, we are able to catch all the relevant urban behaviors. All the temporal

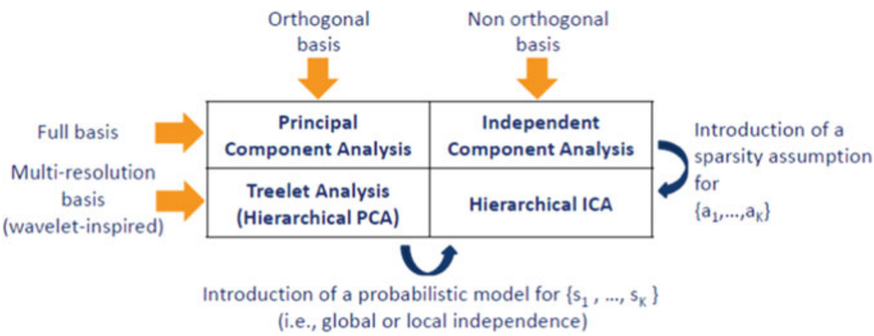

Fig. 1 Schematic representation of the characteristic of the 4 methods used in the analysis of mobile phone data

profiles go from Wednesday to Tuesday, in order to better highlight the transition between working days and weekend. The map color scale is such that blue corresponds to large positive values, and red, to large negative values.

For PCA, from Fig. 2 to Fig. 4, the first three components are depicted. The other components result to be very noisy and difficult to interpret; thus, we focus on the first three ones.

The first component is reported in Fig. 2. This component catches an average activity, with a temporal profile which presents peaks during the daily hours, higher during the working days than the weekend. The spatial map presents higher values in the city center which gradually decrease going toward the suburbs and the countryside.

The second one, in Fig. 3, presents a contrast, in the temporal profile, between daily hours of the working days versus evening hours and weekend. Since the map contrasts the city center, where there are mainly financial districts, and the area around the center, which includes more residential zones, this interesting component can be seen as a contrast between working and leisure activity.

In Fig. 4, the third component is shown. The temporal profile presents some nice peaks between 6 pm and 7 pm of the working days. This is a typical time when a lot of people, working in Milan and living outside, leave the city. Thus, it is interesting to point out that the map, among other areas, highlights Linate Airport and the Central railway station. This suggests that this analysis could be able to catch some interesting mobility behavior, very useful in the development of a car sharing system. However, the map presents other highlighted area, and the temporal profile shows other negative oscillations. This is due to the fact that the orthogonal constraint of PCA could provide misleading components. For this reason, we considered other techniques, whose results will be shown in the following.

For ICA, using fastICA algorithm, we do not obtain an order between the components. Hence, from Fig. 5 to Fig. 8, we selected the four more interpretable components, which allow to compare these results with those obtained with PCA and to show the improvements.

In Fig. 5, we can see a temporal profile similar to that of Fig. 2 (i.e., the average component of PCA), but with lower peaks during the weekend. Furthermore, the map is quite different, highlighting only the financial district, with the other areas that are not concerned at all by this component. Thus, it seems to represent the main working activities of the city.

The second component shown in Fig. 6 presents a temporal profile high during the daily hours, with some peaks late in the afternoon, particularly prominent during the working days. The map put in evidence the ring area just outside the city center, suggesting that this component speaks about a zone active during the day, with a strong increment when people leave the city center after work. This is still a useful information to plan efficiently a car sharing system.

The third component depicted in Fig. 7 is similar to the third PCA component of Fig. 4, but with some crucial differences. The temporal profile presents strong peaks between 6 pm and 7 pm of the working days, as well as the PCA component. However, the rest of the profile is more clear, without any negative peaks which compromise interpretation. This is due to the fact that temporal profiles are no

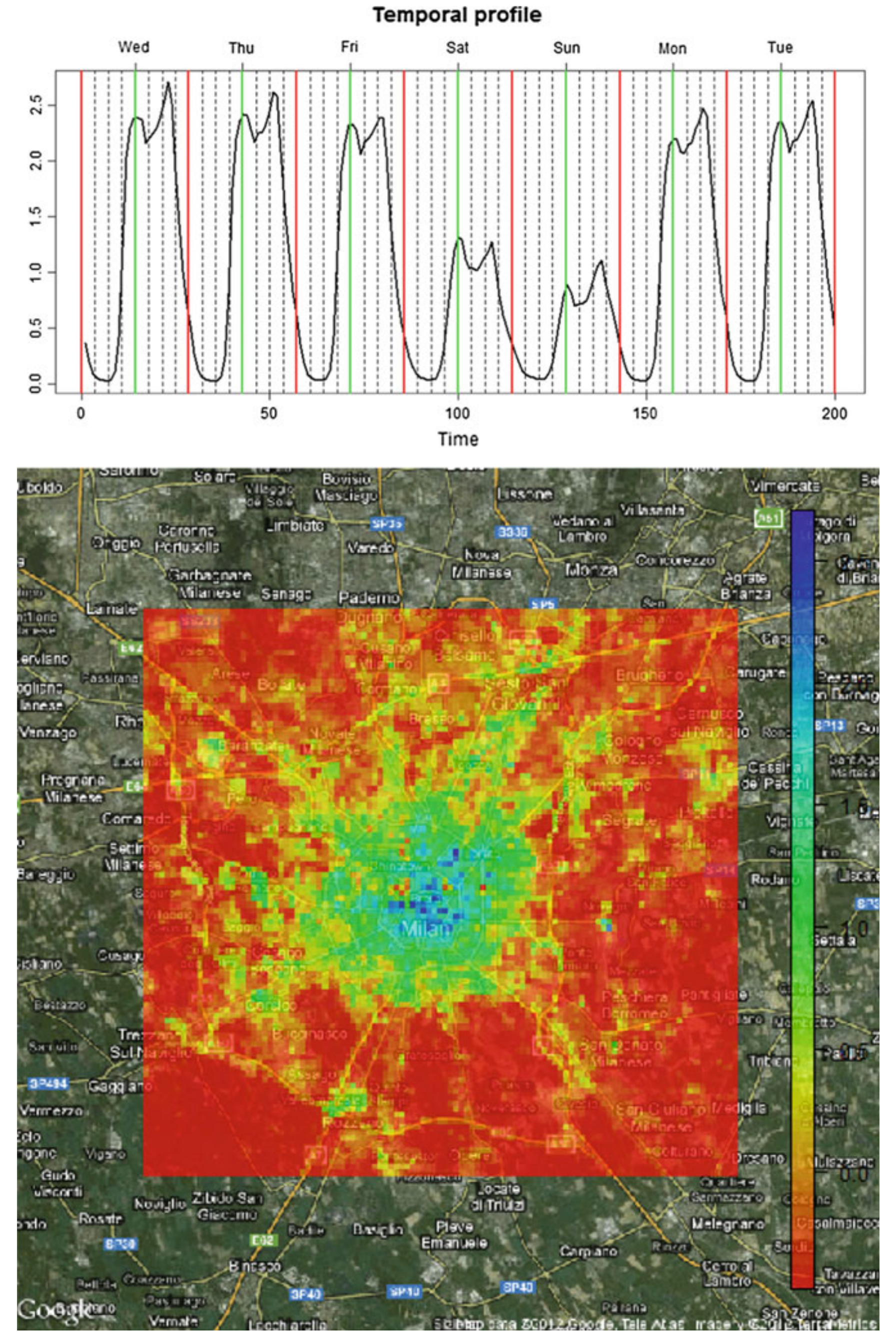

Fig. 2 PCA—first component representing the average

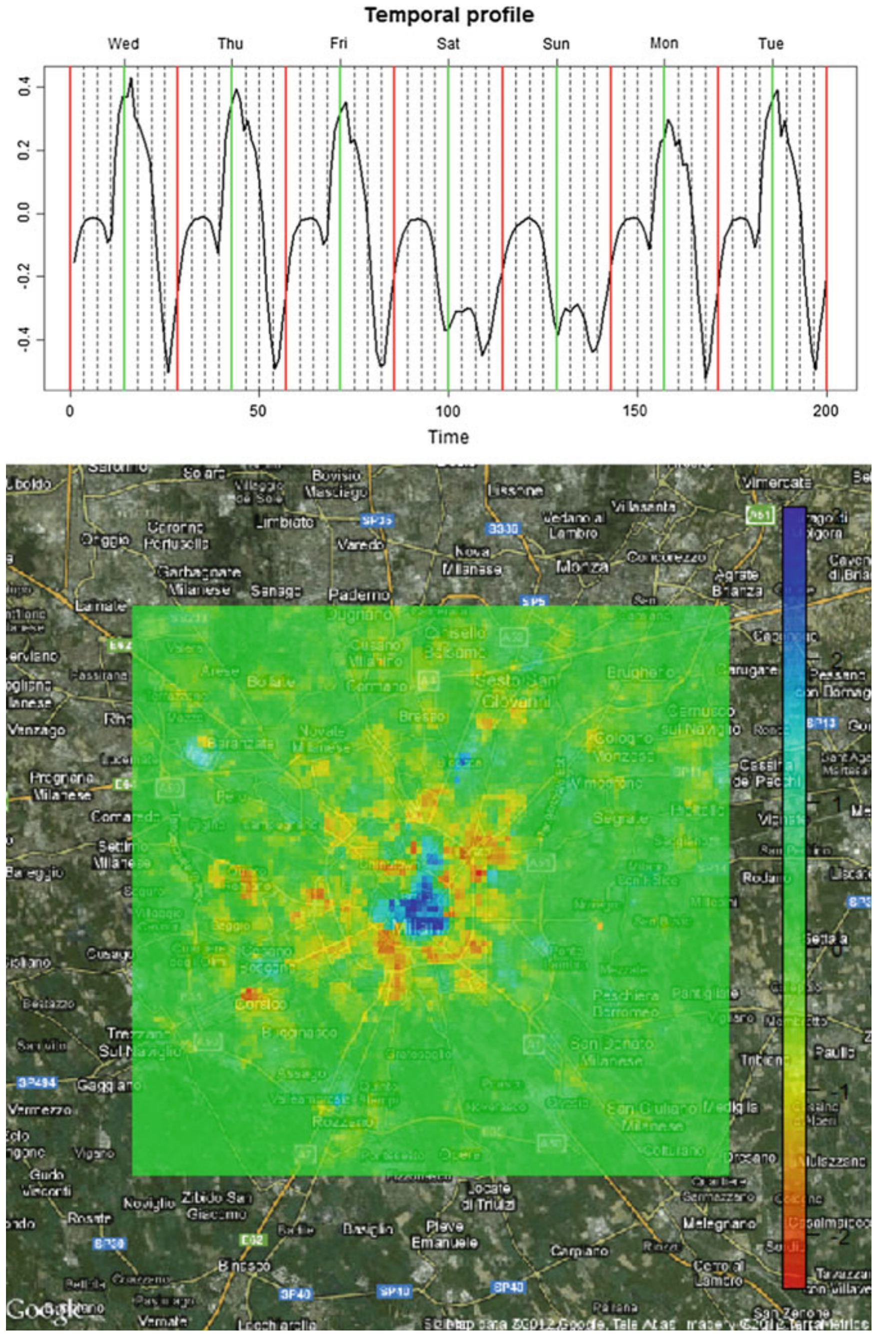

Fig. 3 PCA—second component representing a contrast between working and leisure activities

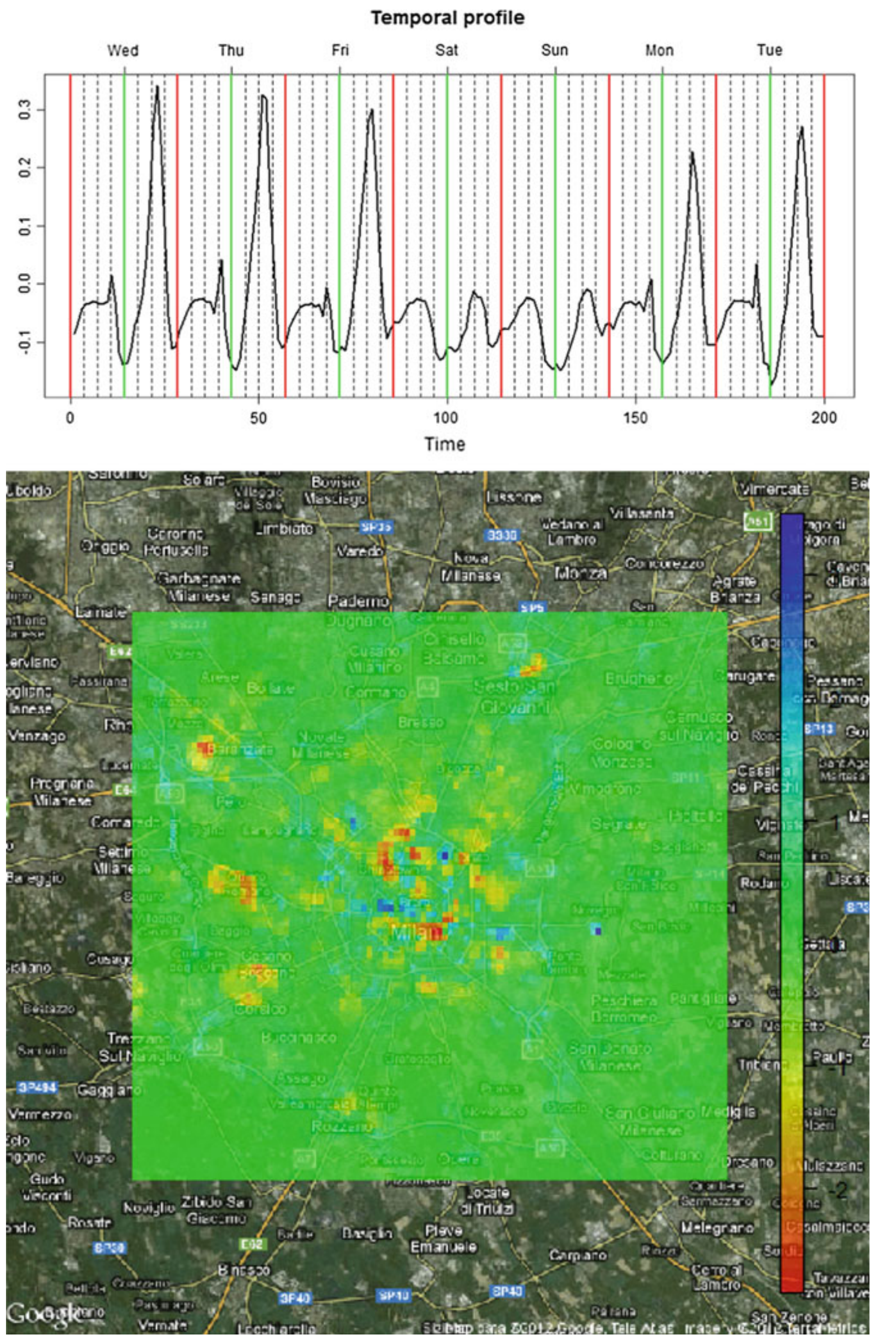

Fig. 4 PCA—third component highlighting, among other areas, Linate Airport and the Central railway station

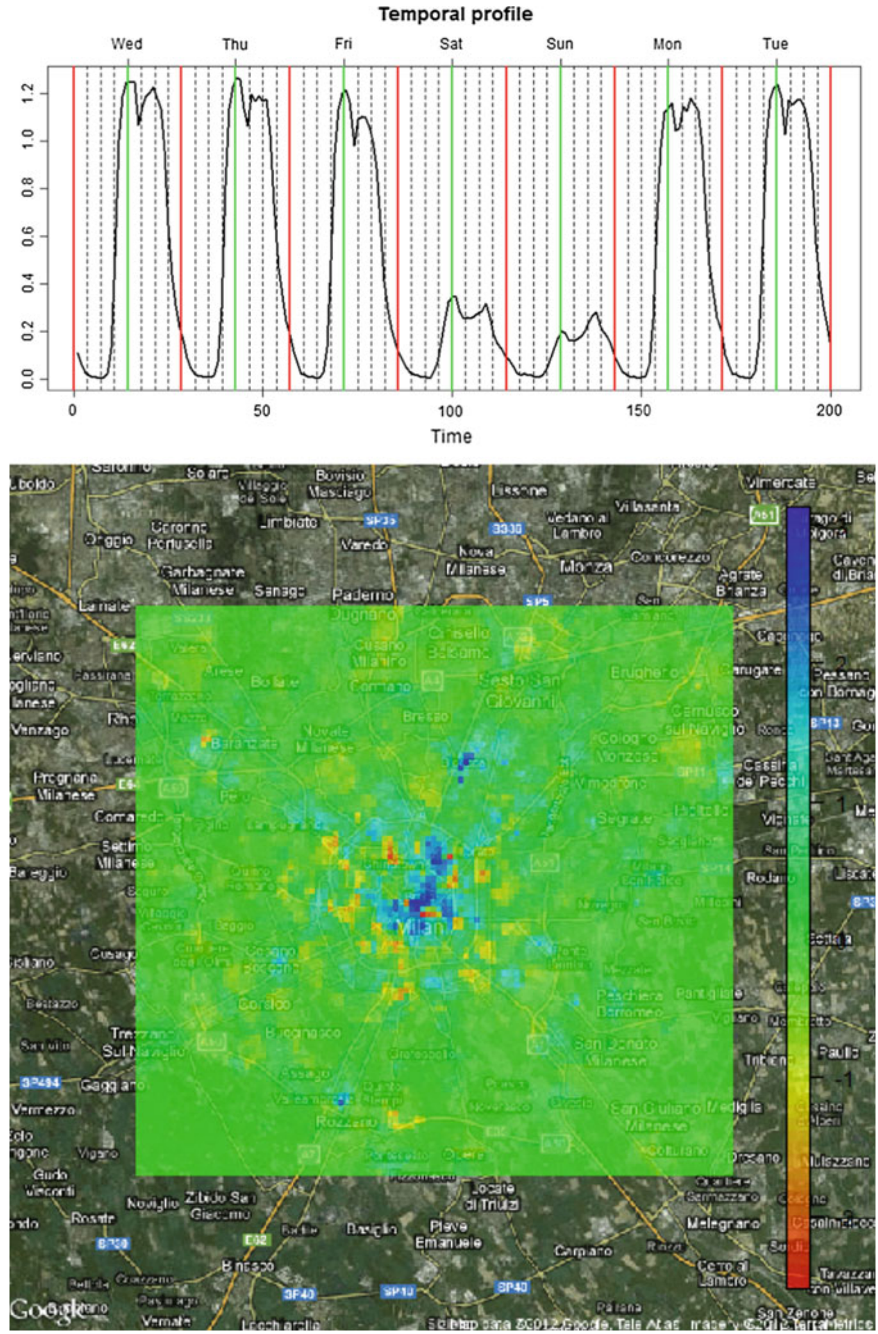

Fig. 5 ICA—first component representing the financial districts

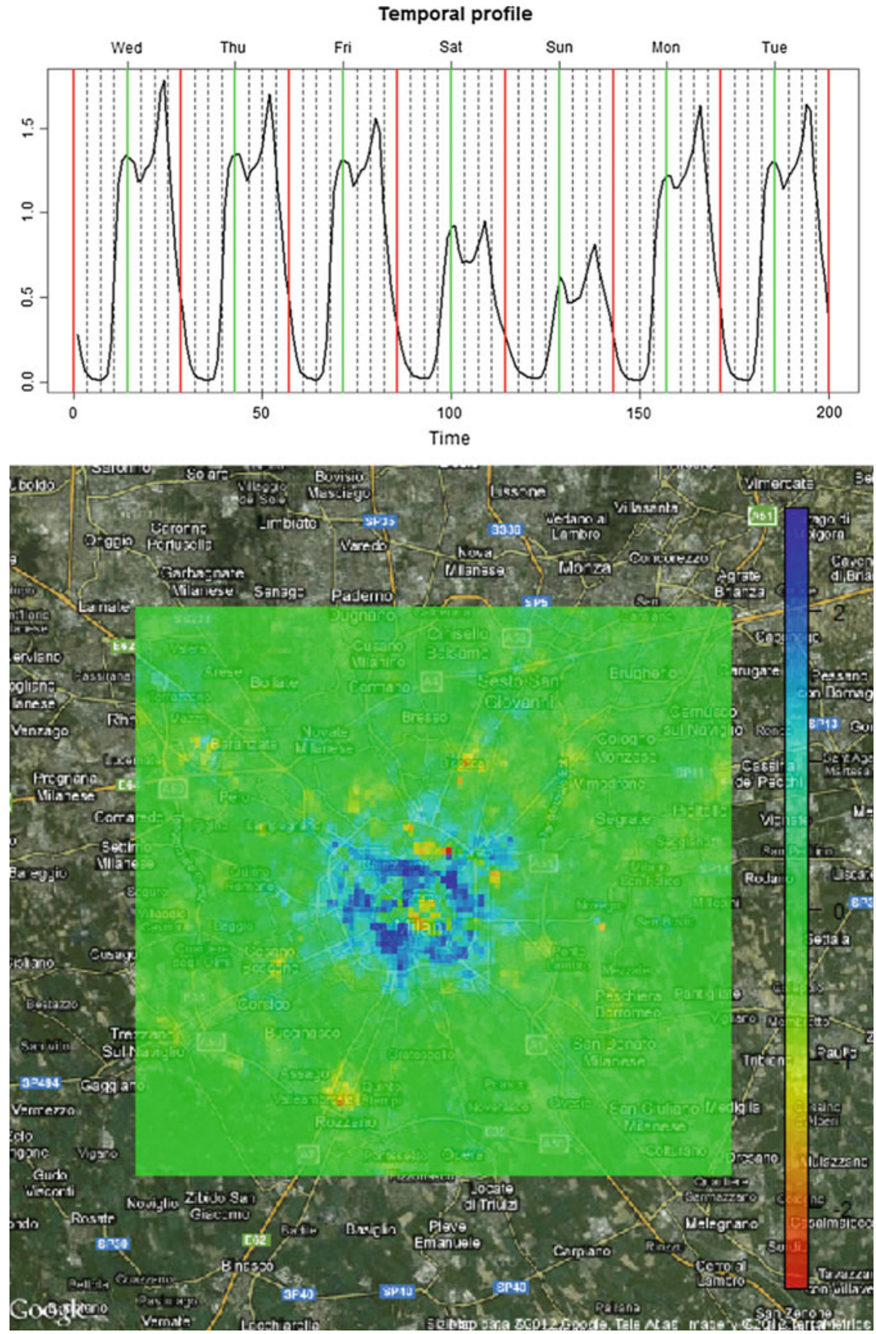

Fig. 6 ICA—second component highlighting the area outside the city center

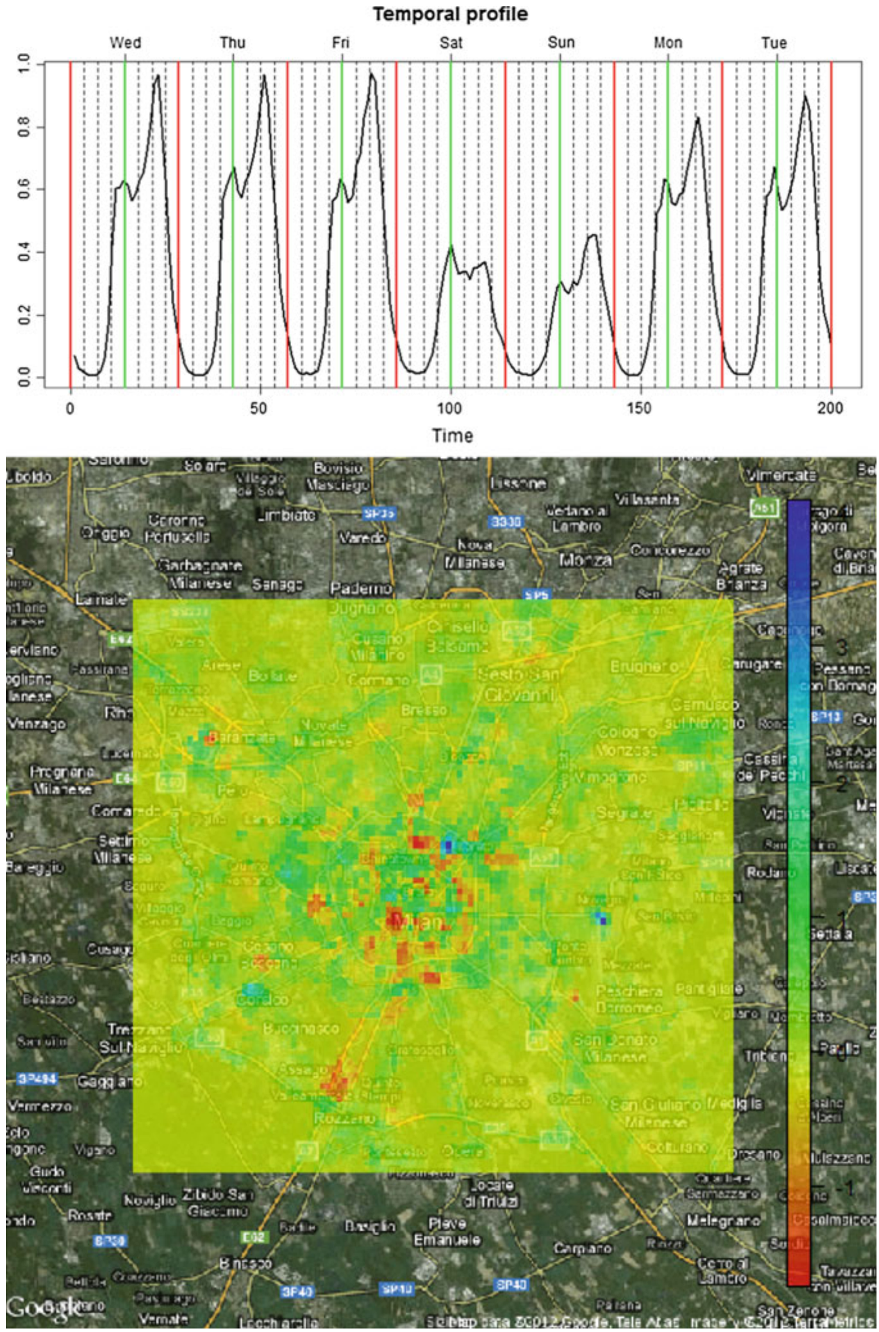

Fig. 7 ICA—third component highlighting Linate Airport and the Central railway station

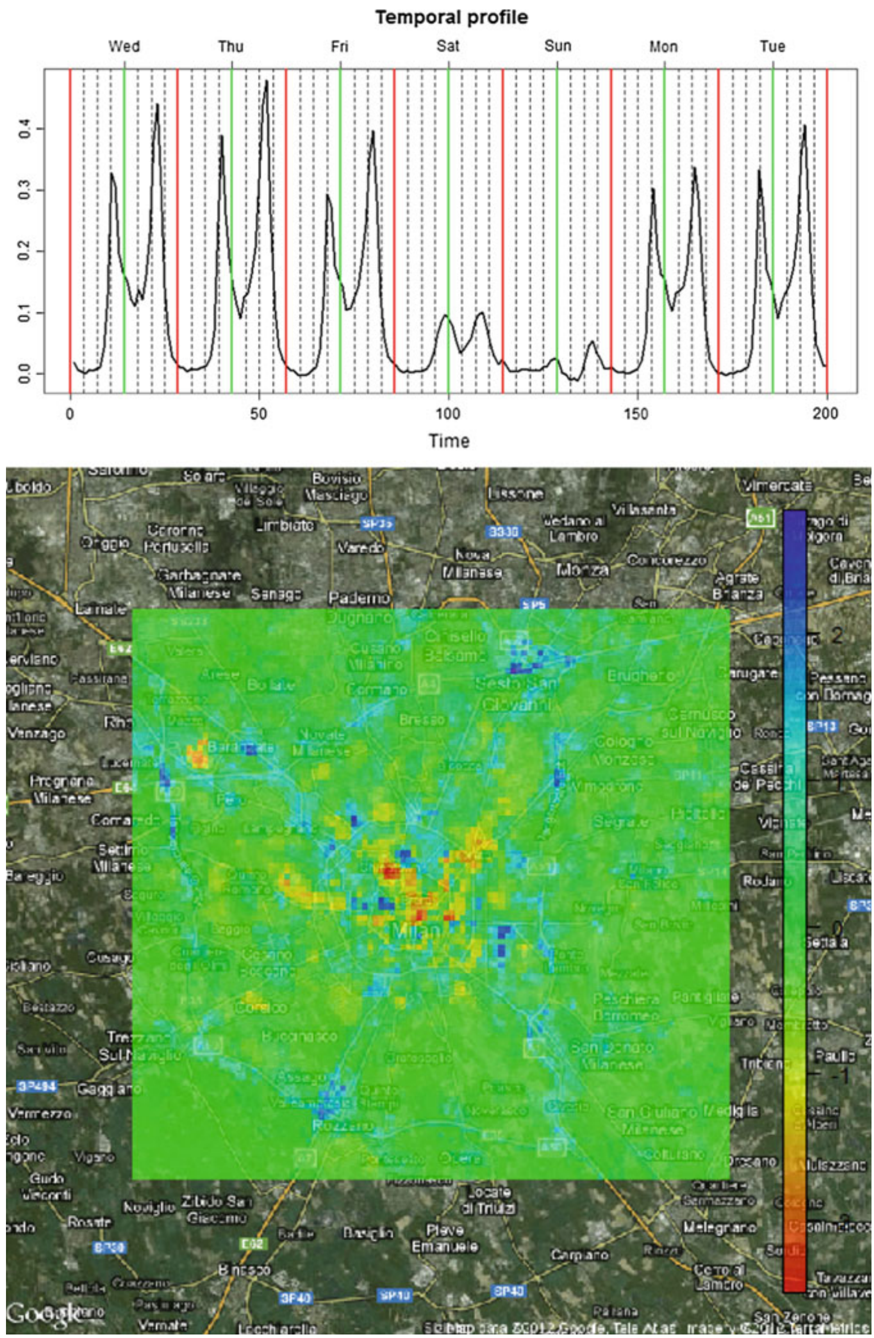

Fig. 8 ICA—fourth component highlighting the highway ring around the city (called “tangenziale”) and the big inflow and outflow avenues to and from the city

longer constrained to be orthogonal, as in PCA. Furthermore, this reflects in a map much more interesting and meaningful, which highlights only two points, corresponding to the Linate Airport and the Central railway station.

The fourth component depicted in Fig. 8 shows the power of Erlang data in detecting urban behaviors also relative to mobility activities. Indeed, the temporal profile shows two prominent peaks around 9 am and 6/7 pm during the working days, with a map indicating the highway ring around the city (called “tangenziale”) and the big inflow and outflow avenues to and from the city.

These four components clearly show that the use of a technique like ICA, which does not present any geometrical constraint on the solution, is able to provide more meaningful results in terms of interpretation, thus being more useful to identify urban behaviors related to resident and/or mobility activities.

As anticipated above, in this kind of application multi-resolution methods could provide very meaningful solutions. In Figs. 9 and 10, we show two interesting components found through Treelets, which sufficiently explain the characteristics of a multi-resolution solution.

In Fig. 9, indeed, we can observe a temporal component defined along all the time interval, as for the PCA and ICA. In particular, it looks like the average component of PCA, and even the map is almost the same of that depicted in Fig. 2.

The second component of Fig. 10, instead, presents a temporal profile active only on a restricted time interval, specifically the nights between 1 am and 7 am (but on Sunday). The spatial map puts in evidence the area of Rho-fiera, an exhibition area where night activity is often present in order to arrange the pavilions. This component is not detected by PCA or ICA, probably due to its limited temporal incidence.

However, as well as PCA, Treelets provide orthogonal basis elements; thus, there are no further interpretable components to show. For this reason, from Fig. 11 to Fig. 14, four components provided by HICA are depicted.

In Fig. 11, we have a component similar to the first component found by ICA and shown in Fig. 5, with a temporal profile active above all during the daily hours of the working days and a map highlighting the financial districts in the city center.

The second component in Fig. 12 seems to be related to the residential activities. The temporal profile, indeed, presents the highest values during the evening of the working days and during the weekend. In the map, the districts around the city center, which are mainly residential areas, are put in evidence. Hence, this component seems to catch a static behavior.

The third component in Fig. 13 presents a temporal profile defined on a very restricted time interval, and this is due to the fact that HICA is also a multi-resolution approach. The profile presents some peaks around 6 pm during the working day, with a map contrasting the city center, with the zone just outside. Hence, this component represents the flux of people moving outside from the city center after work, a dynamic behavior.

The fourth component, shown in Fig. 14, is similar to the second Treelets component, highlighting the nights in the temporal profile, and the Rho-fiera area in the map.

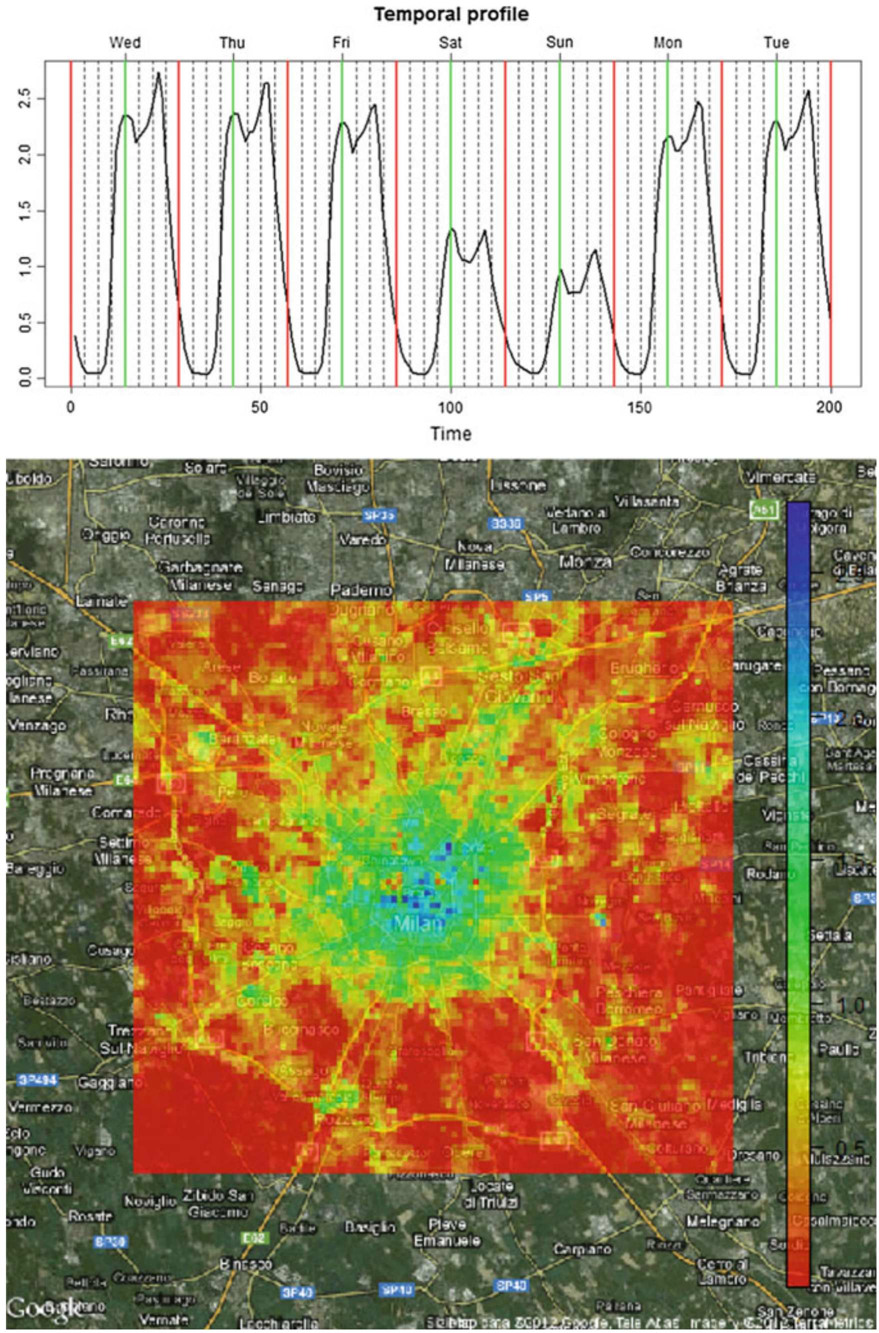

Fig. 9 Treelets—first component representing the average

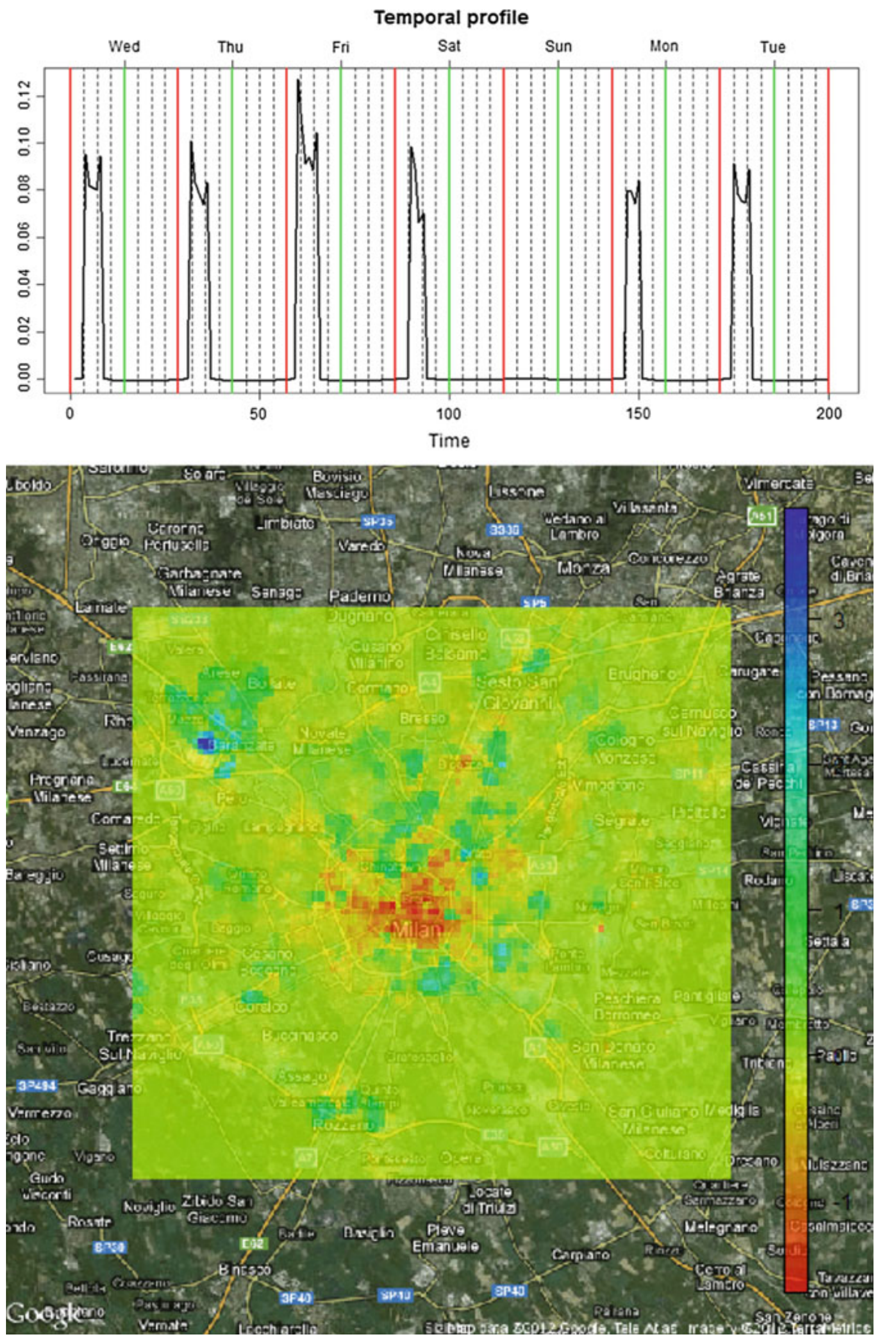

Fig. 10 Treelets—second component, area of exhibition Rho-fiera, active during the nights (but on Sundays)

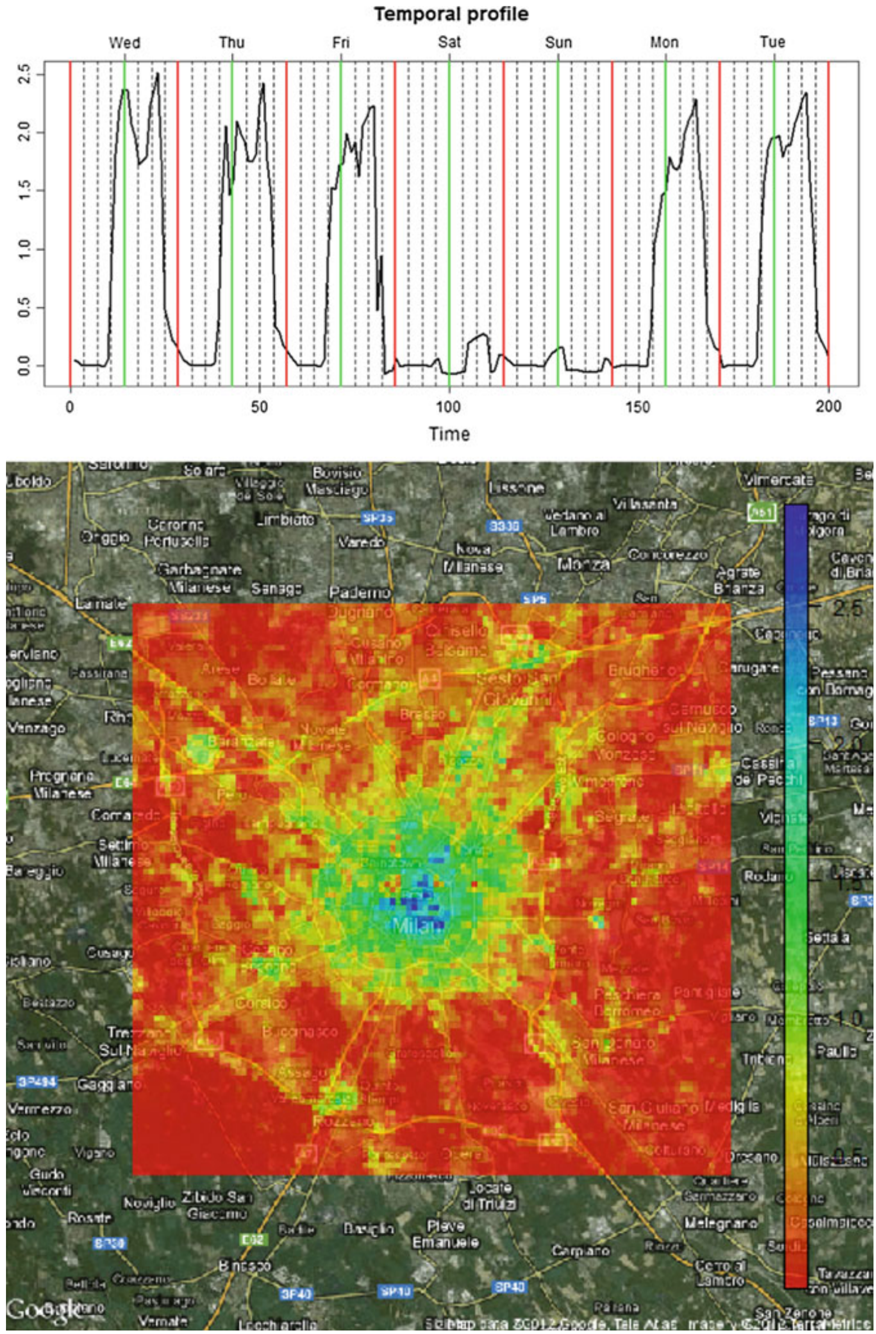

Fig. 11 HICA—component representing the financial districts

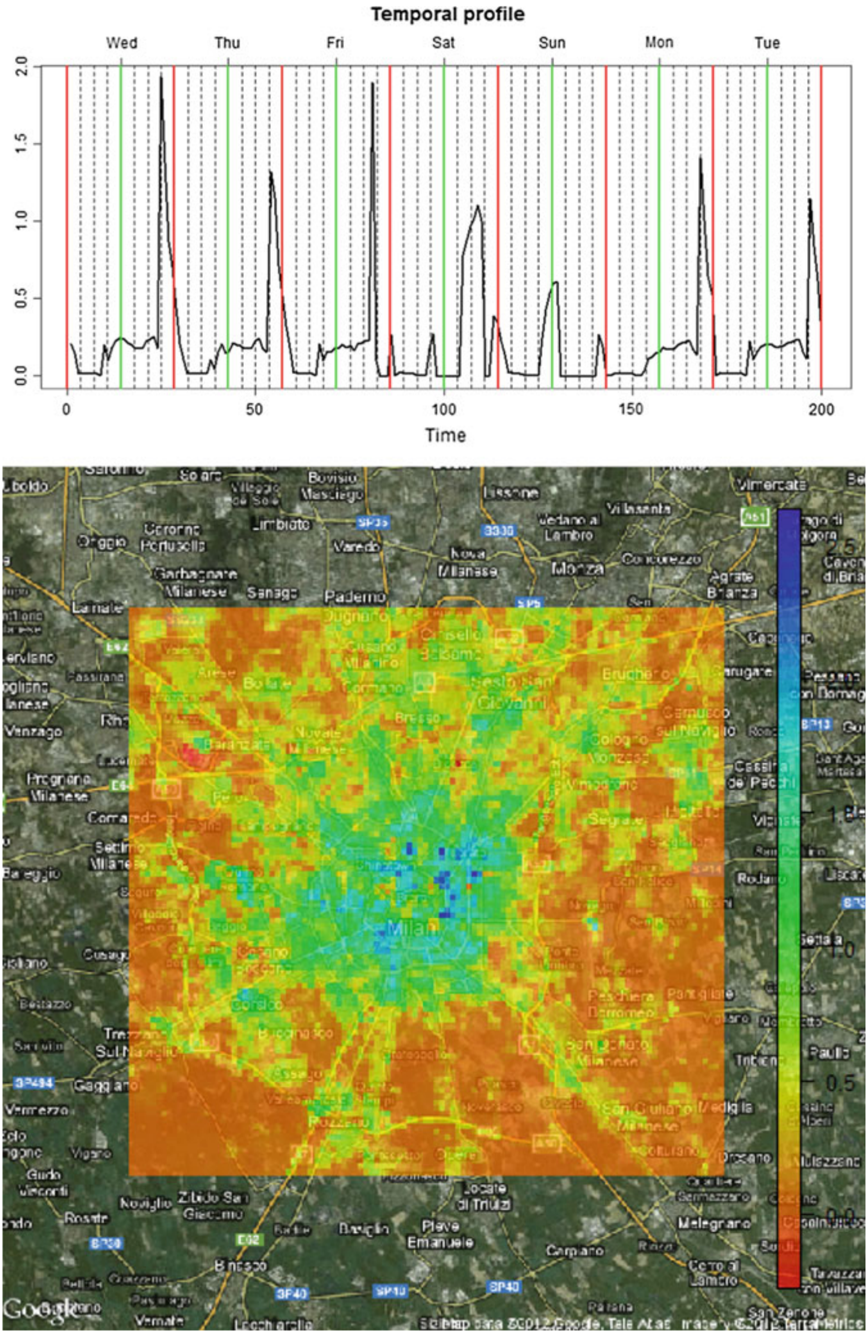

Fig. 12 HICA—second component representing residential activities

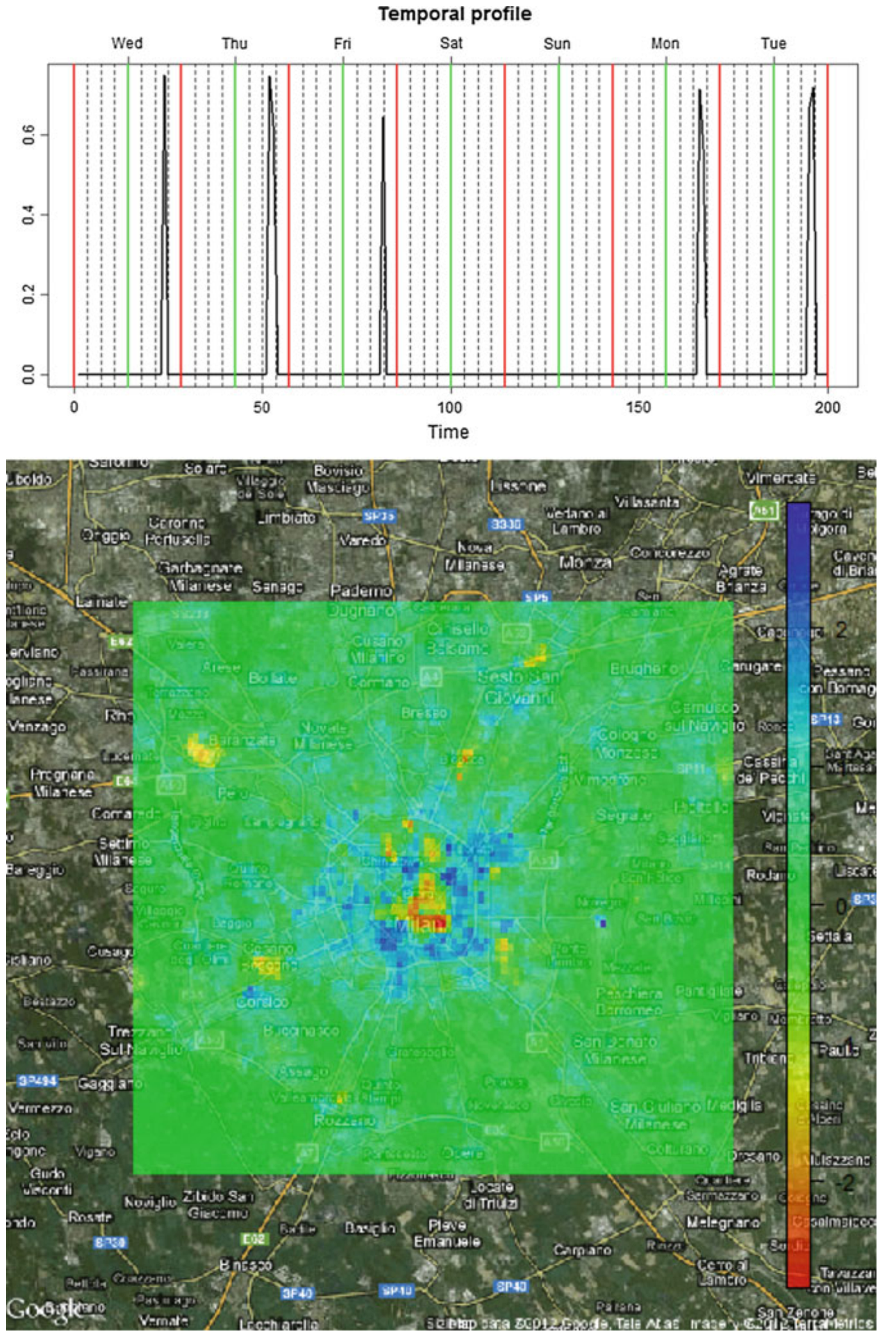

Fig. 13 HICA—third component highlighting the area outside the city center. Temporal profile presents the characteristic typical of a multi-resolution representation in time

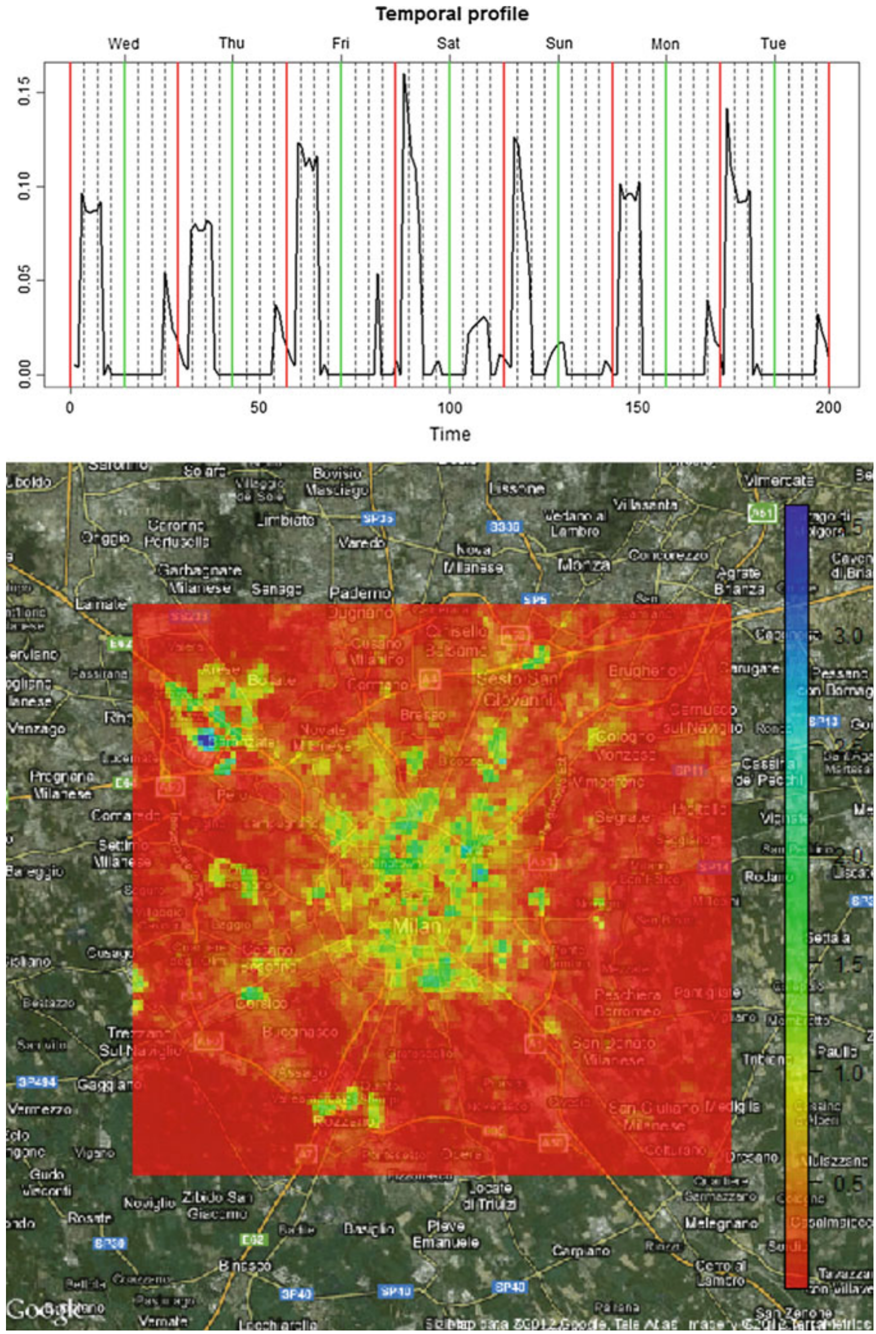

Fig. 14 HICA—fourth component, area of exhibition Rho-fiera, active during the nights

4 Conclusions

In this concluding section, we try to enlighten advantages and disadvantages of the four methods when used to analyze mobile phone data similar to the ones presented in this chapter.

PCA is the simplest among the four. It is provided with a unique and explicit solution based on the spectral decomposition of the sample variance–covariance matrix which makes it theoretically and algorithmically very attractive. From the application point of view, even though it provides the most accurate representation of the original data in terms of Euclidean distance for a given dimension, it is not very suited for the analysis of these data. It provides indeed a data representation in terms of orthogonal components that may be very far from the non-orthogonal physical components generating the data.

ICA overcomes the latter orthogonality constraint among the components, thus leaving space for a proper detection of the latent non-orthogonal components. To deal with the removal of this constraint, the assumption of stochastic independence among the sources is introduced and explicitly used in the component identification. Despite its obvious superiority from the application point of view, ICA presents severe algorithmic and theoretical issues which the practitioner should be aware of. A minor issue is that no explicit solution is available, and thus, the decomposition problem has to be numerically computed. Nevertheless, the literature has plenty of fast algorithm to tackle this task (e.g., fastICA). A more severe issue is that the estimated solution is often dependent on the initialization. Thus, initialization often turns out to be a key point for the analysis that should be consciously managed. A final issue with ICA is the ranking of the components which can be misleading due to the intrinsic non-orthogonality.

With respect to PCA, Treelets provide a data representation which is sparse and multi-resolution which makes the interpretation of the results very easy and attractive for the practitioner. Indeed, components are here associated with specific time instants. Similarly to PCA, the solution is unique and easily computable been based on pairwise PCA and the components can be easily ranked according to their importance. The limits provided by the orthogonality constraint are still in force.

HICA appears to be as the most suited method for analyzing presenting the advantages of both ICA and Treelets with respect to PCA and likely the most attractive for the practitioner. It provides indeed a data representation which is both easily interpretable (i.e., being sparse and multi-resolution) and able to provide realistic components (i.e., being non-affected by the artificial orthogonality constraint). From a theoretical and algorithmic point of view, the limits of ICA are not overcome by HICA. Indeed, both the algorithm initialization and ranking of the components still have to be dealt with some care.

In this work, we showed how Erlang data, if properly questioned by means of suitable statistical tools, are able to provide a deep insight on people movements in an urban context. Despite their Eulerian nature (i.e., single users are not tracked along time and across space, but just their counting is provided in time and space), they indeed provide information which is not limited to static behaviors (e.g., residence and working) but also related to dynamic behaviors (e.g., rush hour traffic). With respect to the deployment of a new car sharing system, the identification of these behaviors is a valuable supporting tool to maximize the matching of demand and offer in space and time. In detail, in car sharing systems with pickup/return stations, this augmented information can be used to optimize station locations and dimensions, while in the absence of dedicated stations, to optimize vehicle relocation strategies.

References

Comon P, Jutten C (2010) Handbook of blind source separation: independent component analysis and applications. Academic, Oxford

Hyvarinen A, Oja E (2000) Independent component analysis: algorithms and applications. Neural Networks 13:411–430

Lee AB, Nadler B, Wasserman L (2008) Treelets—an adaptive multi-scale basis for sparse unordered data. Ann Appl Stat 2:435–471

Secchi P, Vantini S, Vitelli V (2013) Bagging Voronoi classifiers for clustering spatial functional data. Int J Appl Earth Obs Geoinf 22:53–64

Secchi P, Vantini S, Vitelli V (2015) Analysis of spatio-temporal mobile phone data: a case study in the metropolitan area of Milan [with discussion]. Stat Methods Appl 24(2):279–300

Secchi P, Vantini S, Zanini P (2016) Hierarchical independent component analysis: a multi-resolution non-orthogonal data-driven basis. Comput Stat Data Anal 95:133–149

Zanini P, Shen H, Truong Y (2016) Understanding resident mobility in Milan through independent component analysis of Telecom Italia mobile usage data. Ann Appl Stat 10(2):812–833

Analysis of Peer-to-Peer Car Sharing Potentialities

Paolo Beria, Antonio Laurino, Ila Maltese, Ilaria Mariotti and Flavio Boscacci

Abstract Car sharing systems have generated increasing interest among drivers and city administrations. The recent European and Italian experiences clearly show that the conditions for the commercial exploitation of this service exist. Aside from traditional car sharing, a possible evolution could be the peer-to-peer car sharing, whose demand and supply have to be estimated. To this aim, a survey was carried out among Milan's citizens in order to identify the determinants to join a peer-to-peer car sharing. This chapter, after recalling the main studies on this topic, briefly discusses the Milan's mobility context and its car sharing initiatives. The survey is described, and the results of the econometric analysis, identifying the determinants of car owners' sharing attitude, are presented. Finally, an estimation of the shared cars' supply in function of the price set is provided.

1 Introduction

One of the peculiarities of the Green Move project is the analysis of peer-to-peer car sharing (hereafter P2P CS) schemes, where car owners share their vehicles in exchange for a monetary compensation. Unlike classic car sharing systems (hereafter CS), for which *ex ante* studies (in terms of potential users) and *ex post* data

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(in terms of actual users) are available, to date, P2P initiatives have had very few field tests worldwide, and therefore, its attractiveness among users is still scarcely investigated. Compared to traditional schemes, P2P CS initiatives pose two different problems: one is related to the definition of the number of potential sharers (namely the supply side) and the other one concerns the number of potential users (namely the demand side). Several elements impact the potentialities of a P2P CS scheme as, for example, the individual characteristics of both the car renter and the car owner, or the city context (in terms of density, transport infrastructure and services available).

Due to the innovative and complex nature of the Green Move initiative, a survey was planned in order to test the attractiveness of the project among the citizens of Milan. Different aspects have been explored: users' mobility behaviour in different scenarios; impact of the CS attributes on the overall attractiveness of the service; and socio-economic and neighbourhood characteristics as drivers for adopting the service. The chapter is organized as follows. Section 2 recalls the scant literature on this topic, and Sect. 3 briefly discusses the mobility context in Milan. Section 4 introduces and discusses the survey carried out among the citizens. In Sect. 5, an econometric analysis identifies the determinants of car owners sharing attitude, while Sect. 6 provides a methodology to estimate the number of shared cars in Milan in function of the time of the day and the price set.

2 Peer-to-Peer Car Sharing Systems. A Literature Review

Following the success of many CS initiatives worldwide, in the last decade a great number of studies and surveys have been carried out. Their aim was to identify: the socio-economic characteristics of CS members (Martin and Shaheen 2011; Schmöller and Bogenberger 2014); the impact on members' travel behaviour (Deloitte 2014; Hildebrandt et al. 2015; Kim et al. 2015; Sioui et al. 2013); and the drivers of adoption (Shaheen et al. 2015; Lindloff 2014). On the other hand, due to its novelty, specific literature on personal vehicle sharing is still scant; in the following, the main results of these few studies are presented.

According to Shaheen and Bansal (2015) and Shaheen et al. (2012), four sub-models of personal vehicle sharing—defined as CS service model characterized by short-term access to privately owned vehicles—are identified; among these,[1] P2P provides privately owned cars which are temporarily available for shared use by individuals or members of a P2P company. Hampshire and Gaites (2011) assess the feasibility of a P2P scheme in Pittsburgh, using a framework, which analyses both the demand and supply side for this kind of service. Specifically, they emphasize

[1]The three others are as follows: hybrid P2P (together with traditional one); P2P marketplace (direct contact between demand and supply); and fractional P2P (based on the "shared" propriety of the vehicle) (*Ibidem*).

the higher car accessibility provided by a P2P scheme: actually, in lower density areas, it alleviates upfront (fixed) costs for buying the car fleet. They also identify public policy and insurance laws as possible obstacles, as well as the trust among owners and renters (*ibidem*; Shaheen et al. 2012). Hampshire and Sinha (2011), exploring the operational aspects of a P2P scheme, analyse the main trade-off of balancing car utilization with reservation availability. Dill (2014) highlights the lower income of P2P CS members if compared to traditional CS members; furthermore, according to Fraiberger and Sundararajan (2015), a higher impact of P2P CS on below-median income consumers is expected.

Public perception of P2P CS in San Francisco and Oakland is deeply explored in 2014: despite a low awareness of the system, there is a big interest for it, especially among those without vehicle access. Convenience and availability, monetary savings and expanded mobility options are the expected advantages. Furthermore, 25% of surveyed vehicle owners would be willing to share their personal vehicles through P2P CS, liability and trust concerns being the primary deterrents, with frequent drivers obviously less interested than local public transport customers (Ballús-Armet et al. 2014; Shaheen and Bansal 2015). Education and ITS (online platforms for encouraging trust, building and reputation improving) could play a key role. Finally, according to a study on the sharing economy, the whole P2P borrowing is already worth at least $179 a year for 30% of Americans; specifically, Fremstad (2016) finds out that the average household spends $9090 each year on shareable goods: private vehicles account for 80% of these expenses.

3 Milan's Mobility Context

In Italy, CS has gained increasing importance thanks to *Iniziativa Car sharing* (hereafter ICS), an institution promoted in 2000 by the Ministry of the Environment in the major Italian cities. ICS fosters and supports the set up of local CS services integrated into a standardized operational scheme (Laurino and Grimaldi, 2012). Among the 12 ICS cities, Milan represents one of the most successful experiences of CS.

3.1 Milan's Mobility Characteristics

Milan is structured in a central business district, roughly corresponding to the old town centre, and a spread productive area outside the city.[2]

[2]The municipality of Milan itself—with a population of 1.33 million inhabitants—is the core of a broad metropolitan area of up to 3.2 million inhabitants (Istat—The National Institute of Statistics data).

According to AMAT (2012), the citizens of Milan use their cars, on average, only 3% of the daytime, while for the time left, cars sit idle on the streets or in garages. In 2014, there were 686,379 registered cars in Milan, almost 52 cars per 100 inhabitants, quite a lower value than the Italian average (60) (ACI 2015). Furthermore, the motorization rate is decreasing (−13% since 2008) faster compared to other major Italian cities (−4,8%) (ACI 2015).

Only 50% of the trips in the city is done with a private vehicle (car or motorcycle), a value rising to 65% when considering the displacements that occur between Milan and the rest of the region. The average car trip within the city is only about 4 km long, and almost 50% of them are even below 2.5 km. Over 40% of the overall mobility in Milan is determined by movements to and from the outside, which counts for about 850,000 commuters to the city (work and study) together with city users (access to services, entertainment and shopping). For similar reasons, almost 270,000 residents leave the city every day (AMAT 2012). Considering the whole mobility in Milan's municipality area, 53% of the trips are made within the city (47% of which by public transport), while the rest are cordon trips (to enter in or exit from the urban area, 31% by public transport) (AMMA 2006).

3.2 *Car Sharing Initiatives in Milan*

Milan has been a pioneer in Italy for CS; the first CS operators were *Car sharing Italia*, created in 2001 by the environmental association "Legambiente" and *GuidaMi*, born in 2004, supported by the municipality of Milan and by the Ministry of the Environment. In 2007, there was the takeover of *GuidaMi* by the local public transport company ATM Group (owned by Milan's municipality), followed in 2010 by the acquisition and merger with *Car sharing Italia*. *GuidaMi* is a traditional CS service, whose members pay an annual fee and a fare based on distance and time principles, according to the type of vehicle chosen. In 2010, *Evai*, an initiative of electric CS, was launched in Milan by FNM Group (the main transport and mobility group in Lombardy, owned by the Regional Government). Even if *Evai* also provides traditional vehicles, the initiative mainly focuses on electric cars and involves the whole region. To increase the role of CS, in June 2013, the Milan City Council published a call for "expression of interest" in order to attract and identify stakeholders willing to offer free-floating CS within a predefined area of the city. Three companies expressed their interest and started services between August 2013 and May 2014: *Enjoy*, owned by Eni S.p.A., an Italian multinational oil and gas company; *car2go*, a subsidiary of Daimler AG; and *Twist*, supported by an Italian travel agency. The municipality also fostered the development of electric mobility by building many charging stations in the city which boosted the start-up of electric CS services (initially *Eqsharing*, then *Share'ngo*).

The data related to the initiatives currently operating in Milan show positive results, with the number of members steadily increasing (Table 1).

Also, operational numbers are impressive. According to a recent survey (Riazzola 2015), there are on average 8000 rides every day, lasting 20 min for a 6 km distance on average; 60% of the members make a regular use of the service (in general once a month). Furthermore, the majority of the members (64%) are younger than 40 years of age. Finally, interviews among CS users show that 12% of respondents have already decided to give up the first or second private car for using, instead the CS. Moreover, CS has also increased (7.5% of surveyed members) the number of public transport season tickets (*ibidem*). An interesting outcome of the current CS framework concerns the distribution of members between the city and its surroundings. The majority of members live in Milan (59%), 10% live in the neighbouring municipalities and nearly 31% live in areas much farther from Milan. Thus, the occasional city user or weekly commuters seem more interested than the commuters who live in the surroundings.

Despite the interest of the population towards CS, until 2016, no P2P CS still exists. In the following, we will study the interest of Milan citizens towards this alternative form of CS, by means of a field survey.

4 The Survey Among Milan's Citizens

4.1 The Sample

The sample has been built in order to be representative of Milan's population; thus, it considers men and women living in Milan, in the age group 18–59, distributed according to the actual working condition (80% workers, 20% unemployed) and education level (32% graduated, 68% not graduated). The survey collected information also on the household size, number of vehicles owned by the family unit and its variation in time, characteristics of the owned cars, means of transport most frequently used, average distance annually travelled by car, motivation for typical trip by car (shopping, visit to relatives, etc.).

The total sample includes 1211 respondents. Only 25 of them declared no car in their household.

4.2 The Structure of the Questionnaire

The questionnaire, built by Politecnico team together with TRT—Trasporti e Territorio, was structured in five parts and required approximately 20 min to be completed. Given the complexity of the research and the need to have a sufficiently large sample, CAWI[3] technology provided the best solution in terms of cost,

[3]Computer-assisted Web interview.

easiness and flexibility. The survey was launched in November 2012, and it was conducted exclusively online. In particular, it considered:

1. Respondents' socio-economic characteristics;
2. Stated preference exercises aimed at testing the propensity to share the personal vehicle and the desired amount of money to take part to the service;
3. Stated preference exercises aimed at testing the attractiveness of some car sharing service configurations;
4. Previous knowledge of car sharing services and possible use of the CS service for respondents' mobility habits;
5. Respondents' mobility habits.

Each section was composed by several closed questions; in particular, in Sect. 2, respondents were asked about their interest in sharing their personal car, when unused, in exchange for a monetary compensation. Specifically, respondents were presented a hypothetical scheme with the following assumptions:

- Place and time for collecting/returning the car set by the owner;
- Total insurance coverage;
- Total guarantee on the condition of the car (e.g. cleanliness) after each use;
- No need for keys handover thanks to the on-board device.

In the following, we will discuss the results of this exercise.

4.3 Preliminary Analysis of the Results

Overall, the majority of respondents provided a general positive answer towards a P2P CS scheme. Literature (Shaheen et al. 2012), however, suggests to focus exclusively on sharing between "affinity pre-established trusted community members", in order to face the fear of sharing. Coherently, we observe that more than half of the potential sharers stated that they would like to share their car only among a small group of people set by them. On the other hand, the main reasons provided in case of negative response show the idea that the car is a very personal object (36.3%) and that it is expected to be always available (47.9%) as the main barriers towards the sharing. This first outcome confirms other studies (IPR 2009; Shaheen et al. 2012) and strengthens the perception of a car as individual's most valued possessions, which entails some fear when sharing it. Respondents willing to share their own cars were also asked the amount of money desired to join the service. In order to obtain a figure of the price thresholds, we used a bisection method that proposed a series of thresholds to the respondents starting from 30 €/month.[4] These results seem to suggest the existence of a threshold of acceptability under which the

[4]In order to make the survey understandable and easy to fill in, respondents were not asked to specify the number of hours of availability for their car, which means that it is not possible to

willingness to share personal vehicle drops and another one above which sharing attitude does not increase further. Finally, respondents were also asked to indicate the moment of the day in which they were more willing to share their cars, in order to have indications concerning the distribution along the day of the car availability. The data show that there is not a specific moment of the day in which car owners are more disposed to make their cars available; in general, late afternoon has lower availability than early morning hours.

5 The Determinants of Car Sharing: An Econometric Approach[5]

This paragraph aims at investigating the main determinants for adopting a P2P CS among the inhabitants of Milan. Specifically, the probability to enrol in a P2P CS is explored by means of descriptive statistics and econometric analysis. Two discrete choice models (Train 2003; Marcucci 2011) have been adopted: binomial logit model and multinomial logit model, where the probability to become a P2P CS member is dependent on the following groups of explanatory variables: (i) socio-economic, (ii) travel behaviour, (iii) green attitude and policies (Table 2).

The binomial logit model allows exploring the characteristics of those willing to be member of a P2P CS, and those who are not. The dependent variable is equal to 1 if the user is willing to share his/her car, 0 otherwise. The multinomial logit goes into a deeper investigation among the potential P2P CS members; thus, the dependent variable is 1 if the user states the intention to share among all members and 2 if he/she is willing to share the car only among a small group of known people (friends, colleagues or neighbours only), 0 otherwise.

The survey showed that 603 (53.4%) respondents have declared to be willing to share their car, thus becoming a P2P CS member. Among those, 35% stated that they are willing to share their car with all members of the P2P system; the remaining 65%, instead, would share the car only with a group of well-known people (specifically: 55% with friends, 6% with neighbours and 4% with colleagues).

Besides, the “potential sharer” is more likely to be male, young, educated and belong to a family owning more than one car and has or has been car sharing member, and he/she has declared a higher price sensitiveness to oil price increase and the Area C road pricing tool currently in force in Milan (Table 3) Beria (2016).

As concern travel behaviour, the potential sharer is more willing to use the local public transport (LPT), to ride the bike and to walk, than the other group (53.4% vs.

(Footnote 4 continued)

directly correlate the monthly amount of money desired with the hours of availability respondents had in mind when filling the survey.

[5]The paragraph refers to the paper by Mariotti et al. (2013).

Table 1 CS operators in Milan in 2015. *Source* Riazzola (2015)

Operator	Kick-off year	Members	Cars	Type of cars	Business model	Status	Ownership
Guidami	2004	5000	114	ICE/Electric	SB	A	Pu
Enjoy	2013	210,000	644	ICE	FF	A	Pr
car2go	2013	100,000	700	ICE	FF	A	Pr
Twist	2014	26,000	500	ICE	FF	C	Pr
Evai	2010	18,000	>100 (Region)	Electric/ICE	SB	A	Pu
Eqsharing	2013	4000	140	Electric	SB	C	Pr
Share'ngo	2015	7000	250	Electric	FF	A	Pr

Note: ICE = internal combustion engine; business model (SB = station based, FF = free floating); status (A = active, C = closed); ownership (Pu = public, Pr = private)

Table 2 Explanatory variables. *Source* Authors' elaboration on Mariotti et al. (2013)

Variable	Description
Socio-economic variables	
Gender	Dummy variable: "1" if male. "0" if female
Age	Age of the respondent. Continuous variable
Education	Dummy variable: "1" if the respondent achieved a bachelor degree. "0" otherwise
No. of owned cars	Number of cars owned by the family. Continuous variable
Oil price increase	Dummy variable: "1" if the respondent has changed his/her travel patterns due to the oil price increase. "0" otherwise
District of residence	Dummy variable. The district where the respondent lives
Travel behaviour	
Modal choice	Six dummy variables suggesting the main modal choice adopted by the respondent: LPT, bike, foot, motorcycle, car (driver), car (passenger)
Daily travel by car	Four dummy variables underlying the travel motivation for using the car daily or very often: to reach the workplace, to reach the LTP stop, moving in the neighbourhood, leisure in the city
Green attitude and policies	
CS member	Dummy variable: "1" if the respondent is or has been member of CS in Milan (Guidami and E-Vai). "0" otherwise
Area C	Dummy variable: "1" if the respondent has reduced the car use due to the congestion charge ("Area C") introduced in Milan central district in 2012; "0" otherwise

Table 3 Descriptive statistics[a]. *Source* Authors' elaboration on Mariotti et al. (2013)

Variable	Obs.	Mean	Std.dev.	Min	Max
	Potential P2P CS members				
Gender	603	0.504146	0.500398	0	1
Age	603	38.58043	10.38022	18	59
Education	603	0.351576	0.477859	0	1
No. of owned cars	603	1.665008	0.73626	1	5
CS member	603	0.089552	0.285776	0	1
Area C	603	0.446103	0.497499	0	1
Oil price increase	603	0.729685	0.444491	0	1
	Not-Potential P2P CS members				
Gender	526	0.439164	0.496758	0	1
Age	526	40.39734	10.3879	18	59
Education	526	0.275665	0.447274	0	1
No. of owned cars	526	1.54943	0.656419	1	4
CS member	526	0.024715	0.155402	0	1
Area C	526	0.313688	0.464433	0	1
Oil price increase	526	0.576046	0.494654	0	1

[a]The sample has been reduced to 1129 records, because interviewee with no car and those resident outside of Milan have not been considered for the specific question on P2P CS

46%), and less prone to drive the car (36% vs. 43%), even though almost all respondents have got the driving licence and have at least one car available in the family.

The results of the descriptive statistics have been corroborated by the econometric analysis, as stated above. The explanatory variables have been introduced in both the binomial and multinomial logit estimations incrementally: "model 1" includes only socio-economic, and green attitudes and policy variables; "model 2" adds the travel behaviour variables; "model 3" includes also the geographical fixed effects (dummy variable for the Milan neighbourhoods) (Tables 4, 5 and 6 below).

In both the discrete choice models, the probability to join a P2P CS by sharing the personal car is positively and significantly related to: users' education (bachelor degree), car ownership (more than two cars), travel behaviour (bike and LPT use), CS membership (past or present), cost-sensitiveness (oil price increase). Besides, when considering those willing to share their car, they are more likely to be young and affected by the Area C tool, reducing car use; the same holds for those willing to share their own car only with a selected group of people (Table 5). Moreover, compared to not sharers, the sharers show a higher probability to be male, use the LPT, drive the car to reach the LPT stop daily and have reduced the car use because of the oil price increase.

Table 4 Binomial logit—results. *Source* Authors' elaboration on Mariotti et al. (2013)

	Model 1	Model 2	Model 3
Age	−0.0124***	−0.0121**	−0.0123**
Gender	0.2174*	0.2158	0.1980
Education	0.2701***	0.2705**	0.2502*
No. of owned cars	0.2794***	0.2853***	0.2856***
LPT	0.3652***	0.2915*	0.3217*
Bike	0.6610***	0.6638***	0.6579***
Foot	0.1597	0.1688	0.1663
Motorcycle	0.3271	0.3107	0.3104
Car (driver)	−0.0058	−0.0067	0.000
Car (passenger)	−0.1482	−0.1637	−0.0949
CS Member	0.9872***	0.9772***	0.9994***
Area C	0.3317***	0.3397***	0.3473***
Oil price increase	0.5079***	0.5066***	0.5306***
To reach the workplace		−0.0998	−0.1132
To reach the LTP stop		0.4661**	0.4410*
Moving in the neighbourhood		0.0927	0.1050
Leisure in the city		−0.0729	−0.0677
Dummy neighbours	NO	NO	YES
Constant	−0.8179***	−0.8079***	−0.7691**
N. obs.	1129	1129	1129
Log likelihood	−730.3661	−727.9935	−722.9772
PseudoR2	0.0636	0.0666	0.0730

*, **, *** are significant at 10%, 5% and 1%, respectively

Table 5 Multinomial logit model—Results Group 1

	Group 1: All members		
	Model 1	*Model 2*	*Model 3*
Age	−0.001	−0.000	−0.0010
Gender	0.568***	0.581***	0.5601***
Education	0.428***	0.437***	0.3936***
No. of owned cars	0.374***	0.377***	0.3850***
LPT	0.609***	0.516***	0.5282***
Bike	0.931***	0.942***	0.9268***
Foot	0.003	0.021	0.0072
Motorcycle	0.499	0.489	0.4720
Car (driver)	0.214	0.226	0.2449
Car (passenger)	0.302	0.305	0.3823
CS Member	0.950***	0.931***	0.9593***
Area C	0.207	0.212	0.2189
Oil price increase	0.403***	0.406***	0.4362***

(continued)

Table 5 (continued)

	Group 1: All members		
	Model 1	*Model 2*	*Model 3*
To reach the workplace		−0.205	−0.2114
To reach the LTP stop		0.562**	0.5230*
Moving in the neighbourhood		0.265	0.2747
Leisure in the city		−0.043	−0.0262
Dummy neighbours_2			−0.1123
Constant	−2.8898***	−2.9049***	−2.8665***
N. obs.	1129	1129	1129
Log likelihood	−1107.8923	−1104.2871	−1096.0491
PseudoR2	0.0548	0.0579	0.0649

Comparison group = 0 "Not interested to the P2P car sharing"; *, **, *** are significant at 10%, 5% and 1%, respectively

Table 6 Multinomial logit model—Results Group 2. *Source* Authors' elaboration on Mariotti et al. (2013)

	Group 2: Friends, colleagues, neighbours		
	Model 1	*Model 2*	*Model 3*
Age	−0.0186***	−0.0184***	−0.0185***
Gender	0.0255	0.0191	0.0039
Education	0.1834	0.1817	0.1679
Number of owned cars	0.2192***	0.2263***	0.2227***
LPT	0.2264	0.1652	0.2022
Bike	0.5014***	0.4990***	0.4949***
Foot	0.2253	0.2293	0.2309
Motorcycle	0.2241	0.2024	0.2035
Car (driver)	−0.1246	−0.1337	−0.1359
Car (passenger)	−0.4143	−0.4354	−0.3788
CS Member	0.9938***	0.9871***	1.0102***
Area C	0.3979***	0.4055***	0.4147***
Oil price increase	0.5673***	0.5669***	0.5903***
To reach the workplace		−0.0391	−0.0559
To reach the LTP stop		0.3984	0.3836
Moving in the neighbourhood		−0.0053	−0.0104
Leisure in the city		−0.0819	−0.0834
Dummy neighbours_2			0.0178
Constant	−07010	−0.6882	−0.6434
N. obs.	1129	1129	1129
Log likelihood	−1107.8923	−1104.2871	−1096.0491
PseudoR2	0.0548	0.0579	0.0649

Comparison group = 0 "Not interested to the P2P car sharing"; *, **, *** are significant at 10%, 5% and 1%, respectively

6 Quantifying the Potential Supply of Cars

6.1 Analysis of the Supply Functions Resulting from the Survey

When studying a P2P service, it is essential to compare the demand function with the supply one, namely the relationship between the potential users of the shared vehicles with the market price, and the ranges of availability for the cars set by the owners. In order to do that, the survey considered:

- The *monthly revenue* required by car owners to make available their cars when not using them;
- The *frequency* and *period of the day* in which the sharers could make available their cars.

The results on the distribution of the willingness to share the personal vehicle, together with the frequency, stated by the 603 respondents, show that more than half of the respondents declare that they are willing to share the cars every day or 3–4 working days a week, no matter the moment of the day. Lower values involve the weekend when cars are probably used for leisure reasons. The end of the night and the early morning are the moments of lowest use by owners and consequently of higher willingness to share.

6.2 Methodology to Build the Supply Function

To build the supply function of Milan's area, four steps have been followed:

1. For each interview, the willingness to share the car in five different moments of the day has been identified.
2. Since during the interviews, respondents were asked the monthly revenue (and not the hourly revenue) expected for making available the car, the corresponding hourly request has been computed, in order to make it comparable among different slots of availability, assuming that each sharer gives the same value to one hour without the car, no matter the moment of the day.

The following table provides an example based on the total available hours, as stated by the interviewee 1. In this case, the hourly value results 0.55 €/h, which is the ratio between the 150 €/month revenue required to share the car and the total number of hours of availability (274 h), obtained applying the above coefficients.

3. All the answers have been filtered according to some price levels (from 0.1 €/h to 5 €/h), thus providing the daily and the monthly distribution of supply, for a given hourly revenue. This allows to highlight the time slots in which there is the highest availability. The weighted sum of available cars (using the same

Table 7 Coefficients used to convert the slot of the day in hours and the car availability in days. *Source* elaborations of the authors

Slot	Hours/day		Car Availability	Days/month
Early morning	8		Every day	30
Morning	3		3/4 week days per week	13,2
Afternoon	5		1/2 week days per week	4,4
Late afternoon	2		During weekend only	9
Evening/night	5		3/4 days per month	3
			Never	0

Table 8 Example of the answer provided by a respondent on the availability to share during the different slots of the day and example of the corresponding conversion in terms of potential revenues

Id_user	Slot	Availability	Min required revenue	Hours	Required revenue
1	Early morning	Every day	150 €/month	240 h/month	0.55 €/h
1	Morning	3–4 days/month	150 €/month	12 h/month	0.55 €/h
1	Afternoon	Never	150 €/month	0 h/month	0.55 €/h
1	Late afternoon	Never	150 €/month	0 h/month	0.55 €/h
1	Evening/night	1–2 times/week	150 €/month	22 h/month	0.55 €/h

coefficients of Table 7) gives the total number of available cars, every day, during a certain slot, as shown in Table. 8

4. The supply curve is obtained by aggregating all the available cars (whose number is expressed as a percentage of the sample of citizens interviewed).

$$\%\ \text{available\_cars} = f(\text{slot}, \text{hourly\_revenue})$$

Through this percentage, it is possible to calculate the total number of cars potentially available in Milan, being the sample representative of the population. This function depends on the hourly revenue requested by sharers, which differs from the final one since it must include insurance, fiscal costs and the running costs of the car.

Drawing the distribution (Fig. 1), six stylized attitudes of potential sharers can be identified:

5. "**egoist**" or "**fake-sharers**": low car availability for very limited periods (up to 1–2 h/month in some cases), but large amounts of money to share are required (up to 500 €/month). This group includes people that do not really want to share the car, despite their general positive answer.

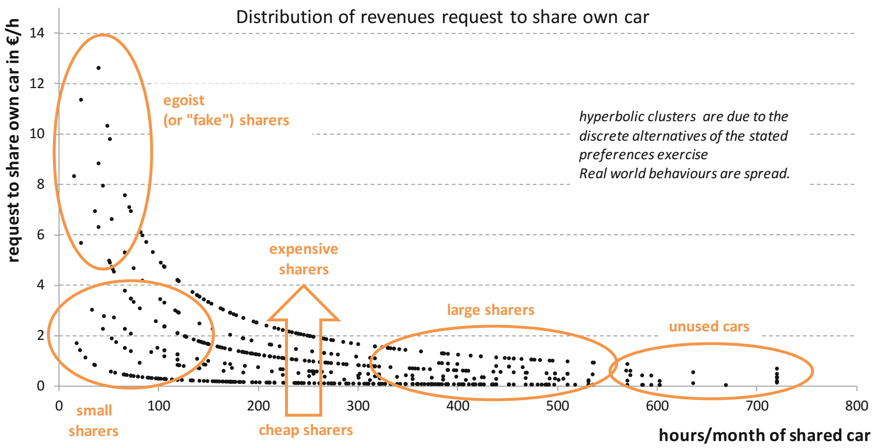

Fig. 1 Distribution of declared unit revenues request to share own car—type of sharers. *Source* elaborations of the authors

6. "**small sharers**": willing to share for few and limited periods of the day and only occasionally for a relatively low amount of money.
7. "**cheap sharers**": average willingness to share (25–50% of time, including the night), in exchange of a relatively low revenue (below 1 €/h).
8. "**expensive sharers**": similar to "cheap sharers" group except for the higher hourly request (above 1 €/h).
9. "**large sharers**": disposed to share for the most of the time (between 50% and 75% of total time). The requested revenues vary.
10. "**unused cars**": willingness to share above 500 h/month, thus nearly always probably due to the fact that cars are substantially unused.

The highest number of answers lies in the central part of the chart, with requests below 4 €/h and with availability between 50 and 400 h/month. Starting from these data, it is possible to identify the periods of the day with the highest availability of cars with respect to the revenue required.

The three graphs below show that passing from 0.1 €/h to 3 €/h, the share of available cars increases significantly. Amounts of 1 €/h guarantee more car availability in general (and systematic in particular: rows 1 and 2). This highlights how sharing is a matter of price rather than of conflict between the personal use and the possibility to share. The period of the day with the highest car availability is the early morning, up to 7:00 am, before the beginning of the working day. The night is the only period of the day in which a larger amount of cars (>5%) is available also for very low hourly revenue. To the contrary, in the late afternoon (column 4) the supply decreases, since people typically come back home or carry out many non-systematic activities (shopping, visits, sport, etc.). The systematic availability

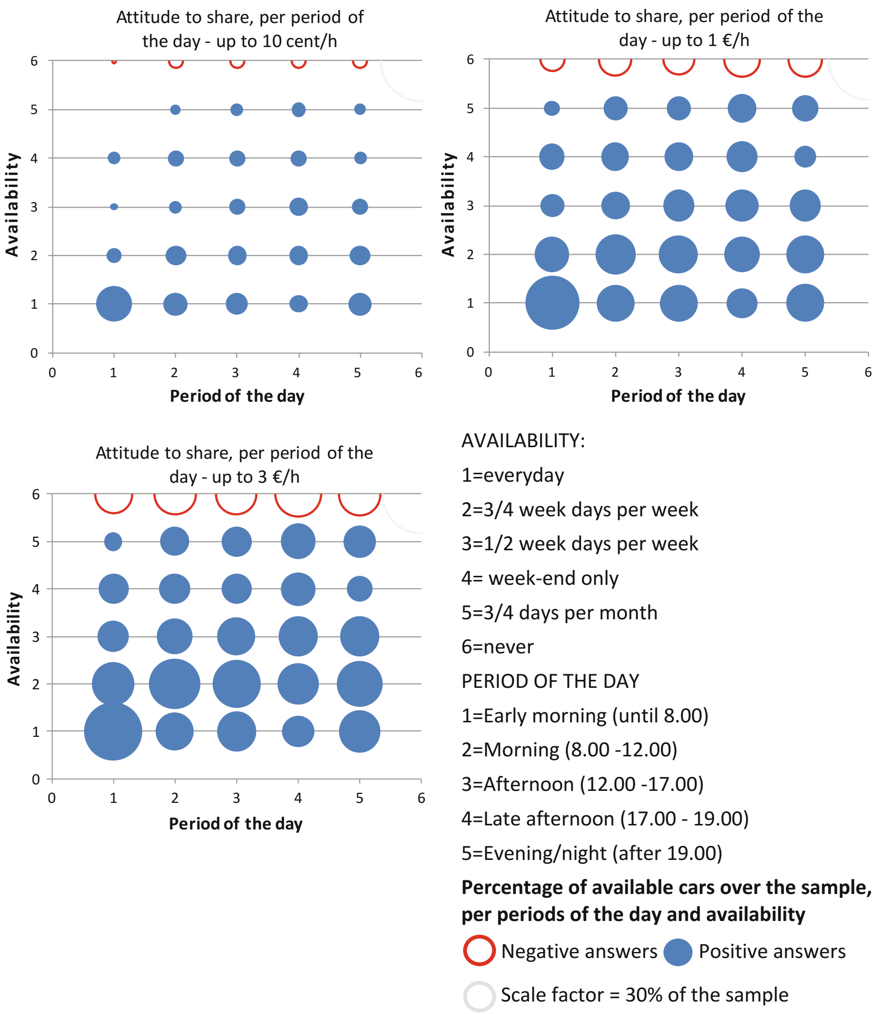

Fig. 2 Analysis of daily availabilities, with respect to hourly revenue. *Source* elaborations of the authors

in the evening (column 5) grows more than the others as the required charge increases. This higher variability suggests that car owners are less disposed to share the vehicle for very low amounts (like it happens during the night, when the car is unused), but more open as the charge increases. In addition, during the night, higher availabilities (rows 1 and 2) are more frequent than during the afternoon, when occasional availability prevails (rows 3–5) (Fig. 2).

6.3 Supply Functions

It is possible to estimate the aggregate supply functions (during the week and during weekends), divided into periods of the day, by aggregating the found values and weighting them as described above (Figs. 3 and 4).

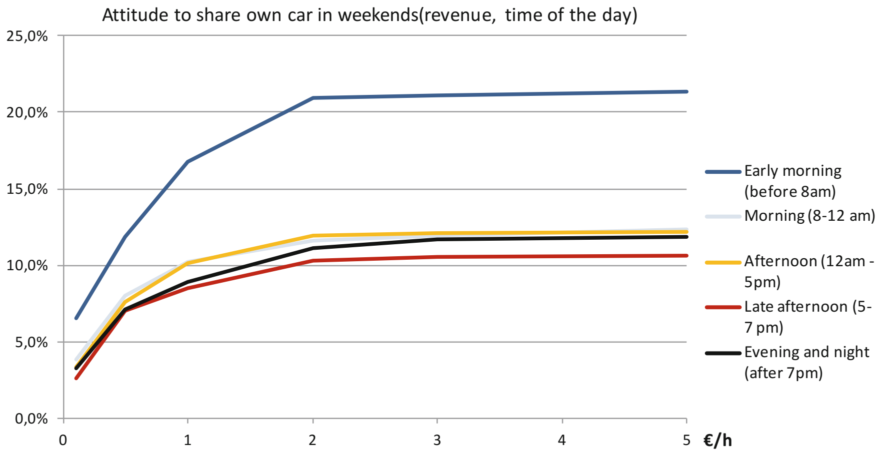

Fig. 3 Propensity to share the personal car during week days with respect to the hourly expected revenue and period of the day. *Source* elaborations of the authors

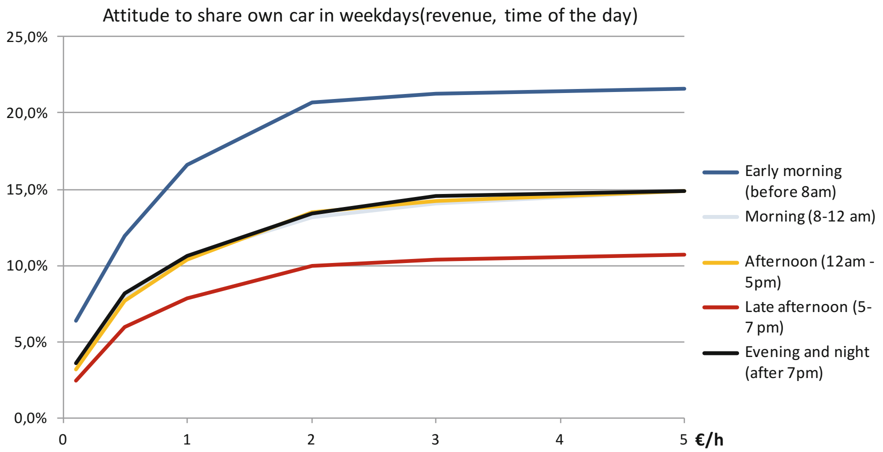

Fig. 4 Propensity to share the personal car during weekend with respect to the hourly expected revenue and period of the day. *Source* elaborations of the authors

Functions show that:

11. During **night and early morning** (before 8:00), there is the highest number of cars available, ranging from 6% to more than 20%, with the level of revenue from 0.1 €/h to 5 €/h. Differences between working days and weekends are minor.
12. During working days, **late afternoon** (17:00–19:00) has the lowest availability of cars, ranging from 2.4% to 10,7% of all cars when passing from 0.1 €/h to 5 €/h. In this period, car owners give the highest value to their own car due to the typical non-systematic trips for personal activities.
13. The remaining three periods (**morning 8–12, afternoon 12–17, and night after 19**) of week days have similar availabilities. Figures range from 3% to 15% of all available cars, moving from 0.1 €/h to 5 €/h.
14. During **weekends**, car availability during night is similar to that of working days, while for the rest of the day it varies between 2.5% and 12,5% of available cars.
15. Finally, it must be noticed that above 2 €/h, the number of available cars increases slightly, less than +0.5%. Therefore, **2 €/h** can be assumed **as the upper threshold, where the large majority of willingness to share is exploited**.

The analysis has been completed by studying which type of car will be more available for sharing, assuming that households with more than a car will share the oldest and/or the cheapest one. Looking at the answers and using the same criteria as above (in particular, the request in €/hour to renounce to their own car), there are just small differences in the attitude and in terms of willingness to share between car owners with less valuable car (either the oldest or the cheapest) and those with newer and more expensive cars. Moreover, in terms of sharing time, owners of more expensive cars tend to accept lower revenues than those with older cars. Looking at the age of the oldest car, owners with newer cars are slightly less disposed to share them than those with older vehicle.

Indeed, the hypothesis, otherwise reasonable, that the sharing of personal cars would translate in older and cheaper cars available can be rejected: the mix of shared cars will be rather similar to that of the average fleet of a city.

7 Conclusions

The chapter has investigated the propensity of the citizens of Milan to join a P2P CS scheme, thus enriching the current empirical literature, which is mainly focused on traditional CS systems. To this aim, two analyses have been carried out. First, the characteristics of the potential sharer have been identified: it is likely to be male, young, educated, cost-sensitive, with a "green" travel behaviour (bike and LPT). Second, the car availability has been measured during the different periods of the day and following different expected revenues, thus estimating the supply function for a P2P CS in Milan. As a result, the maximum car availability occurs during the night up to the first morning hours, whatever the corresponding fee.

According to these results, the citizens of Milan show a good propensity (50%) towards the idea of sharing their cars. Some elements can help to understand this outcome. First, the potential sharers are more likely to be cost-sensitive; therefore, they are more willing to share their vehicles in exchange for a monetary reward.

Second, their travel behaviour (on average preferring LPT and bike to car) shows a certain environmental concern.

Third, from a methodological point of view, being faced with a hypothetical decision, respondents did not perceive the real extent and impact (positive or negative) that a P2P CS might involve in sharing their personal car. Indeed, when faced with real decision, instead of a hypothetical one, respondents may consider more carefully the full impact of sharing their cars and be more sensitive to the proposal.

Besides, the recent decrease of the motorization rate in Milan can be associated with a lowered interest for the car's *status* (Steg and Gifford 2005; Marletto 2008). This is also consistent with the Municipality Sustainable Mobility aims and policies, like the promotion of bike and car sharing systems or the introduction of the Area C congestion charge (Beria 2016).

In conclusion, the creation of a P2P CS system in Milan seems promising, but not imminent. Indeed, the city has a good and efficient LPT,[6] and it is already provided with many free-floating CS systems that are proving to be successful. Nonetheless, the advent of Internet-based technology, reducing the borrowing and lending costs, could allow for personal vehicle sharing to emerge in a significant way in the medium term.

References

ACI (2015) Annuario statistico. Available at http://www.aci.it

AMAT—Agenzia Mobilità Ambiente Territorio (2012) Linee indirizzo del Piano Urbano della Mobilità Sostenibile di Milano. Milan

AMMA—Agenzia Milanese Mobilità Ambiente (2006) Strategia per la mobilità sostenibile al fine della tutela della salute e dell'ambiente Milano 2006–2011, November, Milan

Ballús-Armet I, Shaheen S, Clonts K, Weinzimmer D (2014) Peer-to-peer carsharing: Exploring public perception and market characteristics in the San Francisco Bay area, California. Transp Res Rec: J Transp Res Board (2416):27–36

Beria P (2016) Effectiveness and monetary impact of Milan's road charge, one year after implementation. Int J Sus Trans 10(7):657–669

Deloitte (2014) Global automotive consumer study. Exploring consumers' mobility choices and transportation decisions, pp 1–28

[6]The customer satisfaction surveys made by the Mobility and Environment Agency of Milan show good and ever-increasing results for the LPT services (http://www.atm.it).

Dill (2014) Early insights into peer-to-peer car sharing. Available at http://trec.pdx.edu/
Fraiberger, S, Sundararajan A (2015) Peer-to-peer rental markets in the sharing economy. Available at http://papers.ssrn.com
Fremstad A (2016) Sticky norms, endogenous preferences, and shareable goods. Rev Soc Econ 74(2):194–214
Hampshire RC, Gaites C (2011) Peer-to-Peer Car sharing: market analysis and potential growth. Transp Res Rec 2217:119–126
Hampshire RC, Srinath S (2011) A simulation study of Peer-to-peer car sharing. Presented at IEEE Forum on Integrated and Sustain-able Transportation Systems, Vienna, Austria, 159–163
Hildebrandt B, Hanelt A, Piccinini E, Kolbe LM, Nierobisch T, Management I (2015) The value of IS in business model innovation for sustainable mobility services—the case of car sharing. Proceedings Der 12. Internationalen Tagung Wirtschaftsinformatik, pp 1008–1022
IPR Marketing (2009) Servizio Car sharing del circuito nazionale indagine di customer satisfaction presso gli utenti, privati ed aziende e di notorietà e di interesse presso il target potenziale, Research Report, Research financed by the Ministry of Environment
Kim D, Ko J, Park Y (2015) Factors affecting electric vehicle sharing program participants' attitudes about car ownership and program participation. Transp Res Part D: Transp Environ 36:96–106
Laurino A, Grimaldi R (2012) The Italian way to car sharing. Journal of Land Use, Mobility and Environment 5(3):77–90
Lindloff K, Pieper N, Bandelow NC, Woisetschläger DM (2014) Drivers of car sharing diffusion in Germany: an actor-centred approach. Int J Automot Technol Manage 14(3/4):217
Marcucci E (2011) Scelte di trasporto e modelli a scelta discreta. Collana Economia e Politica Industriale. Franco Angeli, Milano
Mariotti I, Beria P, Laurino A (2013) "Car sharing peer-to-peer: un'analisi empirica sulla città di Milano", *Rivista di Economia e Politica dei Trasporti*, n. 3, art. 5, pp 1–16
Marletto GE (2008). Getting out of the car: an institutional/evolutionary approach to sustainable transport policies. eprints.uniss.it
Martin E, Shaheen S (2011) The impact of car sharing in household vehicle ownership. Access Magazine, pp 22–27
Riazzola S. (2015). Milano sharing city—car sharing. Available at https://www.amat-mi.it
Schmöller S, Bogenberger K (2014) Analyzing external factors on the spatial and temporal demand of car sharing systems. Procedia—Social and Behavioral Sciences 111:8–17
Shaheen SA, Mallery MA, Kingsley KJ (2012) Personal vehicle sharing services in North America. Res in Transp Bus Manage 3:71–81
Shaheen SA, Bansal A (2015) Perceptions of peer-to-peer car sharing in the San Francisco Bay Area, CA, USA. ITE Journal
Shaheen S, Chan N, Bansal A, Cohen A (2015) Shared mobility. Definitions, industry developments, and early understanding, Available at http://innovativemobility.org
Sioui L, Morency C, Trépanier M (2013) How car sharing affects the travel behavior of households: a case study of montréal, Canada. Int J Sustain Transp 7(1):52–69
Steg L, Gifford R (2005) Sustainable transportation and quality of life. J Transp Geogr 13 (1):59–69
Train K (2003) Discrete choice methods with simulation. Cambridge University Press, Cambridge

Testing a New Model for a Sustainable Mobility in the City of Milan: The Condominium Car Sharing

Daniele Fabrizio Bignami and Liat Rogel

Abstract This chapter will describe the testing and prototyping of one service-idea concept: condominium-based electric car sharing. It describes the testing phases in a detailed way, explaining the choice of the prototyping specific contexts, the testing modality and the results. The choice to prototype the service idea, directly in interested locations, was made in order to come in contact with potential users and initiate a co-design process. Involving users has two main goals: understand the needs and the desires of users on the one hand, provide information and make car sharing opportunities more known and available to a wider public on the other hand. The interaction with users also allows the users themselves to come up with service improvements and integrations. The prototype was made in two co-housing complexes in Milan with different sizes and cultural background using the same prototyping method: testing lasted six months with a plan of meetings, focus groups and observation. During the testing, the conditions of use were modified and verified with the users. Users feedback, as well as design insights, were then elaborated and were able to generate a series of results and considerations. Subsequently, during the phase of re-elaboration of the results of our experimentation, we tried to imagine transitory solutions towards a future growth of electric car sharing (and related environmental and urban benefits), exploiting the opportunity provided by Milan's many underground public and private parking lots.

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1 The Goals of the Field Trial Study

The Green Move project included a real trial of the idea of condominium electric car sharing. It was important to include this stage to verify and prototype elements of the solution in an early phase of the project. All things considered the testing resulted useful for another reason; by involving people outside the research group, it fosters communication and dissemination of new mobility scenarios. In one of the testing contexts, communication reached about 100 families. Not all of them took part in the testing, but the awareness of the opportunities for development of new models has been reached. The experimentation allowed exploring and better understanding the different phases: (1) access/acceptance: how is the idea perceived? Is it accepted? What are the barriers for entry and the difficulties met? At this stage, also communication strategies, the systems of registration and enrolment and the pricing system were tested. (2) Use: for what reason and on what occasion it is used, who uses the cars and how? What is the degree of user satisfaction? Here we examine technical issues related to the vehicle and to the reservation system. Finally, at this phase we evaluated the user experience. (3) Future use: how people imagine the service in the future after the trial is over? What are the design ideas and conditions for future use? This is the last moment of verification with users that examines the scenario as a whole, beyond the limited period of the trial. Here we questioned again all elements of the service.

2 Methodology and Phases

Thinking about condominium car sharing, one cannot ignore the trend of integrating collaborative services into living units. When housing units not only offer a basic solution (product/accommodation) but integrate collaborative services (Manzini 2008) for everyday life management, the solutions can be called Collaborative Housing. Or else, where people collaborate to overcome difficulties and create pleasurable urban life. Collaborative Housing is defined as the solutions where collaboration between the residents is an essential part of the housing model. Some examples are: co-housing, self-constructing groups, joint ventures, cooperatives, communes, integrated residences, student houses and elderly co-housing (Rogel and Cotubolo 2012). The integration of collaborative services into existing dwellings has the great potential to transform those places into more socially, economically and environmentally sustainable. The sharing of tools, objects, time and knowledge between neighbours is only natural; it is based on well-known dynamics of the courtyard and the family. Bringing it into nowadays urban areas, where social ties are getting loss is a key towards a more sustainable urban living. Car sharing is one of the opportunities we have in using the proximity of neighbours to create better mobility. In this test, as described below, we began by working in environments that already had a social predisposition.

2.1 The Selected Case Studies

The buildings selected for the trial were chosen looking at their technical aspect: the number of apartments/inhabitants and the presence of adequate (not common) spaces for shared vehicles. On the other hand, we looked at the social composition and the existence of relationships between neighbours. The latter was a first condition since it guaranteed an easier adaption and a quick and better introduction of the project in the communal environment. The two buildings respond to the first two conditions, but have interesting difference: the first, in Donadoni Street 12 in Milan, is a co-housing condominium, which presents large shared areas that were decided and designed by the inhabitants. The second, in Scarsellini Street 17, was built through a construction cooperative and saw a use of an online social platform that has further reinforced the relationship between neighbours.

The co-housing in Donadoni Street is a fairly small house of 30 families. They share a living room with a kitchen, a laundry room, a swimming pool and a workshop space. Spontaneous car sharing already took place among neighbours. The inhabitants are people well-accustomed to the idea of sharing. The building did not have an adequate space to place one or more extra vehicles, but the proximity of the Bovisa train station, where car sharing is already located (provided by the Ferrovienord, brand E-vai), has allowed the neighbours to participate.

The building in Scarsellini is a new building, with 100 apartments. Two empty garages were available with electrical plugs and counters. In the building, there are two shared rooms, one for general use where parties, dinners, sport courses are taking place and another one for children’s play. The social composition here is quite diverse, both in age and in ideology. There are some neighbours that are very active and others that are not at all involved.

2.2 Organization and Procedures of the Trial

The trial was organized following the following phases:

1. Meetings with the people involved: stakeholders, directors, administrators and inhabitants;
2. Technical and users survey: verification of technical conditions and the availability of the neighbours to participate;
3. Launch event;
4. Test and closing event.

Below the phases of trial organization and run are detailed.

1. **Meetings with the people involved**

The first meetings were with those people already active in the community life of the specific building: during these meetings the idea was presented and there was the possibility to discuss it with researchers from different departments of Politecnico di Milano involved in the Green Move project. The meetings gave us the opportunity to introduce the trial to people who are already decision-makers and influencers. In both cases, the meetings were useful and proactive. The idea was accepted well, and their enquiries were mainly aiming to clarify economic and technical details. The idea was presented to the whole of the community as well by mailing list and Web.

2. **Technical and users survey**

Having received the consent of the building councillors and administrators and a general interest from the inhabitants, we proceeded with the verification of the conditions of use.

Some technical conditions had to be verified: in Scarsellini it was crucial to verify that the signal for opening the car would be received in the underground garage. Usually, the cars in car sharing services are positioned outside in open parking lots. Here the car should have been positioned in -1 floor. The garage was already equipped with electrical socket and counter so that nothing remained but to set up the box with accessories. More in general, as a pre-operational simulation, at the campus of "Città Studi" of Politecnico di Milano, we had already tested the basic technical elements for the activation of an electric car sharing service. Among these some of the most time consuming, at the stage: the non-easy steps of request for installation of a charging point of E-moving (E-moving 2016); the rental of some electric cars to be made available to multiple users; the identification of specific and recognizable parking areas (Fig. 1); the replacement of the locks of some (non-private) garages and the methods of key exchange of the garages and vehicles in common areas.

To check the availability and interest of the owners, a survey was launched. This questionnaire based on a larger one ("demand analysis", chap. 5) but lighter and shorter allowed to understand how many potential users are in the building and what kind of use they imagine for the car sharing service.

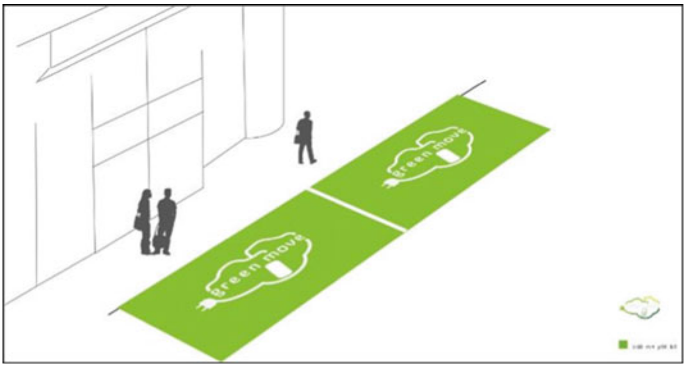

Fig. 1 A preliminary sketch of the two Green Move parking areas in front of a building of the Politecnico di Milano at the "Città Studi" campus

Fig. 2 Some figures illustrating Green Move trial (Scarsellini condominium)

3. **Launch event**

To launch the experiment, we organized a small event with the following purposes: to present the project, to see and test the car, to sign up the service with our support.

4. **Test and closing event**

Our testing was ensured by the use of an existing car sharing service that dedicated four cars only to our use. This has allowed us not to worry about technical support and booking matters while still able to monitor the specific users and position the cars where we planned. In Scarsellini, two cars were placed in the building area, while for Donadoni two cars were positioned in the near train station parking lot. Though in a public area, they were of exclusive use of the trial users.

Kilometres travelled and usage time for each user have been monitored: additional info has been provided by users themselves through a dedicated social network. Half way through the trial there was another promotional evening in which we also organized a focus group to collect feedback.

At the end of the trial there was a final meeting for feedback collection and idea generation (Fig. 2).

2.3 Check and Control System

During the trial the users were monitored and followed using the following channels:

- the car itself englobed a device for the registration of kilometric quantity and time of use.

- through the Internet social network (in Scarsellini) we collected qualitative data and experiential feedback.
- in the two apartment buildings few inhabitants were commissioned to gather opinions and recommendations in a spontaneous way.
- two focus groups were held, in the middle and at the end of the trial. The focus groups aimed to:
  - understand what are the current uses of the cars and the experiences (positive and negative) that occurred,
  - understand why some people that showed interest in the beginning did not use the cars,
  - generate future scenarios of use (to be implemented immediately or in the future) and effective communication.

During the meeting, users talked about their experience of use or their motivation for not using the service. With a guided work, the group has completed a SWOT analysis of the so-far-offered service (Fig. 3).

Fig. 3 The SWOT analysis completed at the end of the Green Move trial

3 Results

The results described here are divided on the basis of the three stages of the trial: the first is *access/entry to the service*, then *service use and user experience* and last *future considerations*.

3.1 The Start-up Process: Overcome Barriers

This is definitely the most difficult barrier we found during the trial that needs to be overcome. The initial mistrust and lack of information makes approaching the service slow and difficult. Many people in the buildings were not even interested in having information about the service, considering themselves out of user target. Others, who have passed the first barrier, found the registration to the service complicated and slow. This sometimes caused them to stop the procedure and not complete the registration. Some considerations on elements may influence this first part of the trial are:

- Communication: the first communication of the service should be very simple and very straightforward. For example, advantages of the electric car sharing should be expressed clearly: free parking spaces, the free entrance to city centre, etc., are motivations to use the car sharing services rather than the private car. In addition, give people the opportunity to test electric vehicles without commitment and understand how they work in order to overcome the fear to try a new kind of driving. Equally important are video stories that can easily explain the use. All these could facilitate the initial approach to the service.
- Rates are another important element in the start-up stage, as people do not want to take the risk of a financial commitment before even trying. Prices should be kept low and especially flexible in the beginning.
- The environment: the apartment buildings where the cars were positioned resulted as a "saturated environments" in the sense that almost all of the people living there were already in possession of one or two cars. Usually, car sharing services substitute the second cars, but in this case having been a time-limited trial, people did not take important decisions such as abandoning the second car. All in all, they felt it was simpler to use their own cars rather than the shared vehicle.

3.2 The User Experience

After overcoming the initial barrier, we were able to observe and reflect on user experience. Here we describe the use of the cars and the way it was used throughout the trial. Subsequently, some considerations of how communication and rates have influenced the use are:

- *Types of usage*: the cars were used mainly to answer two types of needs: (1) short-term use for quick chores, often in the city centre. In this case users took advantage of the opportunity to free-park anywhere and not having to pay to enter the city centre (Milan "Area C"—see: AreaC (2016)). (2) For short trips just outside of town, especially in the weekend.
- *Ease of use*: the booking of the car was easy both via website and the phone. The cars were easy to drive with some doubts due to the automatic gear that is uncommon in Italy. Passed the first time, no one has reported difficulties in driving and, more in general, in using the car (Fig. 4).
- *Additional services*: in Scarsellini, some accessories were available as add-ons: specifically, child seats and material for cleaning the vehicles. This has contributed to the participation of families with children in the trial and made it more comfortable if not essential for family use.
- *Communication*: communication during this phase was helpful to increase subscribers and to involve those people that initially enrolled but did not use the service. The main communication task here was to figure out how to create an active community around the service that would be able to create support by itself (members help members). This was the main reason for choosing a quite innovative format of the community TV (Chap. 7).
- *Fees and rates system*: there were tariff changes during use that have modified the same: initially the rate was an hourly rate that included everything. This was comfortable and convenient for short distances use. All in all, longer rides, like the ones we observed during weekends, were not convenient with this type of pricing. Therefore, the second pricing was a combination of an hourly rate, that was lower than the previous one, and an additional kilometric rate. This rate has increased the amount of bookings mainly for trips in which people do not drive much but need the car for the whole day. This is the case of visiting family outside the city or going for a hike in nature. The last change in the tariff involved the integration of a subscription fee and thus a lower per-use rate. People could choose whether to opt for this or remain with the slightly higher rate. A few users have chosen the subscription, the more frequent users. It should be noted that the last tariff change took place next to the end of the trial.

4 Future Scenarios: Studies and Applications

Generally speaking, the condominium car sharing service idea was confirmed as positive by the trial. Some advantages (confronting to traditional car sharing services) are: the location of the car always close to home and the exclusivity of the car by the community of neighbours. In an environment where people know each other,

Fig. 4 A Green Move users feedback

sharing an object like a car makes it more personal. The feeling created by sharing among neighbours is different than rental cars and is more similar to shared ownership. The car customization with some accessories makes this feeling even stronger.

The initial entrance barrier is not to be underestimated. If a group of neighbours should be engaging in paying an initial fee for the service to start, there must be a strong group of users to begin with. This gives us two kinds of ideas: one, buildings under construction can be already designed to fit electric car sharing with the relative infrastructure. With “in hand service” people would be more willing to use it and try it and even decide to abandon their car when moving to a building offering this service. Two, a new stakeholder should be identified to invest in the implementation of condominium car sharing. In the case of car sharing services in a company, it is the company itself buying the cars and offering their use. Who could it be in this scenario? Purchasing the cars is to be excluded from this scenario as it will result very complicated to put neighbours together to such economic investment. We should think about a service model that allows the free positioning of cars in the building and then pay-for-use methods: next paragraph tries to design this new concept idea.

4.1 From Condominium-Based Electric Car Sharing to a Hybrid Model at Neighbourhood Level

Trying to answer the last question, we have developed the following concept idea.

Milan is one of the largest car sharing markets in Italy, accounting for more than a third of all the Italian car sharing members (ANSA 2016; Enjoy 2016). Market-driven forces (Car2Go, Enjoy, Twist), “pro-car sharing” policies (GuidaMi/GirAci, the access to limited traffic areas and parking spaces, etc.) and “pro-electric mobility” (Share’NGo, E-Vai, electric-bikesharing BikeMi, E-moving charging stations) have shown Milan inhabitant how car sharing and electric mobility can help to meet their mobility needs, especially regarding occasional car users, for shopping, visits to friends and family, etc. (Enjoy 2016; Car2Go 2016; GirAci 2016; BikeMi 2016; Twist 2016; Share’NGo 2016; E-Vai 2016, E-moving 2016). Such a trend is not an isolated case, but it is considered logical (Kim 2015) in a framework of increasing car ownership expenses, as in Italy. However, it is uncertain whether this recent car sharing/electric mobility growth will continue, this being true also in the case of Milan, considering, for instance, the inactive members at the end of car sharing companies aggressive marketing campaigns (Martin et al. 2010). In addition, it should be considered if electric mobility expansion will permanently meet the mobility needs of a significant portion of the residents of the city.

In this framework, condominium-based electric car sharing could represent an option to balance the vehicles demand of car sharing services for recreation usage in weekdays and at night B2C (business to consumers), in order to become an option for everyone in need in diverse occasions and hours, and not only for young people or B2B (business to business) users (Mishra et al. 2015). In a parallel way, condominium-based electric car sharing could represent a key element for the expansion of electric charging points and the "culture" of electric mobility.

Just as many enterprises and public bodies have enjoyed budget savings by reducing their vehicle fleets or switching existing long-term contracts with traditional rental car into car sharing programmes, likewise condominium-based electric car sharing could help, not only "low income" people but also persons aiming at being free from thinking about the maintenance of a car (e.g. the second car) or garage, or if they are not adept at handling a smartphone or looking for a car sharing vehicles in the neighbourhood.

Yet, as a matter of fact, in most condominiums in a city such as Milan, it is not easy to find free parking places to share cars, nor to reach a minimal sufficient scale from an economic point of view. Nonetheless, the city of Milan has today a rare opportunity: a widespread distribution of new underground car parks built, thanks to the Italian Government acts (from the 122/89 law, also called Legge "Tognoli", to the National State of Emergency Act of 15 November 2001) which encouraged the development of such urban parking areas in the last 20–25 years (Ferilli 2008; Peluso 2011). The high number of parking lots is realized in this period (nearly 140 in public concession and several more built by private owners), and the large number of parking spaces (up to 300 or more in each one of them) perhaps an oversized number (Cfr. Italianostra[1]; Comune di Milano 2012a, b; Mottini 2010) has produced the fact that a large number of garages is still "for sale" or constantly free "for rent", as shown in Fig. 5, taken during the spring 2016, to exemplify the situation of the city.

This overabundant quantity of parking spaces could be an opportunity to expand the condominium-based electric car sharing, giving the possibility of car sharing not at the level of a single building, but involving many buildings of the same neighbourhood, in contexts where an 18-/24-h reception/concierge service is already present. The service could be easily upgraded to manage the cars and systems maintenance (or even the reservations), keys guarding and the needed equipment (car customization and cleaning), also becoming a help for people less used to the required technology.

As regards environmental benefits: car sharing reduces greenhouse emissions (reducing vehicle kilometres travelled and favouring the use of public transit), reduces the average number of vehicles per household and the needs for public parking spaces (Jonuschat et al. 2015; Baptista et al. 2015); electric mobility also reduces emissions; in addition, underground car parks further reduces the need for public parking spaces compared to the "classic" car sharing. All these aspects together work in synergy, offering better (extra) performances.

The possibility of success of such a kind of "hybrid model" (among B2B, B2C and P2P) of car sharing is due to the fact that, in a city such as Milan, a portion of the population makes a relatively infrequent use of its own car, as the typical car sharing members of today demonstrate, allowing the possibility of more efficient

[1]www.italianostra-milano.org/cms/files/IN_parcheggi.doc.

Fig. 5 Pieces of the "puzzle of car parking spaces" for sale or rent in some underground car parks in Milan, the result of our survey

fleet operations. As a matter of fact, there is evidence that the B2B market segment of car sharing is now growing faster than car sharing in general, since the member of a working staff is provided access to a car sharing organization's fleet through his employer (Clark et al. 2015). Similarly, an underground car parking could provide an easy access to electric condominium car sharing.

The car sharing concept of the underground-based condominium electric car sharing is the back-to-base one (one-way), in which the user takes a vehicle from a specified location, performs a round-trip tour and returns the vehicle to the same location at the end of the usage. It could be an emerging sub-market of the shared-mobility sector, to be tested in future projects, during which to verify the possibility of overcoming two barriers of our ideal scenario (P2P, peer-to-peer, electric car sharing) but keeping fixed both the location of the car, close to home, and the exclusivity of the use of the cars by the neighbourhood community. This way it would be possible to overcome the two barriers: the low propensity to switch to the electric engine, since one more possibility to test it is given; the cost and availability of the infrastructure required by this model (above all in relation to the acquisition or rental of garages in addition to vehicles and charging points).

Tentatively, a starting estimate (to be tested) of the quantity of shared vehicles to satisfy this car sharing demand could be between 2% and 5% of the places of an underground car park, if we consider the multiple uses of a neighbourhood when compared, for instance, with B2B car sharing consumption of university employees (Zhou 2013), being a university campus comparable to a limited urban area, like a condominium compound.

Interested in such a kind of project could be not only the members of the underground parking condominiums (the owners of other private garages) and the car sharing companies, but also the electric vehicles producers, to promote their products, as well as cooperative companies managing many underground parking sites in Milan, who are still burdened by many unsold garages.

4.2 Other Ideas from the Users of Green Move Trial

Some ideas about the car sharing service came from the users of condominium-based car sharing:

- Create partnerships with commercial and cultural stakeholders: e.g. supermarket or cinema.
- Facilitate the creation of an online community of users and allow transparency of uses: it may be useful to know who uses the car to go where as it could facilitate forms of car-pooling or solve some problems that may arise after use.
- Instructions for use inside the vehicles for the use of the automatic gear.
- Inclusion of additional accessories: navigators, ski carrier, bicycle carrier, etc.
- Integrate both the traditional car sharing and peer-to-peer car sharing based on existing vehicles.

5 Conclusions

Though some barriers are still to be crossed and verified, the idea of condominium electric car sharing seems to have a good potential of implementation. The use of the car in a car sharing service requires the user to plan more: programme the trip, book it and respect timings in respect of other users. Other mentality change is getting used to payment by usage. With the general spreading of shared vehicle services, we have a reason to believe that the condominium version may be successful. Especially for buildings under construction, it could become a standard, dedicating parking spot with charging plugs and accessories for a shared-use car.

The experiment was useful both for research and for the dissemination of good practices of car sharing. Even people who did not eventually use the service have learned a little more about car sharing and certainly are more willing to seize new opportunities.

This phase of the project has been helpful to the redefinition of the scenario and the different elements that constitute it.

The car sharing concept of the underground-based condominium electric car sharing seems to be interesting to be tested as a way to improve participation rates of electric car sharing services in Milan.

References

Ansa (2016) http://www.ansa.it/toscana/notizie/2016/06/16/car2go-cresce-flotta-e-200mila-iscritti_899ba7b3-b7c5–4e81-8fbd-aaa8738e52cd.html

AreaC (2016) Area C web site. http://www.areac.it/

Baptista P, Melo S, Rolim C (2015), Car sharing systems as a sustainable transport policy: a case study from Lisbon, Portugal. In Sustainable Urban Transport, pp 205–227

BikeMi (2016) BikeMi (Milan bike sharing) web site. https://www.bikemi.com/

Car2Go (2016) Car2Go car sharing web site. http://www.car2go.com

Clark M, Gifford K, Anable J, Le Vine S (2015) Business-to-business car sharing: evidence from Britain of factors associated with employer-based car sharing membership and its impacts. Transportation 42, 471–495. Online publication date: 1 May 2015

Comune di Milano (2012a) Mappa on-line dei parcheggi a Milano. http://217.31.113.128/SIT/PARCHEGGI_2/

Comune di Milano (2012b) on-line paper "I parcheggi a Milano: bilancio 2012". https://www.comune.milano.it/dseserver/webcity/comunicati.nsf/d68aa3e55927f9f7c1256c4500573452/df032c0d3c259300c1257adb004d0461/$FILE/12_12_21%20Scheda%20parcheggi%20bilancio%202012.doc

E-moving (2016) E-moving web site. https://www.e-moving.it

Enjoy (2016) Enjoy car sahring web site. https://enjoy.eni.com/it . http://enjoy.eni.com/

E-Vai (2016) E-Vai car sharing web site. https://www.e-vai.com

Ferilli G (2008) An analysis of the city centre car parking market: the supply side point of view, Edinburgh Napier University

GirAci (2016) GirAci carsharing web site. https://giraci.com/it/

Italianostra (2016) Associazione Nazionale per la Tutela del Patrimonio Storico, Artistico e Naturale della Nazione, on-line paper "Parcheggi a Milano: le proposte di Italia Nostra". www.italianostra-milano.org/cms/files/IN_parcheggi.doc

Jonuschat H, Stephan K, Schelewsky M (2015) Understanding multimodal and intermodal mobility. In Sustainable Urban Transport, emerald group publishing limited, Bingley, pp 149–176

Kim K (2015) Can car sharing meet the mobility needs for the low-income Neighbourhoods? Lessons from car sharing usage patterns in New York City. Trans Res Part A: Policy Pract 77:249–260

Manzini E, Jegou F (2008) collaborative services. edizioni poli.design, milano

Martin E, Shaheen SA, Lidicker J (2010) Car sharing's impact on household vehicle holdings: results from a North American shared-use vehicle survey. Transp Res Rec 2143:150–158

Maurizio M (2010), on-line paper "La vicenda dei parcheggi su aree pubbliche a Milano dal 1985 ad oggi". www.manifestopermilano.partecipami.it/infodiscs/getfile/72

Mishra GS, Clewlow RR, Mokhtarian PL, Widaman KF (2015), The effect of car sharing on vehicle holdings and travel behavior: a propensity score and causal mediation analysis of the San Francisco Bay Area. Research in Transportation Economics 52, 46–55. Online publication date: 1 Oct 2015

Peluso C (2011) I problemi legati alla realizzazione dei parcheggi sotterranei. http://www.partecipami.it/proposals/problem_show/1/57
Rogel L, Corubolo M (2012) HousingLab, exploring new ways of housing our cities, CUMULUS Northern worls mandate conference proceedings
Share'NGo (2016) Share'NGo car sharing web site. http://www.sharengo.it/
Twist (2016) Twits car sahring web site. http://www.twistcar.it/

Communication Design for Social Engagement. Micro TV and the Integration of Branding and Storytelling into Participatory Processes

Maria Luisa Galbiati and Francesca Piredda

Abstract The Green Move project promoted an innovative interdisciplinary research approach. Imagis Lab research team actively contributed integrating tools and processes from communication design and participatory video. Within the Experimentation actions for experimenting green mobility services and vehicles, a Micro Web TV was designed and produced in collaboration with the community of Villaggio Scarsellini condominium in order to foster users' engagement. *Scarsellini TV. Vicini più vicini* was launched in 2013 and produced five different formats for documenting the community's everyday life, providing video-tutorials explaining how the service works and how you can get the best from the vehicles and the service, the best practices within the condominium itself to be communicated to the rest of the community in order to improve people's engagement and making them suggesting further possible uses. The paper describes on one hand the design approach to communication: the first part introduces movie design as communication strategies based on audiovisual storytelling and positions this kind of design approach within the other disciplines involved on the Green Move project. Then, the second part describes the specific contribution to the Experimentation research activities and the outputs produced (communication and TV formats), and analyses data from the surveys to the users during the experimentation and interviews to the community after the micro TV experience: was Scarsellini TV a socialization action? Did it help to foster the integration of the service into the condominium daily life? Did the user/community get new visions about possible alternative scenarios of sustainable mobility? And finally: did the implemented communication instruments contribute to foster the social innovation and to raise the consciousness of people involved?

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1 Communication as Design

The solution-oriented approach to design is usually focused on assessing the project's functional aspects in order to gain an understanding of its added value and identify the innovative elements in the smart and sustainable solutions panorama. The communication dimension tends to be neglected, even in the case of urban scale projects where citizens, stakeholders and all those potentially interested in getting to know and use a service should be informed about it. This attitude is fairly usual in social innovation, environmental sustainability, service or local government public participation projects. There are many reasons for this and at least two of these are worthy of further attention. The first one is that communication is seen as a creative activity, which is alien to the technical-scientific rigour of many research communities. The second one is that communication is often taken as a tool, which is exclusively linked to commercial companies and branding. Overlaps exist within the same Green Move project and the term "communication" is used by researchers in different ways depending on their discipline of reference: on one hand, they refer to technological platforms and protocols developed for the functioning of the system and on the other hand to scientific and academic dissemination.

Actually, communication is much more complex than this, as far as it intersects with both the business dimension and the more general sphere relating to all human activities needing to be notified, supported, made public and participated (Volli 1994). In fact, the same verb "to communicate" (from Latin: *cum-munus*) means performing a task with others, sharing, bringing individuals or communities into an event, a story, a danger or good news. Communication is thus an important mover for profit making activities and more generally it also gives substance to that human relations context which is part of everyday life. Communication works according to a system of rules (syntactic, semantic, pragmatic), which are valid both for interpersonal relationships and for commercial or social communication (Testa 2000; Gadotti and Bernocchi 2010; Puggelli and Sobrero 2010). We can understand how it works and attempt to apply its processes to all contexts in B2B and B2C segments or for small groups of interest.

This is the task we took on in the Communication Design context: understanding communication processes and applying them to innovative multi-channel spheres (Santambrogio 2016), new televisions (Piredda 2008), transmedia storytelling projects (Ciancia 2016), branded content (Bonsignore and Sassoon 2014) and web series (Galbiati and Piredda 2010), which are nowadays well established tools and forms.

The Green Move project was an important opportunity to experiment with effective communication formats[1] taking account of the socially innovative nature of the context in which the project has been developed. Communication was taken

[1]By effective communication we mean a communication process capable of transmitting information using logical and analogue languages with a precise communication goal and clear target

to mean a trigger to give the project its own identity, to extend its public scope and introduce easy to understand narrative forms.

In order to achieve these goals we developed the GM project adopting the movie design approach (Galbiati 2005). Movie design is a discipline, which takes on board audiovisual communication from the perspective of corporate communication. This requires a twofold knowledge background: an awareness of the strategic framework which enables a product, an event and a service to acquire a recognisable and well liked public image and, at the same time, an ability to manage all the technicalities of audiovisual communication from the technical, linguistic and aesthetic points of view.

Applying communication strategies to projects with a social orientation is not different from doing so with consumer products such as washing powder or smartphones. Certainly the nature of the contents requires communication changes but the strategic framework remains the same. For this reason, we learnt that for communicating a project within the social innovation sphere it is very useful to learn both from the world of branding (for the strategic part) and from the world of cinema (for the ability of images to generate empathy), as explained in the next paragraphs.

1.1 What We Learned from Branding

Communication is a fundamental important asset in branding and identity building but it can also perform the same role for services, small-scale initiatives, events or processes, which may or may not be branded. Identity building means identifying the key values that a company wants to transmit to its consumers. It is a complex process, which is designed to generate engagement and consumer's expectations coherent with needs.

Many factors contribute to transforming a product into a brand. Just for citing a few of them: company reputation, differentiation from similar products, quality, ability to supply additional services, narrative building and communication. Another fundamental important role in this is performed by the communication strategy that orients creative choices and identifies the best-suited media for transmitting the message.

The proliferation of digital technologies has made this task more difficult because defining targets is more challenging with the latter tending to escape traditional classifications. Furthermore while in the past brand was considered the whole of the products and the functions linked to it, it is now increasingly seen as a narration (Matrone and Pinardi 2013), a story, a belief, a principle of reliability

(Footnote 1 continued)

audiences. For this reason, effective communication requires a strategic framework in which to define all its elements in a coherent way.

around which the values linked to our ways of thinking and living accumulate. At the heart of a brand building exercise there is a relationship of trust, a perception of reliability, which binds together consumers (users) and the brand itself. In contrast to a product, which may have a short life cycle, a brand can have a short life generating an ongoing assessment, support and innovation process in a strategic perspective, which looks to the future. A communication project drives success and it is a strategic resource for the company because its goal is to build an emotional bond with the public that is the true focus of contemporary marketing strategies. This is true of products, services, towns, nations, individuals, cultural destinations, innovative services such as car sharing and Airbnb, music sharing platforms like Spotify and TV series.

Communication thus plays a delicate but fundamental important role: transmitting brand values to its audience, orienting its identity and philosophy in such a way that brands take their place in the hearts and minds of less and less focused consumers that are continually bombarded with different messages and information. We have learnt from the global brands the importance of empathic communication, which is capable of touching directly the innermost chords of its consumers. Nike, Diesel, Apple, Coca Cola, to cite just few examples, represent today a field of study from which to learn effective communication models.

Everything is encompassed by communication to satisfy a more and more challenging, more cynical and also more self-aware target, one which has lost those standardised qualities around which market research was built for years, and become an increasingly profiled and segmented target whose lifestyles are in constant evolution, an increasingly cultured, pragmatic, shrewd, diffident, sceptical and ever more challenging consumer who has been defined "patchwork" by many (Fabris 2010). For this reason in recent years firms have been obliged to change their communication behaviour passing from a "one to many" approach to a "one to one" approach, from a monologue on the virtues of their products to a dialogue with consumers in which the latter expect to take an active part in an exchange of ideas with companies. Markets are conversations[2] and all organisations now base their actions on this logic, including tertiary sector, no-profit and community services organisations.

An alternative marketing and communication climate has thus developed which orients the cultural legacy of brand image towards a heritage in which experience is taken fully on board: a multi-form territory whose nature is based on user emotional and sensorial involvement strategies.

In this logic we have transferred these principles to the Green Move project too. We have treated it as a brand, we identified its values, built a brand image and created a narration in order to take on those elements of identity and personality which may be perceived by a target group. We looked for responses not simply on

[2]In 1995 this definition appeared on the web in the now famous Cluetrain Manifesto drawn up by a group of researchers including IBM's consultant Rick Levine. The manifesto sets out 95 items on paradigm shifts between the old and new economies.

the level of information but also in terms of the processes and languages in which information is targeted.

The integrated communication strategy used in the GM project thus followed the traditional business oriented communication strategy steps: context analysis, users analysis, stakeholders and competitors analysis, identifying the correct tone of voice, choosing media and useful tools to communicate the service both to the internal and external players. Transforming GM into a branding operation has meant creating a framework in which sponsors, stakeholders, small communities and public and private players can activate profitable relationships and virtuous processes which are coherent with the objective of benefiting the whole community. Videos were thus made to present the project, as they were held to be useful and easy to understand tools. Those responsible for the project were interviewed in support of the initiative. A website was made to showcase all the results and a condominium TV was experimented with in order to get a specific user group involved. A final presentation was also put together to tell the story of the whole project.

1.2 What We Learned from Cinema

In a branding project putting user experience centre-stage, digital images and technologies take on strategic importance. Screens are now a veritable cultural paradigm capable of contaminating people's cognitive universes and organising their actions and thoughts (Manovich 2002). The use and abuse of screens, devices, audiovisual, multimedia and transmedia images has become part of our daily vocabulary.

Cinema is fundamentally important for branding because it takes advantage of the ability to narrate and makes people emotionally involved. French people immediately perceived its historical scope at its first screening in a Paris café in 1895.[3] For the first time people experienced a totalising experience by seeing a virtual image as if it were real.

For designers like us taking part in the GM communication project, cinema was an exploration area from which we learnt what it means to observe, interpret, tell a story and represent, exploiting audio-visual techniques and languages to obtain effective and participatory communication. We did it primarily by enquiring into the ways in which cinema has put the city centre-stage as well, in more general terms, as the private and public spaces, transforming them into a human event set (Galbiati 1989). Cinema succeeded in bringing across the complexity of life's ebb and flow and its real or imaginary places immortalising scenarios and depicting the

[3]The invention of cinema by the Lumiere brothers dates to 1895 when the first screening of *L'arrivée d'un train en gare de la Ciotat* took place in Paris. It is said that audiences were frightened by the images they saw moving on the screen and ran out of the café in the belief that the train might come off the screen into the café.

spirit of the times, characterising every era with its moods and emotions. In contrast to a map or graphics, cinema places human beings and their dramatic events centre-stage thus allowing spectators to identify with characters and activate a silent dialogue. It generates those feelings, which we all know and which give us an opportunity to be moved, get angry or laugh at a film's scenes. To a lesser extent contemporary audio-visual production uses the same paradigms, making itself a language capable of speaking to different levels because it mobilises elements relating to identity, memory and the collective imagination. Audio-visual products also take the form of elements capable of prompting new visions and new collective imaginations.

Moving images (Deleuze 1984) are the maximum expression of the efficacy of cinema storytelling, the true engine of its success. And this is perhaps the densest of the emotions that cinema has brought to the audio-visual communication designer.

Audio-visual and storytelling tools have thus been taken on as design tools to the extent that they have generated visualisations useful in any attempts to understand an area and can be used to facilitate dialogue with citizens and stakeholders (Galbiati and Piredda 2012). They have also been useful instruments for the learning and negotiation process in the disputes, which are always a feature of urban planning projects. And last but not least visualisations have generated practicable ideas and prototypes and been the subject of thought and debate between players taking part in social dialogue.

A new generation of communication products, which transcend the concept of physical space to play a part in the virtual dimension of the Internet acts as counterpart to the cinema experience. These communication artefacts are objects, which are at the centre of attention today both as a result of the brands, which try to find a way of exploiting their potential and for the web generation for whom the Internet is a new global dialogue dimension. We are seeing a shift from a broadcast logic (top-down and one to many) to a social network system that is generated thanks to collective intelligence whose characteristics (the participatory logic, the bottom-up contents generation) have breathed life into new information and know-how platforms such as WEB TV, Wikipedia, blogs, YouTube and the social media in general, an area of the web which is today laying down the traditional communication architecture law.

1.3 Movie Design Practices: Examples of Educational Activities and Applied Research

The branding discipline and cinema language are at the heart of what we have called Movie Design. The latter is a term, which attributes a design-oriented strategic and creative perspective to the project of communication artefacts, which is characterised by the equilibrium between art and management.

In particular, one of the Movie Design projects at the School of Design, Politecnico di Milano (www.imagislab.it) is linked to sustainable transport themes, which accord well with the GM contents. The project is entitled Cammina Milano[4] (Walk Milan) and consists of a communication project for social innovation designed in accordance with Milan city council. The goals of the project are traceable to three actions: promoting a sustainable mobility culture among citizens; facilitating dialogue between Milan city council and stakeholders; building a new image of Milan. In order to satisfy these requisites we created communication formats, which act as tools capable of promoting and developing a dialogue between public and private players in order to generate shared visions (https://www.youtube.com/playlist?list=PL1z2q1-ekJ1DXbRb0Yw7epN9Z19xtrS-E). Ten video documentaries were made for the purposes of exploring Milan in its public life expressions and register citizens' opinions on the mobility issue (the activity of listening to the city; Sclavi 2003). A similar number of video scenarios were planned with the goal of giving form to the collective urban imagination which emerged during the exploration phase (scenarios building phase) and lastly commercials were made with the aim of promoting good mobility practices sustaining bicycle use, pedestrians, the use of public transport and bike and car sharing. The audio-visual narratives, conceived within a strategic framework, brought out an image of a living city with all its passions and critical issues in a constant switchback between past and present, sense of belonging and demand for better living conditions, a participatory and emotional story. From this emerged unexpectedly high self-awareness in the city, a desire to improve it by means of good practices even in the face of sacrifices and changes in established behaviours.

By means of three actions: listening (documentary), visualising (video-scenarios) and promoting (commercials) (Piredda et al. 2013; Galbiati et al. 2010) an audio-visual system was created which took the form of a new city thought and planning process. Looking up-close at citizens' ways of life and stereotypes brought us closer to an ethnographic and anthropological city dimension, an approach which is often undervalued in the decisions taken by national and local governments.

Analysis and planning tools led to a framework in which co-design practices and partnerships were placed centre-stage by those taking part in the project. The results of this work (documentaries, semi-finished products, mood boards, commercials, photographic repertoires, conceptual maps) were used in workshops and round tables in which citizens and stakeholders took part thus facilitating the decision-making process and activating debate on possible scenarios for models of sustainable daily life.

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[4]Cammina Milano (2009–2010) was part of a three-year project entitled Immagina Milano (Imagine Milan), an action research and educational plan, which generated documentaries, video-scenarios and commercials, aimed at promoting good urban practices in various city districts. Over the years a range of themes were developed (sustainable mobility, revitalization of the suburbs, multi-culturalness, historic memories, green city, smart city and much more) by means of projects linked to various areas of the city of Milan.

This research acted as starting point for the shaping of research and planning practices which we have been experimenting with since 2012 for a more circumscribed local dimension, the town district. In addition to well-established tools, we also activated a Social TV project (television using social media—YouTube, Facebook, Instagram and Twitter—as the principal means of distribution) for the purposes of facilitating the participation of the greatest number of inhabitants of an area of the city suburbs, the Dergano and Bovisa districts. We brought into this project the district councils and citizens associations, which have been working for years to improve the quality of life in the city.

The communication process thus increasingly incorporated bottom-up evaluation. If the digital platforms favour interaction dynamics in themselves, strategies exploit the potential of these in order to stimulate feedbacks from users and strengthen the relationship between online contents and offline action in the area by means of transmedia storytelling. The user-centred and community-centred approach is thus expanding as a design framework and communication practice confirming tendencies underway in all communities which see design as a tool for facilitating and shaping sustainable solutions for a better life.

Today the Plug Social TV platform (facebook.com/plugsocialtv) collects web-series promos, brief documentaries, interviews, extra contents and spin-offs[5] produced by joint action of students and citizens together. The added value of WEB TV thus consists in becoming a social innovation engine as the fruit of joint local level action capable of putting forward universally relevant issues, which can be adapted to the various local contexts.

2 Movie Design for Social Engagement

Due to the experience gained in the context of new television and transmedia strategies, over the years we have developed audio-visual storytelling processes and techniques relating to participatory videos and community narrations (Anzoise et al. 2015), (Ciancia et al. 2014).

On an international level many groups are researching and experimenting with forms capable of taking advantage of the interactive and participatory potential of media convergence and the development of sharing platforms. Just to name a few, Crucible Studio is a research group within Media Centre Lume (http://lume.aalto.fi/en/) and the Department of Media (http://media.aalto.fi/en/) of the Aalto University School of Arts, Design and Architecture. It studies and develops narration of the digital, non-linear and interactive media. In the audio-visual context, special attention is paid to new forms of documentary genre: in addition to the work of the National Film Board of Canada (nfb.org), i-Docs (i-docs.org) is a Digital Cultures

[5]Plug Social TV has also promoted additional Facebook pages and Instagram and Twitter profiles, which develop specific story-lines dedicated to specific groups of users.

Research Centre (http://dcrc.org.uk/) initiative based in the Pervasive Media Studio (http://i-docs.org/about-idocs/watershed.co.uk/pmstudio), in Bristol. Furthermore, the Imagis research group at Politecnico di Milano (which we are part of) is experimenting with micro-narratives in terms of forms and practices: narrative structures take advantage of social media's specific features and affordances (Facebook timelines and feeds, Instagram grids, Twitter hashtags, for example) allowing the organization of multimedia fragments according to drama and meaning making principles (Ciancia et al. 2014; Piredda et al. 2015). We are in the web and social media era, why are we still referring to TV?

The Green Move experience represents an opportunity to explore a controversial media, Web TV and narrowcasting (that is the tendency to incept small, highly personalized audience groups. Even though it is highly developed internationally (USA above all, as a result of the presence of a great infrastructure of cable transmitters), in Italy, it is still struggling to find sustainable business models despite its historic and cultural roots in the early independent Telestreet TV channels, as far back as the 1970s. Furthermore, the translation of established TV formats and genres to digital media is a mandatory step. Audio-visual clips and episodes produced for YouTube and Facebook still put forward communication artefacts that are typical of broadcast identity (Pajè and Branzaglia 2009). The use of familiar and recognizable communication formats, in fact, facilitates access by user communities. In case of the condominium life, it favours the establishment of a communication pact in which residents see themselves as center-stage players and experts as within their reach in relation to themes and issues on which discussion can continue in online platforms and face-to-face meetings.

2.1 From Community TV to Micro TV

Community TV has a specific target group represented by communities of practice sharing specific interests. The bulk of these WEB TVs have tiny audience numbers, well below 100 per day. Despite this, their value and success factors do not lie in traditional audience concepts but rather in the opportunity to enrich the media ecosystem with differentiated content provision: different themes and genres are provided, from local information to opinions and criticisms, amarcord, community and youth lifestyle (Colletti 2010). The shift from broadcasting to narrowcasting systems is a logic, which has also been adopted by online televisions whose positioning can be defined in relation to the following axes: the main generalist-themed one and the global-local one (Piredda 2010). Community TV is conceived and developed as a result of voluntary work by the members of a community which can be made up of artists, activists, fans or ordinary citizens. These are set up for a range of motives: publicising the association and its work, raising awareness of contents which would otherwise remain unknown, stimulating the creation of a sense of unity among members and helping co-ordinate and organise activities. Very often they exploit the power of the social media as distribution platforms in order to increase their scope and reach a larger number of people. They generally use formats, which opt for the tutorial and newsfeed genres to keep people up-to-date and stimulate debate. The majority of the videos are self-referential, aiming to entertain and have fun within the community itself.

Micro TVs are the direct heirs of the first independent Telestreet TVs. They are mainly focused on super localised areas and targets. Experiences set up in individual condominiums are not new and are the tip of the iceberg: see, for example, Teletorre19 (www.youtube.com/user/teletorre19), active in Bologna from 2001 to 2008 and GrattacieloTV (http://zebraproduction.it/?p=26) active in Ferrara from 2011 to 2013. Amateurs and semi-professionals with a passion for videos or wanting to communicate organise the editorial committee, draw up a more or less well defined editorial plan and ongoing programming.

2.2 Communicating Green Move

Green Move is a complex project because of the interdisciplinary skills needed and the service system put forward in terms of technologies, business, user and community models required in the design phase and effectively involved in the experimentation phase. Such a system of participants, technologies and socio-economic processes requires an integrated communication strategy capable, on one hand, of giving a shape to the system itself, configuring it in such a way as to make it comprehensible and shareable by those interested in it and, on the other hand, of facilitating the participation of potential users in trying out services thanks to its ability to make values and its reference universe concrete.

Green Move was chosen as good practice born in the context of Politecnico di Milano's research and needed an institutional tone on the strength of its established reputation and recognisability deriving from the university's history. The tone is then informal and never stuffy because the project is close to citizen-users with whom it has built up a direct and transparent relationship.

The integrated communication strategy is based on the hypothesis that facilitating and supporting active community building around a service and the values underlying it makes it more attractive to potential investors who find themselves dealing with a profiled group of users practically involved in a process of sharing the service, the products and also defined values. This community is a privileged observatory on the conditions of use of services, demonstrating daily use of them.

Enquiries relating to stakeholder analysis—developed by the Department of Management Engineering within Green Move project—were useful in defining the players to be involved in the Green Move system, their respective goals and expectations about each one of the service configurations put forward ("condominium cars", "cars and workplaces", "service world" as well as a more generic car sharing service). This enabled us to identify the Green Move's strengths to be promoted (environmental and social benefits for the community and user services) alongside cultural resistance (car ownership culture and perceptions of company cars as benefits) and psychological barriers (different perceptions of electrical vehicles in buying or car sharing).

Analysis of demand and the literature—developed by the Department of Design—enabled potential user profiles to be identified, highlighting the need to target well-defined user categories (e.g. employees or students) bringing out advantages deriving from forms of partnership (between colleagues or condominiums, for example) and forms of sharing between users (such as peer-to-peer sharing).

The communication strategy thus responded to the following general objectives: communicating research under way; communicating research results; enhancing the "polytechnic" identity of the research group (finalising of the various departmental roles); stimulating stakeholders to become potential partners and investors; informing citizens. Specific objectives were also identified. In the initial experimentation phase the communication action was intended to support users signing up to services, overcoming initial reluctance and signing up problems; expressing clearly the advantages of electric cars and car sharing instead of or in addition to car ownership; explaining how vehicles work; offering personal use experiences. In the course of experimentation, on the other hand, it was a matter of increasing the number of users signed up and getting members who had not yet used the service involved; creating an active community around the service that could increase personal involvement levels.

The communication target was split into primary (Regione Lombardia and the local government in general and other stakeholders) and secondary (potential end-users). On one hand, in fact, the institutions needed to understand the innovative character and effectiveness of the system in taking on urban and citizen mobility problems: businesses and car manufacturers and service providers needed information on the way in which their vehicle fleets would be incorporated into the system network. On the other hand, citizens needed information on the characteristics, advantages, ways of using and prices involved and other Green Move system innovations.

The integrated communication system[6] was thus split up into the following actions with specific objectives, players and communication output effectively developed:

- **Introductory video—Green Move. Open, light, electric and close-by** (Mellera 2013): presenting the project and condominium car service

[6]Research team: Marisa Galbiati, Francesca Piredda (co-ordination). Design and production: Lab. Immagine—Politecnico di Milano (Dario Sigona, head; Gabriele Carbone; Gabriele Mellera; Giancarlo Piccinno; Federico Zotti). At that time, Gabriele Mellera and Giancarlo Piccinno were students on the point of graduating (Politecnico di Milano, School of Design, Master's degree in Communication Design). In particular, the design and the production processes of the condominium TV involved: Giancarlo Piccinno as designer, author and video maker. He worked together with two young guys living in Villaggio Scarsellini: Riccardo, as video operator and Leonardo, who took part periodically in the shooting activities. Laboratorio Immagine supplied the shooting devices and technical support in relation to Green Move contents alone. Francesca Piredda acted as project supervisor, researcher and Piccinno's thesis supervisor. Liat Rogel who introduced the team to the residents played a crucial role.

experiment (target: primary and secondary). It is an animation video lasting 1’25” illustrating the main characteristics of the Green Move project. The video was designed for web distribution (mainly on the Politecnico’s YouTube channel and the Green Move website) but also for screening at public project presentations in a wide range of situations (meetings with users and stakeholders, research closing events). The essential graphic style was linked to key words and an institutional but unstuffy voice over. Stylised characters and environments and the representation of spaces in axonometric projection allowed for a very straightforward movement animation but one with very powerful identity elements, which were co-ordinated and coherent with the Green Move brand image, and the project’s institutional colours with the addition of dramatizing elements. The voicing of the logo animation and the payoff completed the ident’s opening and closing. The electrical vehicle service was made into an important graphic element to bind together the video contents by means of a common thread running through it, which introduced the key words and structured the transition between the various parts of the video. The narrative structure is in fact modular with the first three scenes or chapters relating to the project in general followed by a final part illustrating the characteristics of one of the service configurations put forward in the research, the condominium car concept. Lastly, from a productive point of view, the digital animation technique made for short creation times and involved only one person in addition to the speaker (Fig. 1).

Fig. 1 —Key frames from the Introductory video (Gabriele Mellera, 1’25” 2013). Available on the GM website (http://gm.polimi.it) and on the PoliMi YouTube Channel, (https://www.youtube.com/watch?v=bDzxJ5mW5-k&list=PL_06oobzMEusjsq-5b7AJaJi2I2iY4-Mq)

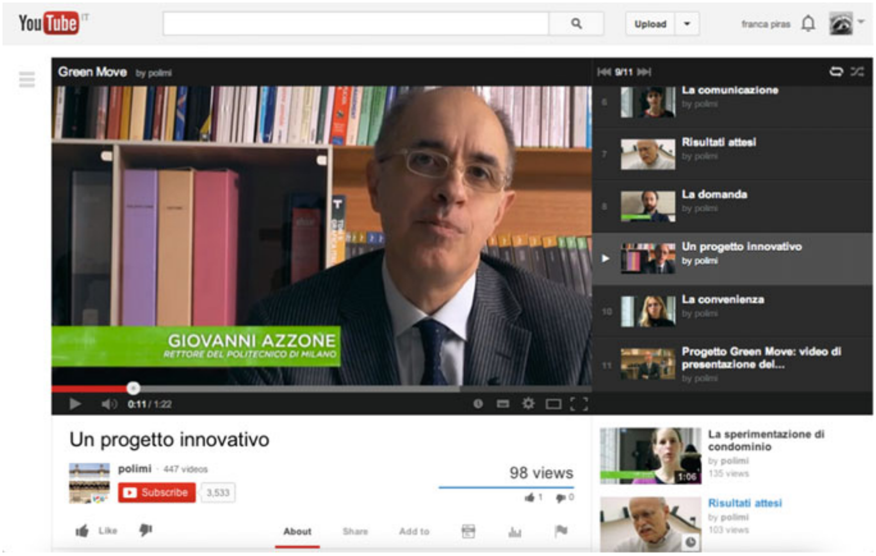

Fig. 2 The video interview (Gabriele Mellera and Laboratorio Immagine 2013) to professor Giovanni Azzone, the Rector of Politecnico di Milano, and the Green Move's playlist on the PoliMi YouTube channel (https://youtu.be/1wze5fXol0M?list=PL_06oobzMEusjsq-5b7AJaJi2I2iY4-Mq)

- **Video interviews** (Mellera 2013) of the project team leaders (target: primary). The main purpose is explaining some of the project's characteristics and putting a face to the members of the Politecnico's team: the video interviews of the various team leaders who took part in the project summed up the contributions made by each Department and the expected outcomes. The researchers put their faces to the project, contributing to enhancing its human dimension and the personal involvement of each of them in the project itself. The purpose of the video interviews was also to integrate the information given in the introductory video and supply greater details. The graphic layout was thus the same and the same common thread was used to bring out the key words and reveal the people involved in the research waiting in the wings. These videos were posted on the Politecnico's YouTube channel reinforcing the institutional nature of the contents of the video and the overall image of the project. These were made in both the intermediate project research phases and for the final presentation. These latter were designed to define the results obtained (Fig. 2).
- **Scarsellini TV. Vicini + Vicini**: condominium television (Piccinno 2014) and 4 formats designed and created together with the residents at Scarsellini (target: secondary). The communication strategy used was strongly experimental in character to the extent that it used its citizen target group and in particular the Via Scarsellini condominium group where the condominium car experiment was

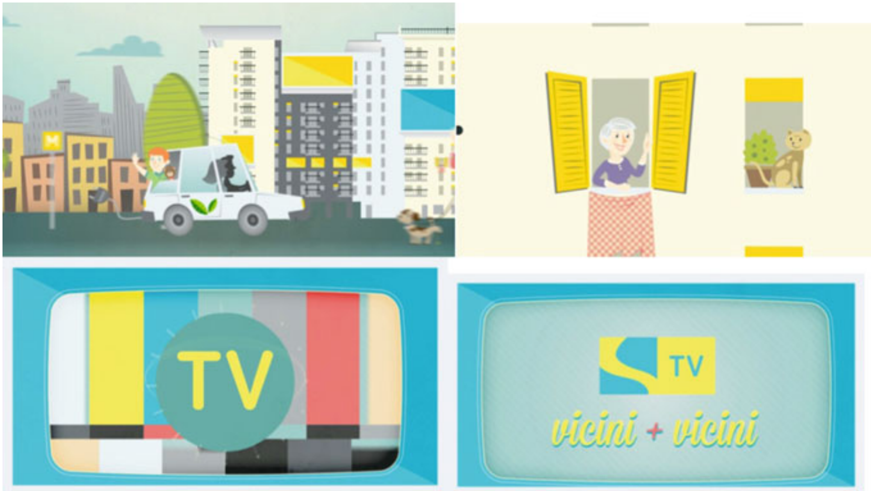

Fig. 3 Key frames from the *ident*, the animated logo of Scarsellini TV (Giancarlo Piccinno, 40” 2014)

carried out. The experiment offered an opportunity to enter into direct contact with a group of Milan citizens from whom mobility needs, habits and expectations and daily lives in general could be identified, documented and told by means of video interviews and direct accounts. From each of these enabled certain profile types were then identified (personas). For example: the retired couple using the condominium car service to take full advantage of their free time were active in condominium life and open to sharing experiences and common spaces; the young couple with small children for whom the condominium was a social fabric similar to the provincial one they were used to. The Green Move condominium car service was thus shown in action via the building of a real, active community around the Green Move brand and its values. The Via Scarsellini experiment was an opportunity to document and tell the story of the service in action and at the same time involve residents in Scarsellini TV content production (Fig. 3).

- **Green Move website graphic project (**http://gm.polimi.it**)** as research results container (target: primary and secondary, for service sign-up). The actual website comes from of a series of proposals for the layout that where designed by Giancarlo Piccinno and Laboratorio Immagine (Piccinno 2014) (Fig. 4).
- **Green Move presentation video (18’) for the final event** (target: primary). It was designed and produced by Laboratorio Immagine and it was screened on the 6^{th} of December 2013 during the event “Green Move, the present and the future of vehicle sharing” at Politecnico di Milano. Many stakeholders both from public administration and companies were present. A voice over introduces the

Fig. 4 Layout proposals for the Green Move website (Piccinno 2014)

topic of sustainable mobility and depicts the state of the art of car sharing approaches and solutions, in particular Politecnico's approach and the Green Move project. The other videos produced for GM, were edited again in order to explain and integrate the words of the speaker. For example, the introductory video, thanks to its modular narrative structure, was useful in different moments of the presentation; the video interviews show the researchers explaining the different actions and the main results. Some slides from the research report have been animated in order to show the technologies developed and how they work. In addiction, Laboratorio Immagine shooted and edited the fictional storytelling of the user journey. A guy books the service online, choosing the vehicle, goes to the parking and uses the car. The video shows the interfaces for different devices and the additional services provided by Green Move (Fig. 5).

Next paragraph provides a detailed description of Scarsellini TV: the process and the outcomes.

2.3 Scarsellini TV, Vicini + Vicini: The Condominium TV

Scarsellini TV focuses on Villaggio Cooperativo Scarsellini, one of the two key elements in the Green Move experiment and on the car sharing service. By documenting perceptions and use it also provided space for the user community itself. The residents told their stories on it and worked to produce shared interest contents for the channel stimulating the shaping of a generalised sense of belonging to the community via video contents production.

During the production phase, part of the format was dedicated to describing the relationship between condominium and the car sharing service registering use

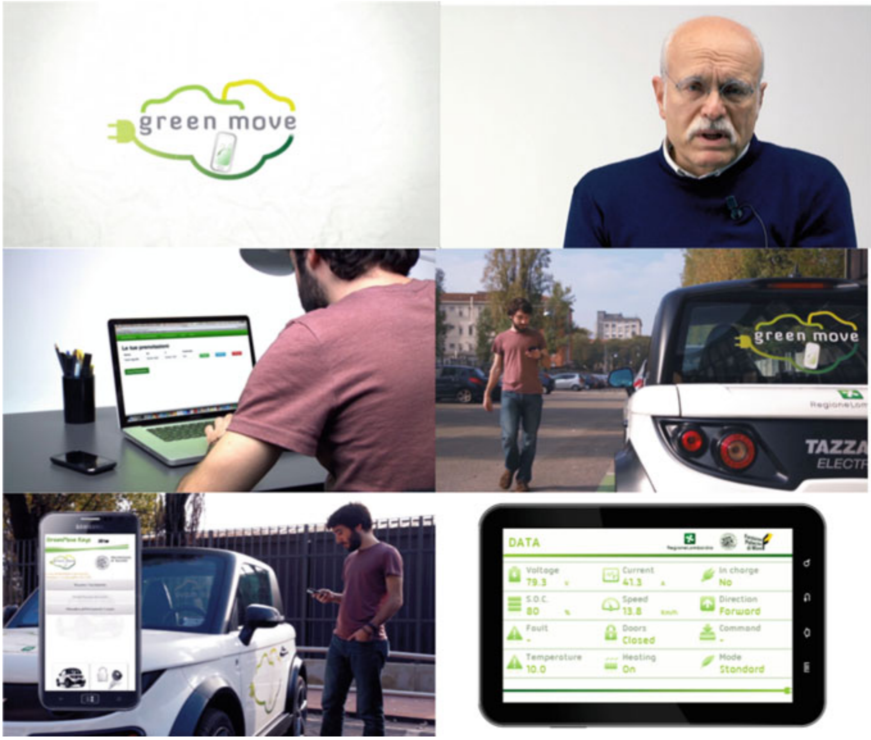

Fig. 5 Key frames from the Green Move presentation video (Laboratorio Immagine, 18’ 2013)

experiences, feedback and sensations. This allowed research contents to be made available for promotional purposes in relation to the various service stakeholders (primary targets: car manufacturers, energy suppliers and institutions such as the Regione Lombardia and Milan city council).

On 13th March 2013 the car service was officially launched in Via Scarsellini 17 condominium. The meeting documentation had the twofold purpose of gathering information on progress in the experiment and establishing via condominium TV a partnership relationship between residents and researchers, which was indispensable to the success of the experiment itself.

The Villaggio Scarsellini community was founded on a shared joint working spirit, on values of co-operation and sharing which motivated and oriented the birth of the residential project itself. HousingLab (www.housinglab.it) played a fundamentally important mediating role: it sponsored a series of preliminary meetings and activated a social network on NING platform (scarsellini.ning.com) which enabled future neighbours to introduce themselves, get to know each other and exchange opinions, in the very first phase. Later it supplied a further channel for more in-depth open discussions, event organisation and an opportunity to find out more and interact also in relation to designing and making condominium TV contents.

The use of a closed platform safeguarded residents' privacy. As far as the stakeholders and researchers themselves were concerned, in fact, it was possible to contact them and obtain feedback from them only by means of a series of meetings and presentations. Communication designers and video makers in particular had to win the trust of the residents by building up personal relationships with them via periodic on site presence. Being allowed to be part of the condominium blog meant waiting for this relationship to mature and being recognised as part of a shared project.

The promise to Villaggio Scarsellini was thus that a further form of exchange and sharing would be created, representing the community itself and respecting its values. The project was, in fact, developed in such a way as to deliver a usable tool to them, which was adaptable to future evolutions. The contents were designed with the goal of making residents free to express themselves. In all work phases, from planning to production, the objective was to maintain ongoing direct dialogue (face-to-face) or by means of the condominium's social network once the design team obtained access to it.

The Scarsellini TV tone of voice was thus informal, friendly and easy going in order to present the TV brand and Green Move in general as neighbourly, a potential reference point of trust. The visual style was designed developing the infographic already present in the other communication contents defined by the strategy (Mellera 2013) that were entrusted with the cartoon style, which was felt to be closest to the condominium's youth user segment.

The very name of the TV was decided together with residents. It was a fundamental identity element given that it represented the initial contact with the project for both primary users and the stakeholder target. The brand and logo were designed from the starting point of the building's shapes and colours and foresaw all possible versions useful to a dynamic brand identity (logo, *ident*, *captions*, etc.).

The primary objective was to get Scarsellini's young people interested, i.e. teenagers from 14 to 18 years old, who were familiar with the new digital media (computers, cameras, and social media) and had the chance to follow the project in the afternoon after school. Two boys, Leonardo and Riccardo, 14 and 16 years old respectively, showed an immediate interest. This was followed by a call to action by means of a poster on the walls of the condominium's common rooms and an announcement published on its social network.

Eight people responded, showing their interest in the initiative without, however, giving any direct involvement availability. In fact, of all Scarsellini's residents the only young people present were the two who effectively took part. The others were all children and thus too young to take an active organisational role or university students busy with study and work. The adults made themselves available for shooting and interaction with the TV cameras but did not take part in organisation and contents production. The initial idea of offering a basic course in video shooting and editing with the support of the technicians from Politecnico's Laboratorio Immagine was thus abandoned.

Once they were finished, all the videos were uploaded to YouTube Scarsellini TV (https://www.youtube.com/user/ScarselliniTV). These were shared on the Ning platform with private access so that only the community itself would have access to them. On the basis of a community decision, the YouTube videos were not indexed in order to safeguard the residents, especially children, filmed in the various episodes.

Contents were distributed every week (Tuesday or Friday). Thanks to Ning platform functions residents were able to comment, share or "like" contents thus supplying immediate feedback.

A Scarsellini TV Twitter profile was also activated which kept the community informed of new contents.

A range of contents were thus designed and made on the basis of 4 different formats each of which had a reference genre with its own identity (logo, colour palette, claim and other animated elements):

Fig. 6 Key frames from the format Scarsellini LIFE

Fig. 7 Key frame from the format Scarsellini SPEAK

- **Scarsellini LIFE**: a chronicle of resident activities mainly in the condominium's common rooms (courses, initiatives, events). Eight episodes lasting 2'. These were filmed from May to September 2013. The format—using a photo album style—obtained the greatest number of visualisations (Fig. 6).
- **Scarsellini SPEAK**: the Vox populi by which residents could express opinions on a range of themes. Seven episodes lasting 2'. Claim: "make your voice heard". Recordings began with video cameras turned out remotely by residents wanting to sit down on the sofas and say what they had to say. The themes were also linked to hashtags in order to encourage people to continue discussions on social media. Posters with technical instructions and advices were provided near the camera (Figs. 7 and 8).
- **Scarsellini NEWS**: the news sheet informing residents of appointments organised at the condominium. These were monthly and helped residents to keep track of the initiatives to take part in. *Scarsellini's agenda*, published and updated constantly on the condominium's social network, was a much-used tool. Two episodes were made (for June and July 2013) lasting 3 min each.

Fig. 8 Posters providing technical information and advices

Riccardo conducted the programme with the support of animated graphics, announced planned events and reminded residents of initiatives under way showing images or documents.

- **Scarsellini GREEN MOVE**: the video documentation on the Green Move service condominium experiment. This developed 5 types of video with the aim of documenting the main service access and use phases in the experiment stage.

Scarsellini GREEN MOVE
8 clips were made: "Green Move, first service sign ups". Documentation for the 12th March 2013 event organised to present the Green Move project to the residents (duration: 1" 41"; filmed by: Gabriele Mellera and Giancarlo Piccinno). SEMS, vehicle supplier partner, also took part. The first resident to sign up, Mr. Enzo Prandi, was given the keys to the garage. "Green Move, condominium car" (3'23", filmed by: Federico Zotti, Gabriele Giussani, Giancarlo Piccinno). Video tutorial explaining service access methods (animation and use scenarios). There are 4 scenes: registration, booking, collection and delivery. "Green Move, car sharing in the city" (2 versions: 3'57" and 1'35". Filmed by: Federico Zotti, Giancarlo Piccinno): Mr. Enzo Prandi goes on a trip to the Triennale di Milano, tells of the benefits of driving an electric car with automatic gear shift, etc.; how privileged he felt to be allowed into Area C, etc. The second, abridged version of this film was used to communicate the project on the occasion of official presentations. "Green Move, tips&tricks" (1'36". Filmed by: Federico Zotti, Giancarlo Piccinno):

a collection of information titbits describing tricks discovered by users to best use the Green Move vehicles. Enzo Prandi tells of a trick designed to limit kilometer consumption when driving (energy saving). "Green Move, concluding interviews (4 episodes, 2'. Filmed by: Gabriele Carbone, Giancarlo Piccinno): interviews of service users recorded at the end of the experiment: they were asked when did they use it and opinions on functioning and willingness to use in future outside the experiment. In general the service was considered convenient, cheap and reliable although each user made different use of it: occasional or frequent as in the case of those without a family car.

2.4 Results: Numbers and Comments

The aim of creating a residents' council to whom ascribe the responsibility for the project and the production of television contents, in technical terms too, was hindered in particular by the lack of suitable profiles for such a process. The only person who took an active part in it as film operator, in addition to play the role of interviewee or participant in documented activities, was a 14-year-old boy who loved videos and, more occasionally, his friend. It was thus difficult to build a management group with the potential for real autonomy.

The main source of data for the first evaluation of the experience was Scarsellini TV's YouTube channel with views and comments on the video.

Furthermore, on the occasion of the experiment completion event, residents were asked to fill in a questionnaire enabling us to assess the Scarsellini TV experience.

The questionnaire was circulated by means of Google Docs and made up of 10 questions (9 multiple choice and 1 open) with the aim of understanding the level of penetration of Scarsellini TV, opinions on contents and layout, the feelings generated by the presence of video cameras, users' attitudes to using the online video contents and the channel's potential future. 19 residents filled in the questionnaire of whom all except one had seen the videos despite the fact that only four of them habitually follow other WebTV or YouTube channels. In general, all of them expressed positive opinions on the contribution of Scarsellini TV to telling the story of the condominium's life and would have liked the experiment to continue and become a collective project (7 interviewees out of 18) or have it handed over to competent people (11 out of 18) using the methods currently linked to the Green Move experiment. Only one resident expressed no interest and had not even watched the videos although he had known of it via the condominium blog. Evidently the presence of external individuals to co-ordinate the operation was seen as indispensable to the channel's success and the will to develop the experience into their own project was lacking.

In order to support the post-production phase, that would be the most difficult to take over for those with little time to devote to it and without the technical skills to reduce time frames, Giancarlo Piccinno's M.A. thesis supplied all the material created in the project and reorganised it to make it more adaptable and intuitive to use. An extensive database of files, information, videos and semi-finished artefacts, illustrations and transitions was created on a blank format on which new clips were to be inserted. A paper manual "Scarsellini TV—Guide to the Material" and a DVD "Scarsellini TV—Materials" was handed over directly to residents and placed in the common room. Furthermore, links to the digital versions were uploaded to the Scarsellini social network.

3 Conclusions

On the occasion of the Green Move service experiments at the Scarsellini condominium in Milan a full-blown Web TV was created together with residents. The contents served to encourage a desire to share which already existed in the community and responded to the goal of demonstrating to service stakeholders how a representative sample of the potential users interacted and used the service itself supplying an additional, qualitative type assessment tool.

In relation to the experiment, in particular, communication on condominium TV contributed to the social innovation process bringing the resident community into the storytelling process and also in later comparison with the representation itself. Whilst mediated by the designer/video maker role, this process represented an innovative way of sharing common values and visions.

In any event, communication's fundamental contribution was to launch the community building process (the Green Move community) by means of an identity building (branding) project which defines shared values and puts a meaning universe centre-stage. In this way, while profoundly bound to its local area, this community could potentially exploit a range of communication channels to enter into contact with stakeholders on the local level and also share good practices with other reference groups on an international level becoming a network nodal point in mobility and sustainable daily lives. Starting from and by means of community, people can promote and develop sustainable service systems and qualifying platforms with powerful economic as well as environmental and social value.

From a theoretical perspective, the Scarsellini TV participatory project provided a contribution to growth in both the methodology and content of the practice-based research approach, in particular the area of research through, by or for creative practice, art and design (Nimkulrat and O'Riley 2009). Scarsellini TV played an instrumental role in the conduct and dissemination of Green Move research, willing to convey how we worked, using the creative processes as a foundation for enquiry (Koskinen 2009).

Focusing on the area of media studies, the "Vicini più Vicini" condominium TV project fits into the debates on new television. From the point of view of practice it promotes joint audio-visual experimentation projects with powerful social impact. Our intention was to understand whether the television models developed over the course of the last decade can be an effective resource to support participatory design system projects. The confidentiality limitations required by the community did not, however, allow the potential of networking characteristic of social media such as Facebook to be exploited in which "Users can be business pages, songs, or newspaper articles. Being social simply means creating connections within the boundaries of the system. Every click, share, like, and post creates a connection, initiates a relation. The network dynamically grows evolves, becomes. The network networks. The social in social media is not a fact but a doing. The social is constantly performed and enacted by humans and non-humans alike" (Bucher 2015). The branding strategy founded on the idea of partner ecosystems (Santambrogio 2016) could not put residents/users, institutions and service providers on a par as the project hoped. Then, on one hand it did not extended it to a virtuous circle of listening and provision capable of bringing all stakeholders in a direct and self-aware way and regenerating relationships between them. Nevertheless, on the other hand, we got some strongly positive result: the participatory video process provided vertical feedbacks between the community and the Green Move researchers, who have the role to build and manage a dialogue among the stakeholders. Moreover, the participatory communication process triggered valuable horizontal feedback within the community (Collizzolli 2010; White 2003) making most of the members aware of the values of such a sustainable mobility service and committed in taking advantage of it in everyday life, by the means of Green Move. We can say that Scarsellini TV showed and actually contributed to change the condominium community behaviour, respecting its desire of intimacy and familiarity.

References

Anzoise V, Piredda F, Venditti S (2015) “Design narratives and social narratives for community empowerment”. In a matter of design. Making society through science and technology, 5th STS Italia Conference—Politecnico di Milano, Milan

Bonsignore P, Sassoon J (2014) Branded content. La nuova frontiera della comunicazione d’impresa. Milano, FrancoAngeli

Bucher T (2015) “Networking, or what the social means on social media.” In Social Media + Society, April-June 2015: pp 1–2, Sage

Ciancia M (2016) Transmedia design framework. Un approccio design-oriented alla transmedia practice. FrancoAngeli, Milano

Ciancia M, Piredda F, Venditti S (2014) “Shaping and sharing imagination: designers and the transformative power of stories.”. In: Moura Hudson, Sternberg Ricardo, Cunha Regina, Queiroz Cecília, Zeilinger Martin (eds) Proceedings of the interactive narratives, new media & social engagement international conference. Canada, Toronto

Colletti G (2010) TV fai-da-Web. Milano, Gruppo 24 Ore

Collizzolli S (2010) Il Video partecipativo dalla comunicazione sociale alla socializzazione della comunicazione. PhD thesis, dipartimento di sociologia. Padova, Università degli Studi di Padova

Deleuze G (1984) L’immagine-movimento. Cinema 1, tr. Jean-Paul Manganaro, Milano

Fabris G (2010) Il nuovo consumatore: verso il postmoderno. FrancoAngeli, Milano

Galbiati M (1989) Proiezioni urbane. La realtà dell’immaginario. Milano, Tranchida Editori

Galbiati M (2005) Movie design. Scenari progettuali per il design della comunicazione audiovisiva e multimediale. Edizioni POLI.design, Milano

Gadotti G, Bernocchi R (2010) La pubblicità sociale. Maneggiare con cura. Carocci, Roma

Galbiati M, Piredda F (eds) (2010) Design per la Web TV. Teorie e tecniche per la televisione digitale. FrancoAngeli, Milano

Galbiati M, Piredda F (2012) Visioni urbane, Narrazioni per il design della città sostenibile. FrancoAngeli, Milano

Galbiati M, Piredda F, Mattana W, Bertolotti E (2010) “Envisioning the City: A Design-Oriented Communication Process for a Sustainable Urban Transformation”. ESA research network sociology of culture midterm conference: Culture and the making of worlds, October 2010. Available at SSRN. http://ssrn.com/abstract=1692118

Koskinen I (2009) “Throwing the Baby Out or Taking Practice Seriously”, In: Nimkulrat N, O’Riley T (ed) Reflections and connections: On the relationship between creative production and academic research. Helsinki, University of Art and Design

Manovich L (2002) Il linguaggio dei nuovi media. Olivares, Milano

Matrone M, Pinardi D (2013) Narrare: narrativa d’impresa. Per essere e essere visti. FrancoAngeli, Milano

Mellera G (2013) Valorizzare il progetto e la ricerca attraverso il gruppo. Il caso Green Move, Master Thesis in Communication Design. Francesca Piredda, School of Design Politecnico di Milano

Nimkulrat N, O’Riley T (2009) Reflections and connections: on the relationship between creative production and academic research. University of Art and Design, Helsinki

Pajè M, Branzaglia C (2009) Video sign: i’immagine coordinata delle televisioni nel mondo. RTI-Reti Televisive It, Milano

Piccinno G (2014) Micro televisioni per micro comunità urbane. Il progetto Green Move e il caso Scarsellini TV, Master Thesis in Communication Design. Francesca Piredda, School of Design Politecnico di Milano

Piredda F (2008) Design della comunicazione audiovisiva. Un approccio strategico per la televisione debole. FrancoAngeli, Milano

Piredda F, Ciancia M, Bertolotti E (2013) Animation as Boundary Object. Promoting Cultural Changes through Audiovisual Design, In: N Ceccarelli (ed) 2CO Communicating Complexity—2013 Conference proceedings—Alghero/Italy/25th-26th October 2013. Edizioni Nuova Cultura, pp 234–243

Piredda F, Ciancia M, Venditti S (2015) "Social Media Fiction. Designing Stories for Community Engagement". In: Schoenau-Fog H, Bruni LE, Louchart S, Baceviciute S (ed) 8th International Conference on Interactive Digital Storytelling, ICIDS 2015 Copenaghen. Denmark, Springer

Puggelli F, Sobrero R (2010) La comunicazione sociale. Carocci, Roma

Santambrogio A (2016) Roivolution. Gestire la multicanalità e incrementare il business con l'ecosistema di comunicazione. Milano, FrancoAngeli

Sclavi M (2003) Arte di Ascoltare e Mondi Possibili. Come si esce dalle cornici di cui siamo parte. Bruno Mondadori, Milano

Testa AM (2000) Farsi capire. Rizzoli, Milano

Volli U (1994) Il libro della comunicazione. Il Saggiatore, Milano

White SA (2003) Participatory Video, images that transform and empower. London, Sage

Part II
The Technology

Architecture of the Green Move System

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Abstract In this chapter, we describe the architecture of the prototype of the Green Move system. The system includes three main components: the Green Move Center, which is the server side of the application; the mobile application that is installed on the smartphone of each user of the system; and the Green e-Box, which is a device installed on each Green Move vehicle that allows the system (including the user) to interact with the vehicle. In this chapter, we describe the key functions of each component and the main interactions that occur with one another. In particular, we focus on three aspects of the architecture: (i) the mechanisms through which the Green e-Box provides a uniform interface to interact with possibly very heterogeneous vehicles; (ii) the keyless approach through which users access vehicles; and (iii) the flexible real-time monitoring of the fleet achieved through Complex Event Processing technology.

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1 Introduction

As described in Chap. 3, new models of sustainable mobility would greatly benefit from the integration and sharing of vehicles that differ in type (cars, scooters, bicycles), technology (electric, hybrid or with classical combustion engines), and ownership (they can be publicly or privately owned, fully or partially shared) within the same system. Such systems should provide common functions, services, and interfaces both to end users and to system administrators, independently of the types of vehicles managed. In addition, the vehicle sharing service offered to users and built upon a heterogeneous fleet of vehicles should be easily accessible, and it should address the multiform needs of a wide range of customers (e.g., people reaching their workplace, company employees, families with children). Hence, the service should be highly configurable, to allow for the possibility of closely matching the user preferences with the services offered during the drive. This calls for innovative solutions in the design of a hardware/software architecture that manages the embedded control units that are onboard the vehicles and connects them to a back-end system that provides the mobility services to the final users, preferably through personal mobile devices, such as smartphones, tablets. In this chapter, we present the technological solutions adopted in the Green Move project to address the above issues.

The prototype platform developed in the project for the realization of electric vehicle sharing systems addresses the issues above in the following ways:

- It provides a hardware/software interface, the Green e-Box, which allows the system to interact with a heterogeneous fleet of vehicles in a uniform way, independently of the specificity of each vehicle.
- It relies on mobile devices to let users access and interact with the system—take possession/release a reserved vehicle, open/close its doors, enable/disable the drive.
- It uses standard protocols to allow external partner services to access information and operations (e.g., the reservation of vehicles) offered by the coordination center.

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- It offers an infrastructure to customize the software configuration of vehicles by pushing new services on them and by removing existing ones, for example, depending on the user preferences.

In this chapter, we first give an overview of the overall architecture of the Green Move system prototype in Sect. 2. Then, in Sect. 3, we provide some details of the Green e-Box, the device interfacing the vehicles with the rest of the system, and we describe how this facilitates the interactions between vehicles and users on one side (Sect. 4), and between vehicles and management system on the other (Sect. 5). To highlight the benefits of the approach followed in the Green Move prototype system, in Sect. 6, we introduce some related services and platforms; finally, Sect. 7 concludes. Chapter 9 presents the mechanisms developed to obtain a high level of dynamism and customization in the software configuration of the vehicles.

2 Overall Architecture

The main elements of the Green Move platform are shown in Fig. 1. They are the *Green Move Center*, which coordinates the system, the *Green e-Boxes*, which allow vehicles to communicate and interact with the rest of the system, and the users' smartphones, on which the *Green Move client app* is installed.

The Green Move Center (GMC) coordinates the activities of the Green Move system and offers services such as user and vehicle registration, vehicle reservation/acquisition/release/monitoring. To retrieve and distribute information among the managed vehicles, the GMC includes the T-Rex Complex Event Processing (CEP) engine (Cugola and Margara 2012a; Cugola and Margara 2012b), a system explicitly conceived to efficiently collect, process, and analyze events.

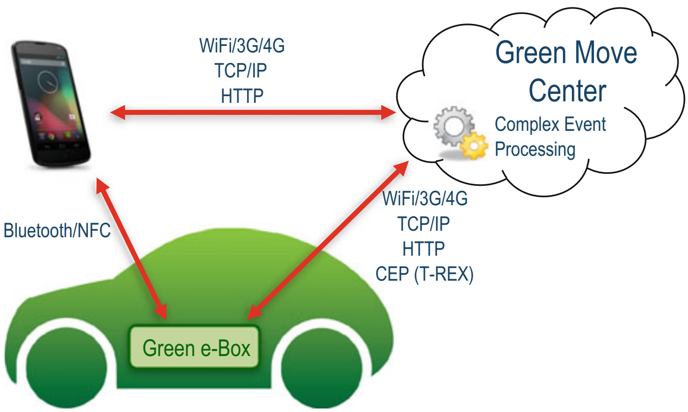

Fig. 1 Overview of the architecture of the prototype of the *Green Move* system

The Green Move platform uses CEP technology to both monitor the vehicles and send them configuration commands. The adoption of T-Rex provides several benefits: *efficiency*, as T-Rex is designed to perform the processing of events and to generate results with a low delay (typically, in the sub-millisecond range); *scalability*, since T-Rex is capable of providing low processing delay and hardware resource consumption even in the presence of a large number of sources, rules, and sinks; *modularity*, as T-Rex incorporates the management of events into a single software component, whose behavior is defined in a simple way through the set of deployed rules defining composite events.

Each Green Move vehicle is equipped with a device, the Green e-Box (GEB), through which it interacts with the overall system. From a technical point of view, the only requirement for a vehicle to be introduced in the Green Move system is to have a GEB; this ensures that the interaction between vehicle and system occurs according to standardized protocols. This allows for the possibility of adding to the system vehicles that are heterogeneous not only in their types, but also in their ownership (Alli et al. 2012). The GMC communicates with GEBs through mobile broadband channels to manage the fleet. The same channel is used by GEBs to send to the GMC vehicle data—which are distributed at regular intervals as T-Rex events—such as diagnostic information, usage statistics, and trip data (e.g., current GPS position, speed, state of charge). GEBs run the Android operating system, which executes the Green Move vehicle app. This app is the software interface between the vehicle and the rest of the system; in addition to executing core functions such as data retrieval and actuation of commands such as open/close doors, it provides hosting facilities for dynamic applications.

The interaction of Green Move users with the system occurs through their smartphones, on which the Green Move client app must be installed. The app communicates with the GMC through a WiFi or mobile broadband channel to reserve vehicles and to retrieve the electronic key that is necessary to access the vehicle. This key, whose contents are outlined in Sect. 4, is exchanged between the Green Move client app and the GEB through a Bluetooth or NFC channel; it is used to send commands from the user's smartphone to the vehicle, such as open/close the doors (if present), and enable/disable the drive. By using a direct (Bluetooth or NFC) link between the user's smartphone and the GEB, this communication can occur at any time, even when there is no data connection available between the GEB and the GMC (e.g., in an underground parking lot). The same connection can be used by the GEB to send data to the users' smartphones, such as customized advice of various kinds (e.g., commercial).

Every component of the Green Move system performs, to varying degrees, data management functions, which are pervasive throughout the platform. The description of these functions is the focus of Chap. 10.

Fig. 2 Vehicles integrated into the prototype *Green Move* system, from left to right: Tazzari Zero Evo, Estrima Birò, Piaggio Liberty e-Mail

3 The Green E-Box

To be integrated into the Green Move system, a vehicle only needs to be equipped with a GEB, which allows it to communicate with other system elements (GMC, users' smartphones) in a manner that is independent of the specific type of vehicle. In fact, for demonstration purposes, the prototype of Green Move system has been realized for a small, but heterogeneous fleet of three vehicles with different characteristics. More precisely, the vehicles integrated into the prototype, shown in Fig. 2, are the following:

- *Tazzari Zero Evo*,[1] a two-seat electric car with a driving range of 140 km and a maximum speed of 100 km/h. The lithium-ion battery pack requires about 9 h for a full charge (0–100%). This vehicle is suitable for urban mobility and/or short-range interurban trips.
- *Estrima Birò*,[2] a two-seat electric vehicle with a maximum speed of 45 km/h and a range of about 50 km. The Pb-Gel battery pack takes about 9 h to be fully charged. Its extremely compact size makes it suitable for urban (or low-speed suburban) streets.
- *Piaggio Liberty e-Mail*,[3] an electric scooter with a top speed of 45 km/h and a range of 70 km. The lithium battery pack requires about 4 h for a full charge. The scooter is suitable for city driving, but, unlike the other two vehicles, it is not for all weather conditions.

[1] www.tazzari-zero.com.

[2] www.estrima.com.

[3] www.piaggio.com.

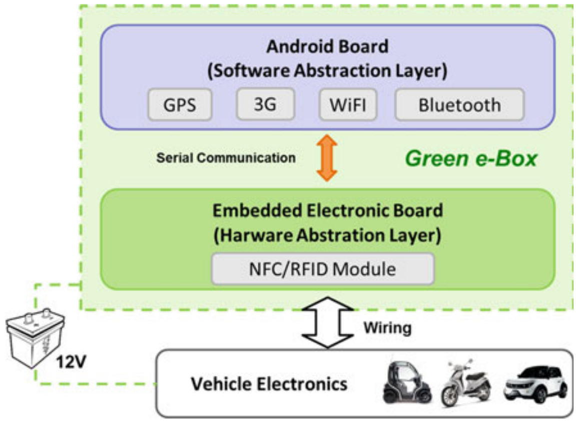

Fig. 3 Green e-Box architecture

The GEB is composed of a low-level embedded board and a high-level Android board (see Fig. 3). In order to have a constant monitoring of each vehicle, even when turned off and not in use, the GEB is directly connected to the permanent 12 V line of the vehicle. The GEB is also wired to the vehicle electronics, and it communicates with the GMC via a mobile broadband channel and with the users' smartphone via Bluetooth or NFC (Near Field Communication) links.

Figure 3 details the architecture of the GEB device, which was designed following the classic software engineering principles of modularity (separate components are responsible for different functions, e.g., retrieving data from the vehicle) and extensibility (e.g., new functions can be easily added that can exploit the data collected from the vehicle).

The embedded board acts as a hardware abstraction layer (HAL), and it is designed to abstract the vehicle-specific details; thus, it creates a virtual layer between software applications and the actual hardware, providing a general communication protocol to the high-level layers built on top of it. To achieve this, the embedded board has a CAN-bus to retrieve data directly from the vehicle ECU (engine control unit) and several analogic and digital input/output channels so that the GEB can be installed on a large variety of heterogeneous vehicles, even those without an ECU (e.g., Tazzari and Birò). A microcontroller handles each signal, acquiring the vehicle data at a constant rate and, since the set of available signals is strongly vehicle-dependent, it collects them into well-defined packets so that they can be easily transmitted to the high-level Android board. The vehicle signals are clustered into six categories: *battery*, *doors*, *speed*, *faults*, *commands*, and *others*. Each signal available on the vehicle must belong to one of the previous categories. For instance, the provided current, the state of charge of the battery, and the battery's state (charging or not) belong to the *battery* group. Figure 4 shows an example of the signals available on the Tazzari vehicle and how they are grouped by the embedded board. The signals of Birò and Liberty are not reported here for the sake of conciseness.

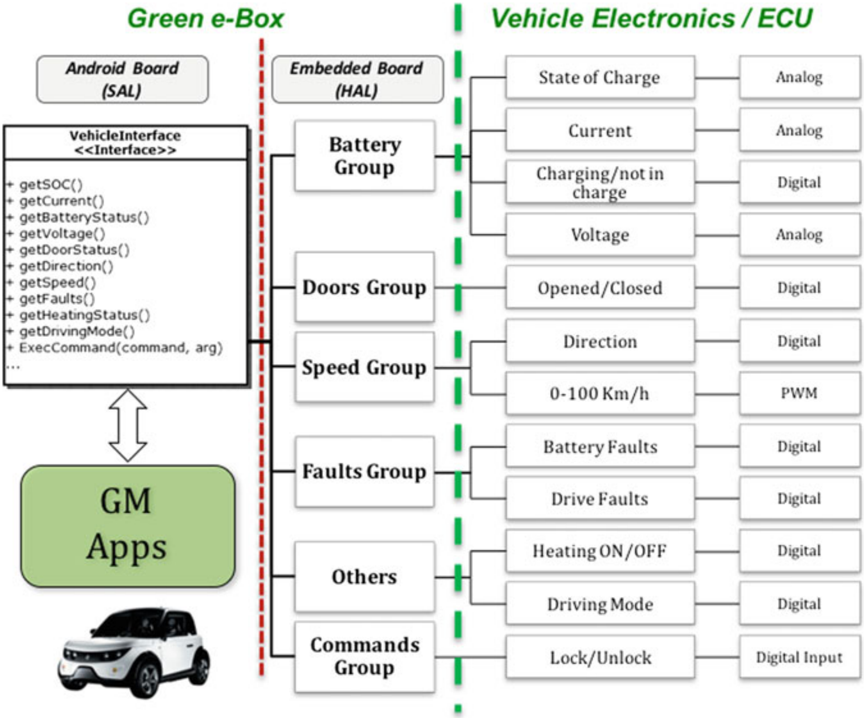

Fig. 4 Green e-Box abstraction layers and measured signals for the Tazzari Zero Evo

The Android board provides the software abstraction layer (SAL) which receives (in a vehicle-independent way) the data from the low-level board; the SAL uses a singleton object to store, for each monitored quantity, the last value received; this object also offers, for each quantity, a getter method that allows other Green Move applications residing on the GEB (see Chap. 9), to easily access the vehicle information. The GEB decouples the high-level fleet management functions from those, implemented in the vehicle ECU, related to the control of the vehicle motion; this isolates the latter from the former, thus establishing their separation and non-interference with one another, which guarantees the necessary safety requirements.

The functions realized by the GEB can be divided into two categories: core operations of the Green Move system (e.g., user authentication, vehicle monitoring), and optional functions that, though not essential, provide added value to GM users (e.g., commercial and traffic information). Whereas core operations are known from the design phase of the Green Move system and change infrequently, optional functions could be added or removed after the system deployment (e.g., because of new commercial agreements between the company running the vehicle sharing system and its partners).

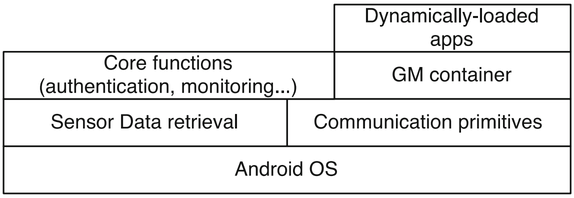

Fig. 5 Layered structure of the functions of the Green e-Box

The software realizing the functions of the GEB is modular, where each module oversees a cohesive set of GEB functions (e.g., vehicle data retrieval, communication with the GMC). Figure 5 shows the layered structure of the GEB software built on top of the Android OS. At the base lay the modules providing the mechanisms for the retrieval of data from the vehicle sensors and for the communication with the GMC. These modules are used to realize the core functions of the GEB, such as, for example, vehicle monitoring, and they are made available to third-party applications through a component called GMContainer.

The GMContainer is a part of the middleware infrastructure that allows system administrators to load and remove applications from GEBs after deployment, thus providing capabilities for the dynamic reconfiguration of the services offered to users at run-time. Chapter 9 explains these features of the Green Move system in more detail.

The GEB is central in the Green Move system, as it takes part in the most significant interactions that occur in it. In the next sections, we describe some of these, which occur between GEB and users' smartphones and between GEB and GMC, and which serve to illustrate some relevant functions performed by the other main components of the Green Move system. Other functions and interactions are described in Chap. 9 and in Chap. 10.

4 Vehicle–User Interaction

In the Green Move system, the user directly interacts with the vehicle—through the Green Move app installed on her mobile device—to get access to the vehicle.

More precisely, every time a new reservation is made by the user, a "virtual key" is generated by the GMC, containing the necessary information to securely access the vehicle at the right time, such as the user, the vehicle, and the date and time of the reservation. The virtual key also contains a cryptographic key, which is used to guarantee the security of the communication when the virtual key is used to access the vehicle. Each virtual key contains its own symmetric cryptographic key, which is freshly generated when the reservation is finalized.

The interaction among GEB, GMC, and the Green Move app installed on the user's mobile device occurs according to the following steps:

- the user, after having created a new reservation, retrieves the corresponding virtual key from the GMC;
- the user asks to get access to the vehicle by sending to the GEB the virtual key received from the GMC;
- the GEB checks with the GMC the validity of the received virtual key;
- if the virtual key is valid, the GEB grants to the user the permission to access the vehicle.

As shown in Fig. 1, the communication between the user's mobile device and the vehicle's GEB can occur through a Bluetooth or NFC channel, although the current prototype focuses on the Bluetooth case. Hence, it does not require an active Internet connection. The security of the connection is guaranteed through the symmetric cryptographic key that is included in the virtual key that both GEB and user's mobile device receive from the GMC. Communications between user's mobile device and GMC and between GMC and GEB occur through the Internet; their security is guaranteed through asymmetric cryptographic keys that are exchanged when the vehicle is added to the fleet, and when the user installs the app on her mobile device, respectively.

For accessing vehicles, the Green Move app offers the user the following functions:

- *retrieval of the virtual key associated with a reservation*, which allows the user to subsequently get access to the reserved vehicle;
- *taking charge of the vehicle*, through which the user gets permission to access the vehicle, which is now under her responsibility;
- *unlock the vehicle*, which allows the user to actually access the vehicle;
- *lock the vehicle, without yet releasing it*; this function prevents others from using the vehicle while the current user is not actively driving it;
- *releasing the vehicle*, which ends the reservation, making the vehicle available to other users.

The locking and unlocking of the vehicle in practice can be carried out in different ways, depending on the features of the vehicle. For example, for the Tazzari Zero car, this is achieved by locking and unlocking the doors of the vehicle; for the Piaggio Liberty scooter, instead, this corresponds to activating and deactivating the ignition. Locking/unlocking the vehicle—and activating/deactivating the ignition—is carried out by exchanging the virtual key that is loaded on both the GEB and the user's mobile device when the user takes charge of the vehicle. This entails that no Internet connection is necessary for either GEB or user's mobile device when this operation is carried out, thus making it available everywhere, including, for example, underground parking garages. Retrieval of the virtual key (by the user's mobile app, or by the vehicle's GEB), instead, requires communication with the GMC, hence Internet connection.

Figures 6 and 7 show the graphical user interface—in the case the reserved vehicle is the Tazzari Zero—and the process through which the user retrieves the virtual key from the GMC and then uses it on the vehicle. When the user requests

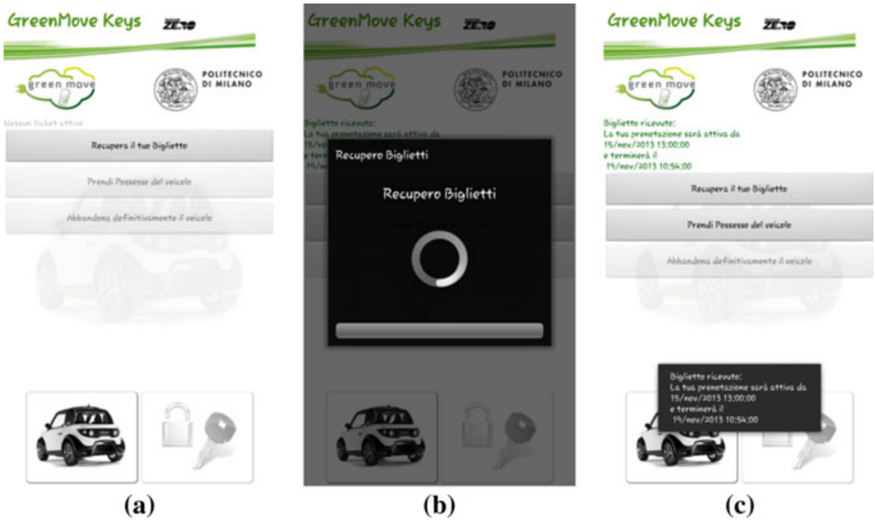

Fig. 6 Retrieval of the virtual key through the user's mobile device: **a** users ask to retrieve the virtual key ("recupera il tuo biglietto" = "retrieve your ticket"); **b** the Green Move app on the mobile device contacts the GMC to retrieve the requested information ("recupero biglietti" = "ticket retrieval"); **c** the virtual key is successfully retrieved ("biglietto ricevuto" = "ticket received")

the virtual key through the mobile app (Fig. 6a), the latter contacts the GMC (Fig. 8.6b), which in turn sends back the key (Fig. 6c). This step can occur well before the user actually needs to access the vehicle. After the virtual key is successfully retrieved, the Green Move app allows the user to take charge of the vehicle (the corresponding button is active in Fig. 6c). At this point, the user approaches the vehicle to get into Bluetooth range and then takes charge of it by pressing the corresponding button on the app (Fig. 7a). As a result, the button on the bottom right corner of the interface, which is used for locking/unlocking the vehicle, becomes active, so the user can press it (Fig. 7b) to actually access the vehicle. Finally, the user releases the vehicle through the corresponding button (Fig. 7c).

5 Vehicle Monitoring

One of the key functions performed by the GEB is the gathering of data concerning the current status of the vehicle (e.g., battery charge, position, speed). Collected data are sent to the GMC to perform a continuous and real-time monitoring of the fleet. To achieve a high level of flexibility in the design of the monitoring mechanisms, the Green Move system relies on the T-Rex CEP engine. Figure 8.8 gives a high-level view of T-Rex.

Fig. 7 Use of the virtual key to: **a** take charge of the vehicle ("prendi possesso del veicolo" = "take hold of the vehicle"); **b** lock/unlock the vehicle (through the key icon); **c** release the vehicle ("abbandona definitivamente il veicolo" = "release the vehicle for good")

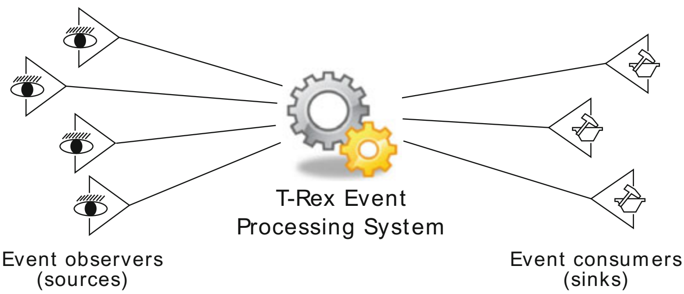

Fig. 8 Overview of the T-Rex system

In CEP infrastructures (Cugola and Margara 2012c), we distinguish between event generators (sources) and event consumers (sinks). The former observe primitive events and report about them, while the latter receive event notifications and react to them. Using the nomenclature typical of publish–subscribe systems, we say that sources *publish* event notifications (or simply events) and sinks *subscribe* to events. The CEP engine sits in the middle with the task of detecting so-called composite events from primitive ones through a set of rules—expressed in an ad hoc language called TESLA (Cugola and Margara 2010)—that are conceived and deployed by rule managers. An example of composite event is "if the vehicle is moving and there is no ongoing rental, then the vehicle is being stolen." The T-Rex engine is loaded with a set of TESLA rules (which can be dynamically added and removed at run-time), which are used to process events and to determine when new —complex—events occur and must be notified to subscribers.

In this framework, the GEB of each vehicle acts both as a source of primitive events, which are processed by the GMC to build an accurate figure of the status of the fleet, and as a sink of complex ones, as explained in Chap. 9.

More precisely, the following is a list of the most relevant primitive events generated by each vehicle's GEB:

- *VehicleData*, a periodic event, which is generated every 60 s, containing the information retrieved by the GEB about the status of the vehicle, such as battery charge, speed, status of the doors (if they are present); these are essentially the data depicted in Fig. 4.
- *Position*, a periodic event, generated every 2 s, containing the current geo-coordinates of the vehicle.
- *Taken*, which is generated every time the vehicle is taken by a user, that is, when the operation depicted in Fig. 7a is completed successfully.
- *Released*, which is the dual of *Taken* and is generated when the user releases the vehicle (corresponding to completion of the operation of Fig. 7c).

The GEBs of the vehicles are not the only sources of primitive events in the Green Move system. The GMC, which stores the information about vehicles' reservations, can also generate them. For example, it generates an event *ReservExpired* whenever the time interval in which a vehicle was reserved by a user terminates.

From the primitive events listed above, the T-Rex CEP engine integrated into the GMC generates complex events according to a set of TESLA rules. In the rest of this section, we illustrate the most significant ones.

Complex event *Theft* is generated whenever the system detects a situation that could correspond to an ongoing theft of a vehicle. The event is defined by the following TESLA rule:

```
define Theft(GreenBox_id: String)
from VehicleData(GreenBox_id = $a and speed > 0.0) and
last Released(GreenBox_id = $a) within 30 days
from VehicleData and
not Taken(GreenBox_id = $a) between VehicleData and Released
where Theft.GreenBox_id = VehicleData.GreenBox_id
```

The rule states that the *Theft* event is generated for a vehicle if: (i) the current status of the vehicle shows that it is moving (`VehicleData.speed > 0.0`) and (ii) since the last release of the vehicle (`last Released within 30 days from VehicleData`) (iii) that same vehicle (`VehicleData.GreenBox_id = $a` and also `Released.GreenBox_id = $a` and `Taken.GreenBox_id = $a`) was not taken again (`not Taken between VehicleData and Released`). The rule also defines that the complex event *Theft* has an attribute corresponding to the id of the GEB (and, by extension, of the vehicle) that triggered the rule (`Theft.GreenBox_id = VehicleData.GreenBox_id`).

The occurrence of a theft is detected also when the vehicle is moving, but it was never released; since the absence of a release would prevent the triggering of the previous rule, which requires the presence of a *Release* event, the next rule, providing a second, complementary definition of event *Theft*, is introduced in the system.

```
define Theft(GreenBox_id: String)
from VehicleData(GreenBox_id = $a and speed > 0.0) and
not Taken(GreenBox_id = $a) within 30 days from VehicleData
where Theft.GreenBox_id = VehicleData.GreenBox_id
```

The next TESLA rule defines a complex event *OpenDoors*, which is generated every time a vehicle is detected to be moving while its doors are open (condition `door_status = 3` corresponds to the doors being open).

```
define OpenDoors(GreenBox_id: String)
from VehicleData(speed > 0.0 and door_status = 3)
where OpenDoors.GreenBox_id = VehicleData.GreenBox_id
```

Notice that if the vehicle does not have doors—or if it has doors which are not electronically controlled—primitive event *VehicleData* will never satisfy constraint condition `door_status = 3`, so the *OpenDoors* event will never be triggered for it.

Finally, the next rule defines a complex event *NotGivenBack*, which is triggered when a vehicle is not released at the end of a reservation period indicated by a user (i.e., when there is not *Release* event between the *Taken* event and the expiration of the corresponding reservation).

```
define NotGivenBack(GreenBox_id: String, reservation_id: String)
from ReservExpired(GreenBox_id = $a) and
last Taken(GreenBox_id = $a) within 30days
from ReservExpired and
not Released(GreenBox_id = $a) between ReservExpired and
Taken
where NotGivenBack.GreenBox_id = ReservExpired.GreenBox_id and
NotGivenBack.reservation_id = ReservExpired.id
```

In the case of all rules presented above, the natural subscriber to the generated events is the console that managers can use to monitor the status of the system. However, the flexibility of the publish–subscribe paradigm supported by T-Rex allows for other actors (e.g., a unit of security guards on alert against thefts) to seamlessly receive generated events. In addition, thanks to the flexibility and the expressiveness offered by the TESLA language for defining rules governing the generation of complex events, new monitoring rules (hence complex events) can be added—possibly dynamically—to the system after its deployment.

6 Related Work

The Green Move project explored innovative solutions both in the area of the *interaction between user and vehicle*—which in the Green Move approach is keyless and smartphone-based, without requiring a membership card—and in the area of the *configurability of the services offered*—which can be dynamically modified on each vehicle after system deployment. As discussed in the rest of this section, more and more commercial car sharing services are pursuing a keyless approach similar, though not as powerful, to the one pioneered by the Green Move project; conversely, none of them has yet reached the level of configurability that the Green Move platform allows.

Using smartphones to de-materialize the interaction between user and vehicle and to dynamically add and modify available services is, especially in the field of electric vehicles (Alli et al. 2012; Dardanelli et al. 2012; conti et al. 2011), a growing area of interest. *INVERS,*[4] *Convadis,*[5] and *Eileo*[6] are the global market leaders in the domain of technologies for car sharing kits. The vehicle sharing systems built through these kits—which are the majority—have a number of drawbacks and limitations compared to the Green Move platform:

their configurability is limited;

- they do not support Bluetooth, nor NFC communication for replacing car keys;
- the ownership of the user database and the rights to the user profiles belong to Convadis/Eileo/INVERS rather than to the vehicle sharing company;
- they do not offer the possibility to add/remove functions depending on the user, location or period.

Some vehicle sharing systems have recently included concepts similar to those introduced in the Green Move project. For example, *Enjoy*[7] is one of the first systems which does not require a membership card for entering the vehicle. The opening/closing of the vehicle doors is performed through a smartphone app, but the communication between vehicle and user smartphone is always mediated by a central server, where the commands are processed and then forwarded to the

[4]www.invers.com.

[5]www.convadis.ch.

[6]www.eileo.com.

[7]enjoy.eni.com.

vehicle. This procedure requires time; thus, the vehicle doors do not open for many seconds (around 30) after the smartphone sends the command. On the contrary, the Green Move platform relies on NFC and Bluetooth communication channels between the user smartphone and the vehicle to directly send open/close commands to the latter. Hence, the interaction is much faster—vehicle doors open immediately after the user sends the command through the smartphone; in addition, it does not require a connection to the server, so it can occur also when this is absent, as in underground parking garages. Interested readers can refer to Bianchessi et al. (2013a) for a review of available car sharing technologies.

The topic of service configurability is even less explored than smartphone-based interaction: no vehicle sharing system offers the possibility to configure the services of vehicles depending on the user preferences or the state of the vehicle. Some of the most technologically advanced services offer, through the computers onboard the vehicles, applications that enrich the driving experience. For instance, *Car2go*[8] offers two onboard services, the navigator and the Driving Style Assistance System. However, no customization is available; the services behave the same regardless of the user's past habits or vehicle type.

7 Conclusions

In this chapter, we have introduced the architecture of the prototype of Green Move system. We have described the main functions of the system components (Green Move Center, Green e-Boxes, and the app installed on users' mobile devices) and how they interact with one another to provide the core mechanisms on which the vehicle sharing system is built, such as vehicle taking and releasing, fleet monitoring. The next chapters introduce some advanced, value-added services offered by the Green Move prototype, which are based on the architecture described above.

References

Alli G, Baresi L, Bianchessi A, Cugola G, Margara A, Morzenti A, Ongini C, Panigati E, Rossi M, Rotondi S (2012) "Green move: towards next generation sustainable smartphone-based vehicle sharing," sustainable internet and ICT for sustainability (SustainIT). IEEE, pp 1–5

Bianchessi A, Ongini C, Alli G, Panigati E, Savaresi SM (2013a) "Vehicle-sharing: Technological infrastructure, vehicles, and user-side devices -technological review," International conference on intelligent transportation systems (ITSC), pp 1599–1604

Bianchessi AG, Cugola G, Formentin S, Morzenti A, Ongini C, Panigati E, Rossi M, Savaresi SM, Schreiber FA, Tanca L, Vannutelli Depoli EG (2014) Green Move: A platform for highly vonfigurable, heterogeneous electric vehicle sharing. IEEE Intell Transp Syst Mag 6(3):96–108

[8]www.car2go.com.

Bianchessi A, Ongini C, Rotondi S, Tanelli M, Rossi M, Cugola G, Savaresi SM (2013b) A flexible architecture for managing vehicle sharing systems. IEEE Embed Syst Lett 5(3):30–33
Conti M, Fedeli D, Virgulti M (2011) Bluetooth for electric vehicle to smart grid connection. IEEE Intel Solutions Embed Syst 1:13–18
Cugola G, Margara A (2010) "TESLA: a Formally Defined Event Specification Language". Proceedings of the ACM international conference on distributed event-based systems (DEBS)
Cugola G, Margara A (2012a) Complex event processing with T-REX. J Syst Softw 85(8): 1709–1728
Cugola G, Margara A (2012b) Low latency complex event processing on parallel hardware. J Parallel Distrib Comput 72(2):205–218
Cugola G, Margara A (2012c) "Processing flows of information: From data stream to complex event processing," ACM Comput Surveys 44(3):1–15
Dardanelli A, Tanelli M, Picasso B, Savaresi S, di Tanna O, Santucci M (2012) A smartphone-in-the-loop active state-of-charge manager for electric vehicles. IEEE ASME Trans Mechatron 17(3):454–463

Green Move Dynamic Applications

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Abstract In this chapter, we describe the middleware that has been defined and implemented in the prototype of the Green Move system to dynamically manage value-added applications that run on the Green e-Boxes of vehicles and that are used to tailor the user experience of Green Move customers. A Green Move dynamic Application (GMA) is a bundle of code that can be installed or removed at run-time (i.e., after the system has been deployed, even while the vehicle is in use), depending on the current situation and on the user preferences. GMAs can be developed by the administrators of the Green Move system, but also by third parties. In this chapter, we describe the primitives offered by the GMA framework to facilitate the development of GMAs. We also show how the system allows GMAs to be installed automatically, when certain conditions are met, thanks to the complex event processing capabilities of the Green Move system prototype.

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1 Introduction

The architecture of the Green Move system described in Chap. 8, which includes the Green Move Center (GMC), the Green e-Boxes (GEBs) installed on vehicles, and the Green Move app installed on users' mobile devices has been designed to support a high level of flexibility and configurability of the services offered to users.

In this chapter, we focus on the mechanisms developed to tailor the functions offered by a vehicle to the preferences of its current user. This is achieved through the notion of *dynamic application*, i.e., a piece of software that can be loaded on the GEB of a vehicle at any time, whether it is in use or not, and which extends the functions offered to the user. Dynamic applications can access the data that are present on the vehicle—speed, acceleration, state of charge of the battery, etc.—to create value-added services for the user.

We present a pair of prototype dynamic applications. The first one addresses the issue of *range anxiety*—that is, the fear that the battery will empty before reaching the destination—by providing feedback to the user concerning his driving style, to nudge him toward a more economical one. The second application provides context-dependent advice to the user, such as commercial or cultural suggestions; this application can also be used to coordinate the fleet, for example, by notifying drivers of points of interest that are in their proximity—e.g., available charging stations. The Green Move platform allows these applications to be dynamically installed on vehicles, while they are in use, depending on the situation they are in. For example, the driving style application can be loaded only for users who have indicated, among their preferences, the desire to receive that kind of feedback; or only when the system determines that the user is exhausting the battery while still far from his destination, so a more economic style of driving is necessary to maximize the driving range. Dynamic applications also support a scenario where multiple implementations are available for a given functionality—for example, with different styles for presenting feedback to the driver—and the one that best fits the user preferences is loaded at the beginning of the trip and unloaded at the end. In addition, a mechanism where applications are installed dynamically after the fleet has been deployed allows administrators to remotely perform updates of the functions offered by the GEBs without physically operating on them.

In the next section, we briefly survey existing solutions that enable the execution of user-oriented software applications on vehicles (especially cars) and highlight their differences with respect to the mechanisms developed for the Green Move platform, in particular with respect to the issues of configurability and interactions of users and vehicles. Then, we describe the mechanisms underlying Green Move dynamic applications and present a pair of prototypical ones.

2 Related Works

In recent years, more and more vehicles—especially cars—have been equipped with devices capable of running applications that enhance the user experience during the drive. In particular, most Original Equipment Manufacturers (OEMs) produce systems for In-Vehicle Infotainment (IVI) and telemetry systems for the monitoring of the state of the vehicle. Most telemetry systems are proprietary based on real-time operating systems; they are typically not integrated with IVI. IVI systems are also usually proprietary, though lately a few OEMs are converging on common solutions.

Mobile solutions for hardware platforms and operating systems are the most commonly used basis for building IVI systems The iOS-based *CarPlay*[1] IVI by Apple offers the possibility to install third-party applications—though not dynamically—and to interact with the driver's phone to share the data and audio channels; at the moment it is not clear if it offers any access to vehicle data.

General Motors have developed a proprietary solution,[2] which allows for a closer integration with the vehicle. In particular, it exposes two sets of application programming interfaces (APIs): In-Vehicle APIs and Remote APIs. In-Vehicle APIs allow developers to access a small set of vehicle data, audio/video capabilities, navigation information, user interfaces, and communication channels. Remote APIs offer access to the vehicle data and the ability to send commands to the vehicle. Through these commands, one can lock/unlock the vehicle doors, retrieve diagnostic information, or retrieve the vehicle's position. This system offers functions similar to those that have been developed for the Green Move platform; however, unlike the latter, it does not seem to offer any capability of dynamically changing the services offered onboard.

The *GENIVI Alliance*[3] has developed an open-source infrastructure for in-vehicle infotainment. The *Tizen*[4] software platform, originally born as a mobile operating system, is now shifting its focus to the IVI market through the GENIVI Alliance open-source platform.

All the solutions above focus on creating an operating system that offers access to multimedia and network functions, and in some cases to vehicle data. Applications developed for these platforms have to be manually installed and started by the user.

OSGi[5] is a service-oriented component-based framework that allows developers to create and manage dynamically loadable applications. The OSGi infrastructure is built upon three basic abstractions: modules, life cycle management, and services. A *module* is a single portion of functional code, wrapped in a deployable unit called

[1]www.apple.com/ios/carplay.

[2]developer.gm.com.

[3]www.genivi.org.

[4]www.tizen.org.

[5]www.osgi.org.

bundle. The *OSGiContainer* provides the bundles' execution environment and primitives to manage their life cycle. Bundles can be dynamically downloaded, installed, and started. *Services* are built upon modules. Every module can offer and consume services. OSGiContainer provides standard modules to manage security issues. Knopflerfish[6] and Apache Felix[7] are two available implementations of the OSGi framework. The OSGi architecture targets generic Java virtual machines rather than Android's Dalvik, although Android implementations are available. The Green Move mechanisms for managing dynamic applications, instead, have been specifically designed for vehicle sharing systems: They allow for the installation of new components without driver intervention and for the access to vehicle data. In addition, the Green Move APIs for programming dynamic applications are simple and lightweight, but nevertheless they fit different kinds of applications, as shown later in this chapter.

To summarize, finding new solutions for an optimal management of electric, flexible, and heterogeneous fleets is one of the main challenges facing today's urban mobility. The Green Move project has tackled this issue through a platform that allows both a high level of automation in the interaction between users and system, and powerful customizations of onboard services through the notion of dynamic applications.

3 Overview

The Green Move system allows administrators to modify the functions offered by GEBs installed on vehicles on-the-fly, at any time, while the system is running. This is achieved by dynamically loading and unloading applications that run on GEBs. These applications on one side are built on top of the basic functions offered by GEBs that are described in Chap. 8, and on the other side extend the services offered by GEBs, in particular to users.

Consider, for example, the following scenario, typical for electric vehicles, which need a long time to recharge. The user, by driving aggressively in town, is quickly consuming the reserve of energy stored in the battery and runs the risk of not being able to reach his destination; the system, which is monitoring the status of the vehicle, and in particular the battery charge, through the mechanisms described in Chap. 8, notices the depletion of the battery charge, and decides to aid the user by suggesting a kinder driving style, one which can make the battery last longer; then, to help the user in this regard, the system dynamically installs an application which, by elaborating the data retrieved by the GEB concerning speed, acceleration, etc., of the vehicle—i.e., parameters that affect the rate with which the battery is

[6]www.knopflerfish.org.

[7]felix.apache.org.

depleted—presents the user with a measure of the aggressiveness of his driving style, so as to steer him toward a gentler style, less demanding on the battery.

As a second scenario, consider an organization— for example, Politecnico di Milano—whose employees use the vehicle sharing system when they have to move within the city for institutional reasons. Imagine that the organization and the management of the vehicle sharing system have an agreement that grants the former some privileges such as preferred access to the vehicles during certain days and time slots, or the possibility to have customized functions available for its employees. Then, when an employee of the institution—say, a courier—takes one of the vehicles to visit various places in the city, the system automatically loads on the vehicle an application for managing not only the route followed by the employee (which might be optimized according to the list of tasks to be carried out), but also the tasks themselves (e.g., to keep track of the deliveries and the pickups).

In the second scenario, the tracking application must be available only for a subset of the users of the system; in addition, it might not be available all the time, as agreements between institutions can change or expire. Hence, it is crucial to have a flexible mechanism that allows the system to dynamically configure, in real-time and on-demand—i.e., at irregular, unscheduled moments in time—the services offered to users by the system. Even in the first scenario, which in some cases could be served by an application preinstalled on all vehicles and activated only when necessary, a dynamic mechanism for the loading/unloading of applications on GEBs would be very useful, as different “driving style coaches” might be available to users, and the one to be actually installed could be a real-time decision made based on the preferences of the user.

The Green Move platform supports the scenarios described above through the notion of Green Move dynamic Applications (GMAs for short), which can be installed on and removed from GEBs while the system is running. Figure 1 shows the steps through which a GMA is uploaded on a GEB. The mechanisms for the management of GMAs leverage the architecture and the technologies that are at the core of the Green Move system, and which are described in Chap. 8. First (Fig. 1a) a T-Rex event is sent to the GEB, which notifies the latter that a GMA is to be installed; the event contains the address on the GMC where the GMA can be retrieved. Then, the app running on the GEB accesses the GMC (Fig. 1b) and retrieves the code of the GMA (Fig. 1c). Finally, the interfaces implemented by the GMA allow the GEB to instantiate the application and start it (Fig. 1d). Similar mechanisms are used to uninstall a GMA from a GEB, or to reload a running GMA.

The GMC gives the administrators different options to select the vehicles on which a GMA is to be uploaded: single vehicles (unicast), groups of vehicles (multicast) or the whole fleet (broadcast).

The next chapter details the main mechanisms and components of the middleware that supports the distribution and management of GMAs.

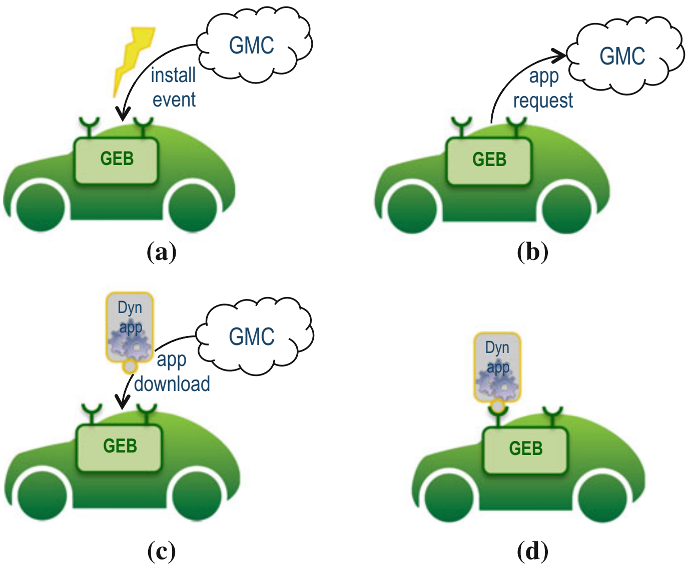

Fig. 1 Overview of the steps for the installation of a dynamic application

4 Green Move Dynamic Applications Middleware

The middleware for managing GMAs is based on two main components: the *Code Server*, which resides on the GMC and the *GMcontainer*, which instead is part of the GEB. In the following, we introduce their main features.

4.1 *Code Server*

The Code Server is a module of the GMC that allows trusted parties to upload their applications, to verify them and to distribute them to GEBs through the Green Move middleware. It also allows administrators to get the current list of devices running a certain application, to stop any running instance and uninstall it, or to deploy it a second time. Applications are uploaded as signed JAR files, which are verified for authenticity before being made distributable.

4.2 *GMcontainer*

Figure 2 shows the main elements of GMcontainer, the component that is part of the GEB and that is in charge of managing GMAs on vehicles. In particular, the GMcontainer listens to the events sent by the GMC depicted in Fig. 1; it reacts

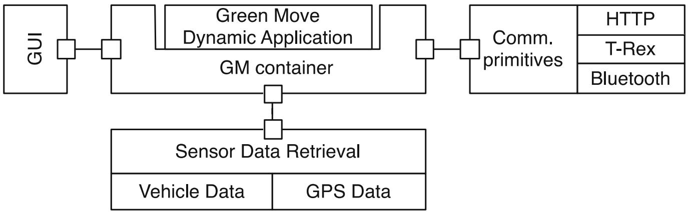

Fig. 2 Schematic view of the Green Move dynamic application container

to them by downloading the GMA code, instantiating it, and removing it when it is no longer needed. In addition, the GMcontainer keeps a persistent registry of the GMAs installed.

The interface implemented by a GMA allows it to retrieve from the GMcontainer references to other components of the Green Move environment running on the GEB. In particular, a GMA can use primitives that allow it to: (i) send messages through a variety of communications channels; (ii) acquire the vehicle data (speed, acceleration, state of charge, etc.) from the sensors; (iii) display information on the graphical user interface (GUI) of the GEB if one is available.

A GMA can communicate with remote components in several different ways. It can use an HTTP channel that is made available and mediated by the GEB. Such a channel can be used to interact with external services to send/retrieve information (e.g., weather, traffic, advertisements) through standard protocols. For security reasons, the HTTP connection is managed on the GEB by a software proxy which has the possibility to check the traffic and, for example, block access to blacklisted servers.

A standard HTTP channel, however, is ill-suited for transmitting (or receiving) streams of data, such as telemetry or composite events. For this reason, the GMcontainer offers GMAs access to a T-Rex channel, through which they can publish or subscribe to events. The T-Rex channel allows a GMA to distribute information to other vehicles, if the latter subscribe to the events published by the former.

A GMA can also use the Bluetooth channel mediated by the GMcontainer (see Fig. 2) to send messages to the smartphone of the user during the rental. This allows a GMA to communicate with the Green Move client application, or another companion application on the user's smartphone, as explained in Sect. 5.2.

The GMcontainer offers GMAs the possibility to interact with the vehicle through a high-level interface. The interface is very general, and it can be used to read the status of the vehicle, such as the state of charge of the battery or the speed of the vehicle. However, as mentioned in Chap. 8, the Green Move platform targets fleets made of heterogeneous vehicles, so different kinds of vehicles might offer different kinds of data; for example, not all vehicles have doors and, for those that do not, a "door status" is not available. Through this high-level interface a GMA can also send commands to the vehicle. For example, "open/close door" commands can be issued if the GMA resides on the GEB of a vehicle that has doors. As before, the sending/receiving of commands is mediated by the GEB, which can monitor the interaction.

If the GEB has a screen (not all do, such as those of scooters), a GMA can use it to provide information to the user. For example, a GMA might display suitable diagrams to give the user feedback on the driving style. The GMcontainer offers GMAs two different possibilities to show information on the GEB GUI: display a short, purely textual message on the main view of the GEB app; or build a full-screen, graphical view that is under the control of the GMA. The availability of different primitives allows GMA programmers to select the one that better fits the needs of the application, for example from the point of view of the energy consumption.

4.3 Implementation

From the implementation point of view, the GMcontainer is realized as an Android Service. GMAs are Android components that adhere to the single entry point convention enforced by the GMcontainer. This means that applications could be coded in any language that can be run on top of the Android Java Virtual Machine (Dalvik), such as Ruby or Python. The current implementation assumes that the application code is sealed in a standard JAR file.

To allow the system to uniformly manage heterogeneous applications, each GMA must implement a standard interface, which exports primitives that are used by the GMcontainer to set-up, start and stop the application. More precisely, the primitive for setting up and starting the GMA is used by GMcontainer to pass the application the reference to the GEB components that it can use during its execution, and which are depicted in Fig. 2. The primitive that is used by GMcontainer for stopping the application, instead, is responsible for the disposal of the GMA's own resources (sockets, running threads, and so on).

As mentioned in Sect. 3, GMAs are installed and uninstalled by sending GEBs suitable T-Rex events (Cugola and Margara 2012). These events can be generated in several ways, possibly as a consequence of other events that occur in the system. In the latter case, they are defined as rules expressed in the TESLA language (Cugola and Margara 2010). For example, the following TESLA rule, upon the release of the vehicle by the user (marked by event *Released* described in Chap. 8), generates an *Uninstall* event for each GMA that has been loaded during the last rental, thus cleaning up newly installed GMAs from the GEB.

```
define Uninstall (String: GreenBox_id, String: class)
from Released(GreenBox_id = $a) and
each SendApp(GreenBox_id = $a) within 5 days from Released
consuming SendApp
where Uninstall.GreenBox_id = SendApp.greenBox_id and
      Uninstall.class = SendApp.class
```

Notice that the *Unistall* event has two fields: GreenBox_id and class, where the latter is a string identifying the main class of the application. SendApp is the event that is used by the Green Move middleware to notify GEBs of the need to load a GMA; it has three fields: GreenBox_id, class, and appUrl, where the first two are as for the Uninstall event and the third one points the GEB to the URL on the GMC from where the GMA is to be downloaded.

The next sections present meaningful examples of prototype GMAs that illustrate the features available to dynamic applications and what benefits can be gained from them.

5 Examples of Green Move Dynamic Applications

In this section, we present a pair of GMAs that have been implemented to show the capabilities of the Green Move middleware. The first one realizes the "driving style coach" scenario introduced in Sect. 3, whereas the second one is an application that provides personalized advice to users (for example, about commercial offers in their proximity) while they are moving around the city. In this chapter, we focus on the mechanisms provided by the Green Move middleware that allowed us to realize the applications. Chap. 11 (for the driving style application) and Chap. 10 (for the personalized advice application) present the algorithms and principles that are at the basis of the two applications.

5.1 The Driving Style Dynamic Application

The driving style GMA helps the user save battery during the trip, by nudging him toward a smoother style of driving. To achieve this, it computes several indexes that provide an estimation of the driving style of the user and communicates them to the GMC; in addition, the application displays the information to the driver, to induce him to keep a driving profile that is conducive to saving energy.

The application takes advantage of the features offered by the Green Move middleware supporting dynamic applications, such as the possibility of accessing vehicle data (e.g., speed and acceleration), the primitives for accessing the GUI on the GEB, and the communication mechanisms—in particular, the publish-subscribe primitives offered by T-Rex—to interact with the GMC. Figure 3 shows a general overview of the driving style GMA and its interactions with both the vehicle and the user.

The GMC can use the information sent by the driving style GMA to provide users with an enhanced service or additional features (e.g., personalized fees, user alerts, better prediction of the vehicle's range, fleet optimization).

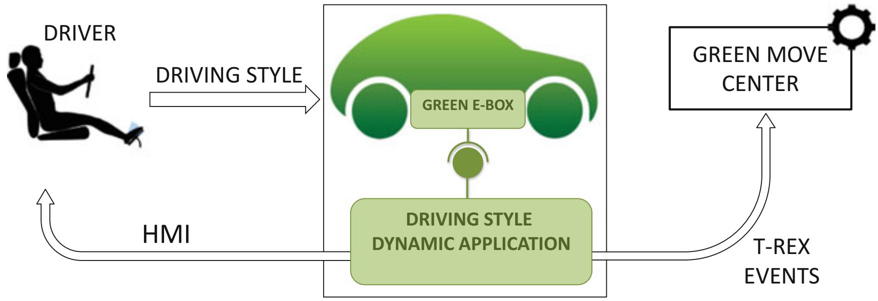

Fig. 3 Overview of the driving style GMA

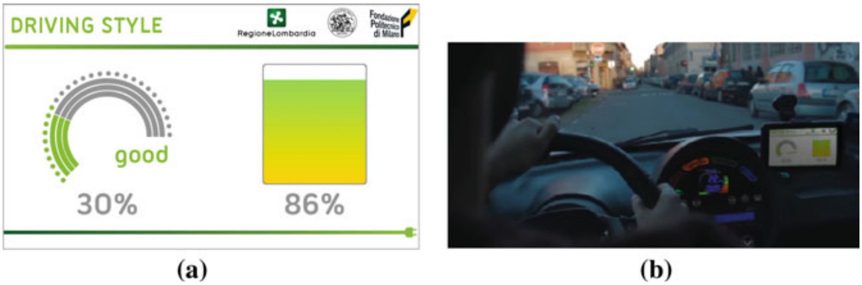

Fig. 4 User interface of the driving style GMA **a** and the application running on a GEB **b**

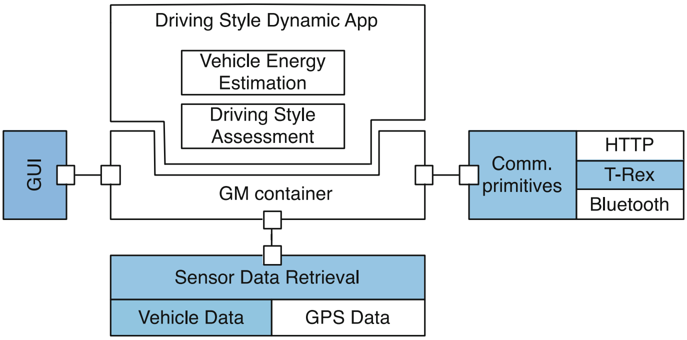

Fig. 5 Features of GMcontainer exploited by the driving style GMA

As mentioned above, the driving style GMA provides feedback to the driver in real-time. To achieve this, the application exploits the primitives provided by GMcontainer to access to the GUI of the GEB. Figure 4 shows its user interface, which provides an immediate and simple representation of the user's driving style.

As shown in Fig. 5, the driving style GMA exploits a number of the features offered by the dynamic application framework, and in particular:

- *the GUI's primitives*, to display the driving style indexes on the GEB;
- *the T-Rex event channel*, to send messages to the GMC;
- *the vehicle data retrieval interface*, to gather data about the vehicle (e.g., speed and acceleration).

According to the scenario outlined in Sect. 3, the application is automatically deployed on a GEB when the user is at risk of not reaching his destination because of an aggressive driving style that too rapidly discharges the battery. This is achieved through the definition of suitable T-Rex events. In particular, the GMC knows the initial state of charge (*SoC*) of the battery, thanks to T-Rex event SocWhenTaken defined by the following TESLA rule:

```
define SocWhenTaken (String: greenBox_id, int: soc)
from Taken(greenBox_id = $a) and
last VehicleStatus(greenBox_id = $a) within 5 days from Taken
where SocWhenTaken.greenBox_id = VehicleStatus.greenBox_id and
      SocWhenTaken.soc = VehicleStatus.soc
```

More precisely, a *SocWhenTaken* event is generated when a rental starts (which corresponds to event *Taken* described in Chap. 8); it carries the information concerning the last value of the SoC that is retrieved from the vehicle.

At regular intervals while the vehicle is moving, the GEB sends *VehicleStatus* events to the GMC (see also Chap. 8); when the residual charge of the battery is less than a given threshold, a *SendApp* event is generated containing the information needed to load the driving style GMA. *SendApp* is a composite event, whose definition in the TESLA language is the following:

```
define SendApp (String: greenBox_id, String: appUrl, String:class)
from VehicleStatus(greenBox_id = $a) and
last SocWhenTaken(greenBox_id = $a) within 1 day
from VehicleStatus and
not Released(greenBox_id = $a) between VehicleStatus and SocWhenTaken
and VehicleStatus.soc < SocWhenTaken.soc*k/(1 + k)
where SendApp.greenBox_id = VehicleStatus.greenBox_id and
      SendApp.appUrl = "<GMAurl>" and SendApp.class = "<GMAclassName>"
```

In particular, the *SendApp* event is generated when the current value of the SoC is less than the SoC consumed since the beginning of the rental multiplied by a constant factor k (which is empirically determined); that is, the event is triggered when constraint $SoC_{\mathrm{curr}} \leq k(SoC_{\mathrm{init}} — SoC_{\mathrm{curr}})$ holds.

5.2 Dynamic Application for Personalized Advice

As a second example, we introduce an application, called *GMadvisor*, that provides users with customized, context-dependent advice, while keeping user preferences private from the rest of the Green Move system. The application, whose underlying mechanisms and algorithms are presented in Chap. 10, is an example of GMA that mixes data collected from different sources (users, vehicles, external players) and shows how the Green Move middleware can support distributed architectures involving components other than GMC and GEBs. In fact, as depicted in Fig. 6, the application is based on three components:

- A server storing the set of advice that can be sent to users (e.g., position of charging stations, points of interest).
- The *GMadvisor client app*, which is installed on the mobile device of the user and is responsible for storing the user preferences—necessary for customizing the advice—that should not be shared with the rest of the system; the app also displays advice to the user if the GEB does not have a GUI.
- The *GMadvisor GMA* dynamically deployed on the vehicle's GEB, which sends the id of the user and the position of the vehicle to the advice server, receives the advice and—if it has a GUI—displays those that, according to the client app, match the user preferences.

Similar to the driving style GMA, the GMadvisor GMA exploits various features of the Green Move middleware for dynamic applications, shown in Fig. 7. More precisely:

- It uses the GEB GUI to show suggestions on the device's display, if one is available.
- It communicates with the user's mobile device through the Bluetooth channel, to exchange information that allows it to select the advice to show.

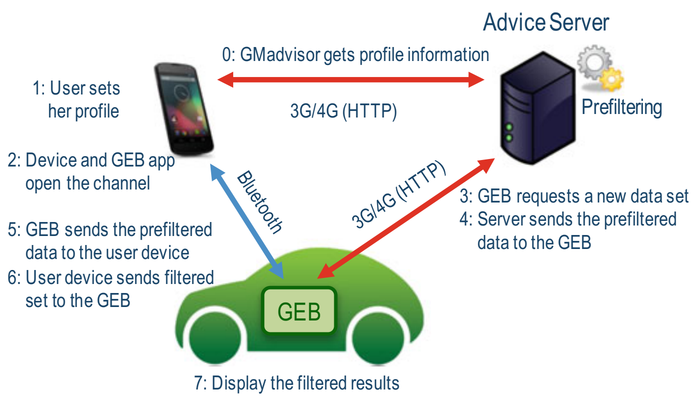

Fig. 6 Components of the GMadvisor application and interactions among them

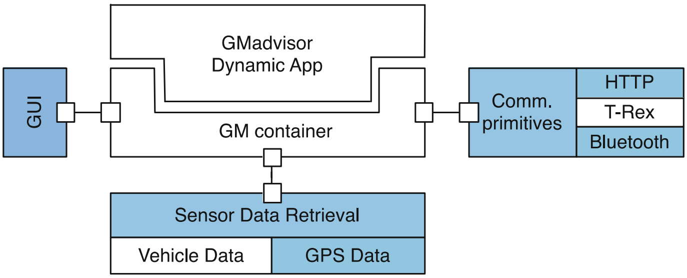

Fig. 7 Features of GMcontainer exploited by the GMadvisor GMA

- It communicates with external servers through the HTTP channel, and in particular it retrieves from an advice server the information to be distributed.
- It retrieves real-time data from the vehicle to determine, for example, the current position of the user.

The GMadvisor GMA can be deployed automatically by the system. This is achieved by generating a suitable T-Rex event upon a *Taken* event triggered by a user starting a rental (if she selected in her profile the preference to receive advice). It can be removed from the GEB through the *Uninstall* event shown in Sect. 4.3.

6 Conclusions

The Green Move platform is highly configurable, as it includes a middleware that allows applications—GMAs—to be dynamically loaded onto vehicles' onboard computers—the GEBs—before and during trips, and then to be removed when they are no longer needed. In this chapter, we have outlined the core features and mechanisms implemented in the Green Move prototype system to support the execution of GMAs. The flexibility offered by the Green Move platform through GMAs allows system managers to tailor the services offered during the vehicle rental to the user's needs and preferences, as witnessed by the prototype applications described in Sect. 5.

Future improvements of the middleware presented in this chapter will focus on the strengthening of the security of the framework in aspects concerning the distribution of GMAs to GEBs and their execution on the target devices, in particular for what relates to the isolation of applications between each other.

References

Bianchessi A, Ongini C, Rotondi S, Tanelli M, Rossi M, Cugola G, Savaresi SM (2013) A flexible architecture for managing vehicle sharing systems. IEEE Embed Syst Lett 5(3):30–33

Bianchessi AG, Cugola G, Formentin S, Morzenti A, Ongini C, Panigati E, Rossi M, Savaresi SM, Schreiber FA, Tanca L, Vannutelli Depoli EG (2014) Green move: a platform for highly configurable, heterogeneous electric Vehicle Sharing. IEEE Intell Transp Syst Mag 6(3):96–108

Cugola G, Margara A (2010) "TESLA: a Formally Defined Event Specification Language". Proceedings of the ACM International Conference On Distributed Event-Based Systems (DEBS)

Cugola G, Margara A (2012) Complex event processing with T-REX. J Syst Softw 85(8): 1709–1728

Context-Driven Pervasive and Personalized Information Management

Emanuele Panigati, Fabio A. Schreiber and Letizia Tanca

Abstract The creation of intelligent pervasive spaces is one of the most interesting opportunities offered by pervasive systems: social and physical ambients can be created with the aid of ICT technologies, providing enhanced capabilities for humans to interact with the surrounding environment. In general, these features are useful for providing security services, energy management, water and pollution control or to create assisted-living ambients for impaired or elderly people, but constitute also proactive and intelligent supports to novel applications in traffic management.

1 Introduction

The creation of intelligent pervasive spaces is one of the most interesting opportunities offered by pervasive systems: social and physical ambients can be created with the aid of ICT technologies, providing enhanced capabilities for humans to interact with the surrounding environment (Colace et al. 2015) (Liu 2008). In general, these features are useful for providing security services, energy management, water and pollution control or to create assisted-living ambients for impaired or elderly people, but constitute also proactive and intelligent supports to novel applications in traffic management.

Many of these solutions are made possible thanks to the adaptability and context-awareness of pervasive systems; by sensing the environmental conditions, the system dynamically recognizes the situation and context into which it currently

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operates and behaves accordingly. Adaptability and context-awareness are strictly related to each other and in many real situations are considered as interchangeable; however, while context-awareness actually refers to the ability of the system to recognize the current context and to provide, at any time, the necessary contextual information and services (Bolchini et al. 2007), adaptability refers to the system capability to execute behavioural variations in response to changes of context or other parameters that can affect the behaviour of the system, even the internal software itself (Cheng et al. 2009). Therefore, adaptability and context-awareness are complementary in building pervasive applications.

This is the scenario that encompasses the Green Move (GM) system. To fulfil the system objectives, as described in the previous chapters, we propose a context-aware approach to realize and manage situation-dependent services and support the processing of data flows to extract interesting information accordingly. The approach drives the data that flow from sensors, institutional data sources, users etc. since its gathering phases, selectively retrieving the relevant ones only in quantity and format useful according to the current context. For instance, driving downtown is different from driving in the suburbs, thus the user reasonably expects different information—like traffic density or the presence of restricted areas—and with different frequencies.

With a growing number of vehicles and users, the amount of collected and exchanged data will make the efficiency of advanced services a critical issue: in this perspective, the use of selective and efficient context-aware data-gathering processes, which filter the information on the basis of the context(s) of its acceptor(s), can certainly improve the effectiveness and scalability of the system.

2 Green Move Information Management

Consider the architecture of the GM system, envisaging the three main components shown in Fig. 1: (i) a central platform designed to manage infrastructural aspects and information flows, (ii) on-vehicle components (*Green e-Boxes*, or GEB), and (iii) the users' personal devices.

The central platform of the system includes GM data and application servers, the main tasks of which are: (i) maintaining data in all the needed formats and (ii) making the GM web-based application and pervasive information messages and ads available. Thus, the central platform comprises the GM context-aware (*GMCA*) and the GM Information Distribution (*GMID*) modules (see Sect. 7) to handle vehicle reservation and assignment, user experience personalization and information distribution in the whole system.

As described in Chap. 8, the ICT core of each vehicle connected to the system is known as the *Green e-Box*, an Android-powered board configured with ad hoc applications integrated within the GM system.

The user personal device interacts with the GM server by means of the GMID to display useful ads and/or service information; moreover, it communicates with the

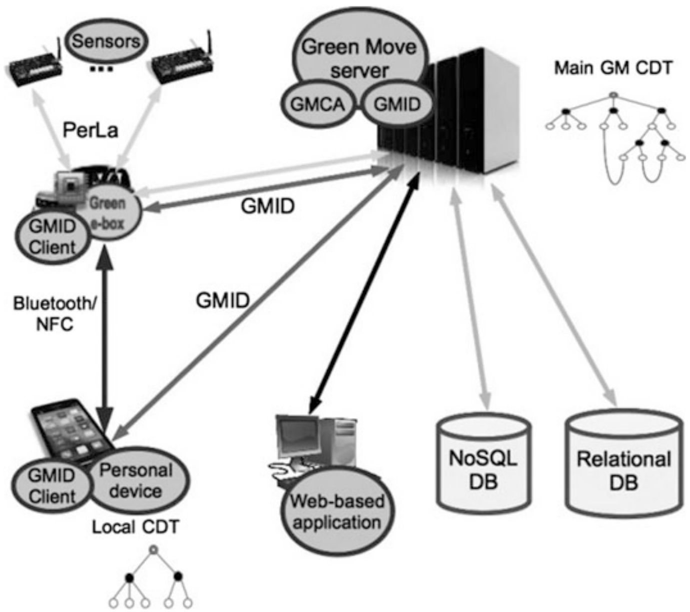

Fig. 1 GM data management system architecture

Green e-Box to handle the vehicle management operations (doors lock/unlock, engine enabling, …), using either a *Bluetooth* or *NFC* connection.

2.1 The Green Move Database

The main data store is a relational database containing the data concerning users, vehicles, Green e-Boxes and accessory information. **Highly dynamic data coming from sensors are managed in the system** using the PerLa framework (see Sect. 5) and are used for taking immediate actions—like notifying a driver that the battery charge is low or about a traffic jam in the neighbourhood—as well as for subsequent analyses—e.g. for building traffic models. Since sensor data come in streams and transactional *ACID* properties need not be guaranteed, they are stored in a *NoSQL database*, thus allowing fast and effective access.

The conceptual schema in Fig. 2 represents the main entities and relationships in the GM database. The **VEHICLE** entity contains data about each vehicle registered with the system and is related to the **GREEN_EBOX** entity, which is also responsible for data gathering from sensors, e.g. GPS. User data are collected in the **USER** entity: from the hierarchy it appears that this entity contains data about the users that plainly make use of GM services—the **CUSTOMERs**, and also about users that share their own vehicles through GM—the **OWNERs**; however these roles are not fully disjoint, e.g. a customer can also be the owner of some GM vehicles. Users are related to their personal devices by the **owns** relation, and to vehicles by means of two different relationships: (i) the **owned by** relationship connects every *owner* to his/her owned vehicles, (ii) the **makes** relationship, through the entity **reservation**, connects the users with their own assigned vehicle. Data about any other kind of service referred to a particular reservation are contained in the entity **SERVICE** and in its related entities.

All the data represented in Fig. 2 are stored in the GM relational database, except for the data related to **GPS** and **SENSOR**, which reside in the NoSQL database.

Running example

In the following, the examples of data management refer to a simple scenario: "Mr. Guido Verde" registers himself to the GM condo-sharing facility available at his condo, including a parking lot with a recharging station.

Once registered, he decides to take full advantage of all services: he specifies his data to the system and downloads the GM application to his smartphone filling the private part of his profile. Besides more occasional usages, Mr. Verde typically uses the electric cars to take his granddaughter to school every morning, and sometimes stops, on the way home, at the supermarket for some shopping. Thanks to the profile stored in the GMID client on his smartphone, Mr. Verde can receive interesting traffic and commercial information and ads according to his current context (GM configuration, location, selected interest topic…).

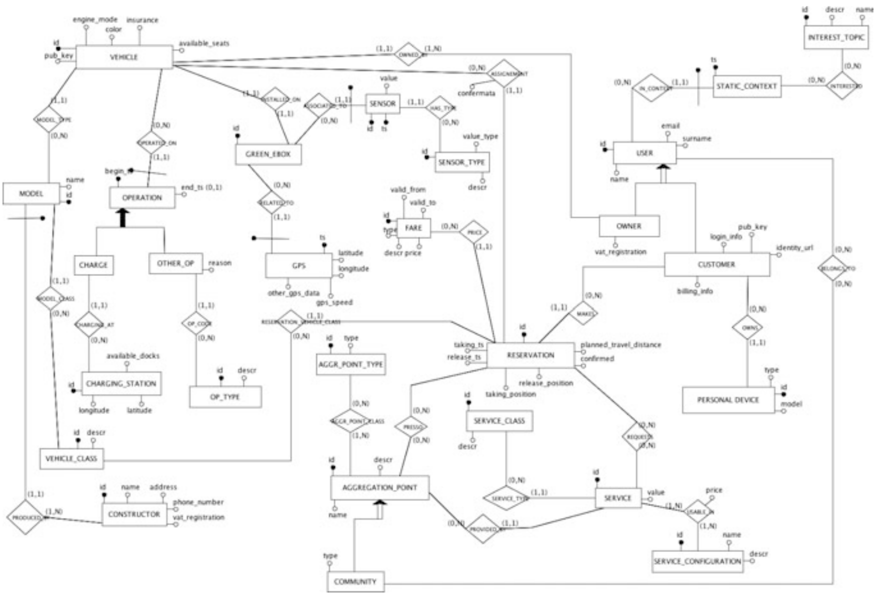

Fig. 2 Excerpt from the E-R model designed for the GM system

3 Context-Awareness in Green Move

The specific features of the GM scenario have driven some interesting innovations to the Context Dimension Tree model (henceforth simply CDT) (Bolchini et al. 2007) (Bolchini et al. 2013), a powerful and flexible modelling formalism, where contexts (Dey 2001) are composed starting from an application-dependent set of properties that characterize the users, the interacting systems and the environment surrounding them.

The context-aware approach is used in the GM project for supporting three main tasks: (i) user experience personalization, (ii) sensor data retrieval and evaluation and (iii) information distribution.

Tasks (i) and (ii) are performed by the GMCA, while task (iii) is the responsibility of the GMID. In the following, we explore these tasks and how the GM system realizes them.

3.1 Modelling Context

The CDT of Fig. 3 represents the perspectives adopted to contextualize GM data and to offer personalized car sharing and information distribution services (see Sect. 6). A CDT is made of nodes from a set $N = N_D \cup N_V \cup N_{VP} \cup N_{DP}$.

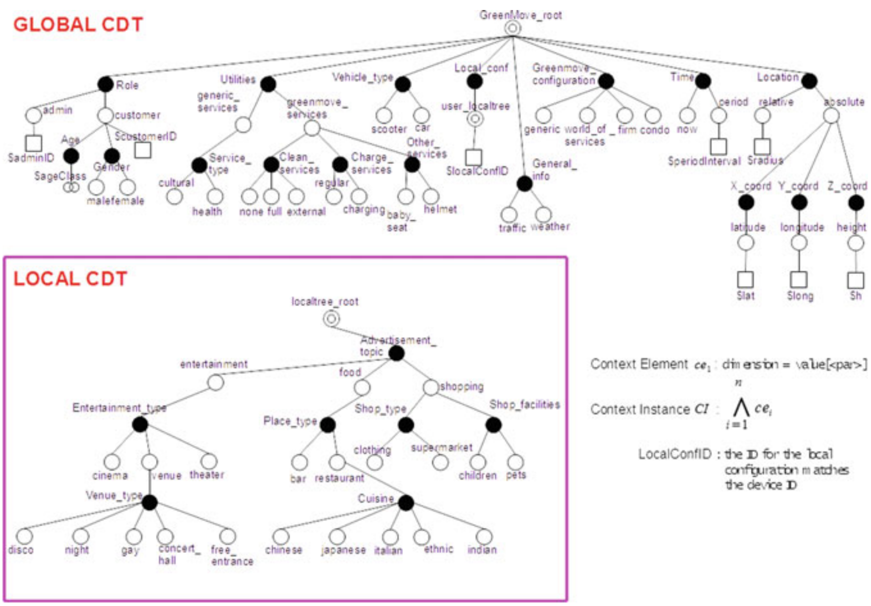

Fig. 3 Primary **a** and local **b** CDTs designed for the GM project

Circular black nodes represent the *context dimensions* $d_i \in N_D$ considered for the GM application scenario, i.e. the different perspectives identified by the designer to analyse the possible contexts, that is, the perspectives w.r.t. which the data are filtered. Circular white nodes represent the *values* $v_i \in N_V$ taken by the dimensions; these values can in their turn be analysed w.r.t. other dimensions, or have *value parameters* $p_i^V \in N_{VP}$ attached to them. A value parameter is represented by a white squared node and allows to refer to specific data: as an example, the value "customer" of the dimension "Role" features the parameter "customerID". Children of a dimension can be values or *dimension parameters* $p_i^D \in N_{DP}$. A dimension parameter is represented by a white double-circle node and acts as shorthand for representing a high number of possible values of the parent dimension; an instance of a dimension parameter is therefore equivalent to a value.

Context elements ce_i are built starting from CDT nodes; they represent statements of the form *dimension* = *value*. In particular, a value can also contain a parameter (e.g. **`customer < IDvalue >`**), or can be a dimension parameter (e.g. **`ageClass`**). From a formal point of view, a context (also called *context instance*) *CI* is defined as a conjunction of context elements $CI = \bigwedge_{i=1}^{n} ce_i$.

In the CDT of Fig. 3, the dimensions found immediately below the root, called *top dimensions* (Role, Utilities, Vehicle type, Local conf, General_info, GreenMove_configuration, Time, Location) determine, through their directly attached values, the main perspectives for filtering the data in the GM database; their sub-dimensions provide a more detailed specification where needed. Note that Fig. 3 contains two CDTs, a *primary* and a *local* one. Sect. 3.2 explains this in detail.

In general, a valid GM context can be defined composing dimensions and values (in the following a dimension name will be **`Typewritten`** while value names will be *emphasized*):

- **`Role`** dimension: in Green Move, each user has a role: she can be "*admin*" or a simple *"customer"*. Both admins and users are identified by an ID; a customer in addition may provide also a **`Gender`** and an **`Age`**.
- **`Utilities`** are the dimension representing the main subjects that may be of interest of a Green Move user. As explained in Sect. 3.2, some of these topics are part of the local CDT (those related to private user data, that should be known to the system but to no-one else); the interest topics that are in the primary CDT are instead the *generic_services* and *greenmove_services* A *generic service* has, as sub-dimension, the **`Service_type`** and the *greenmove_services* has, as sub-dimensions, **`Clean_services`**, **`Charge_services`**, and **`Other_services`**.
- The **`Local_conf`** dimension is explained in Sect. 3.2.
- **`General_info`** is about *traffic* and *weather.*
- The user can drive a particular **`Vehicle_type`**, e.g. a *scooter* or a *car*.

- **Greenmove_configuration:** The four different possible sharing-service configurations (*generic*, *world of services*, *firm* and *condo*) are the allowed values of this dimension.
- The two dimension **Time** and **Location** allow to state contexts related also to the current temporal and location values.

An example of context instance represents the situation of Mr. Verde looking for a cultural aggregation point: here the dimension **Role** takes the value *customer* < *1101* >, the dimension **Service_type** takes the value *cultural*, the dimension **Vehicle_type** takes the value *car* and the dimension **Greenmove_configuration** takes the value *condo*.

Note that a context does not necessarily contain a value for each dimension of the CDT: in the composition of a context, some dimensions may be left un-instantiated because irrelevant in that situation. Note also that application constraints, preventing the construction of unwanted context instances, may be defined on the CDT; this is not further discussed here.

The main objective of the CDT filtering approach is *data tailoring*, that is, as a support to filtering the data according to the different contexts; this is obtained at design time by associating a *contextual view*—i.e. a view selecting only the interesting data—with each of the possible contexts described by the CDT, as described in (Bolchini et al. 2009) (Bolchini et al. 2013) (Rauseo et al. 2011) and in the next section.

3.2 Privacy Management: The Local CDT

The GMID of GM tailors and distributes information that is coherent with the users' whereabouts and interests. Privacy requirements ask that in GM the private profile and specific needs and tastes of a user be unknown to the main system, resting within the user personal device (Panigati et al. 2012) (Rauseo 2013).

Accordingly, in GM the context data are stored partially in the GM server and partially in the user device. To do this we introduced a *combined CDT,* comprising a *primary CDT* and one or more *local CDTs*.

In the real-world CDT reported in Fig. 3, the **Local_conf** dimension represents the conjunction point between the primary and the local CDT. The local CDT features, in this example, the **Advertisement_ topic** dimension, providing the topics of interest for personalizing the ads that will be sent by the *GMAdvisor* application described in Sect. 7.2.

The local CDTs are maintained locally to the user devices and used to complete the context-based data filtering. Generally speaking, for each GM customer, the system will compose a specific combined CDT starting from the primary one, maintained by the server, and the local one, available on the customer's personal device. Different local CDTs can be envisaged to support different categories of users with different filtering requirements. A GM user is supported by a local application in choosing his/her current private context and interests from the context elements of the local CDT uploaded on the personal device.

Note that the composition of a local CDT with a primary one must comply with the CDT design constraints described in detail in (Bolchini et al. 2009).

A *combined context CC* is then easily defined as the conjunction of a context *CP* of the primary CDT and a context *CL* of a local CDT, and thus it is nothing more than a conjunction of their context elements (*ce*):

$$CC = CP \wedge CL = \bigwedge_{i=1}^{n} ce_i \wedge \bigwedge_{h=1}^{m} ce_h = \bigwedge_{k=1}^{n+m} ce_k$$

For each user, at run time, the system collects sensor values (e.g. the position, from GPS coordinates) and other contextual information from the user (e.g. current interest topic); this information gives values to CDT dimensions, and thus generates the corresponding context elements. The modules that encode the definition, properties and constraints of the CDT are run against the collected context elements, generating the current context instance.

Once the current context has been generated, the program computes the corresponding *contextual view*, providing a version of the database appropriately tailored according to the current context. At design time, together with the CDT, the designer has defined as many *partial views* as the context elements from the CDT; each partial view represents the fragment of the original dataset that has been recognized by the designer as interesting for that context element. The contextual view associated with a generic context is then generated at run time by intersecting the partial views defined for its context elements and presented to the user for further querying, as required.

4 Context-Aware Reservations

Due to the user-centred perspective of the GM project, context-aware techniques are used to tailor the user experience against the users' current context.

Referring to the running example, we follow Mr. Verde, who has just logged into the web interface to the GM system. He is making a reservation for a car to take his grandchild to school next morning. Since Mr. Verde performs the same reservation every morning, by analysing the current context and the history of Mr. Verde's previous context instances the system is able to guess that he may need a child seat.

Contextual preferences are used to rank the data and services, according to the interests demonstrated by the users in the different contexts; for instance, Mr. Verde will be offered a vehicle with a children's seat whenever he tries to reserve a car for 8:00 in the morning. This analysis is performed automatically by using the *contextual preference-mining* framework PreMINE (Miele et al. 2009) (Beretta et al. 2011): indeed, since it would be unfeasible to require a user to answer a large set of questions about his/her interest and preferences in each possible context, we decided to use mining techniques to extract and learn them directly from historical data.

Once Mr. Verde gets into the car and starts driving around the city, the GMID service is able to identify useful information (traffic jams, street works in progress, …) with respect to the context data detected by the system (e.g. values for location and time dimensions): this information is provided to the vehicle Green e-Box to be displayed on its screen (if present) or on Mr. Verde's personal device, his smartphone, running the client. If Mr. Verde has already set up his private contextual data on his personal device, the GMID service can also send him ads about possibly interesting offers (e.g., since he goes shopping, grocery items on offer or a special sale of vegetables) and other useful information according to his interests, as described in the sections that follow. The ranking among interesting and non-interesting information is based on the local context at hand and the matching is performed directly on the user device in order to preserve privacy.

5 Context-Aware Pervasive Data Acquisition

In a complex car sharing system with social interactions like GM, many information flows have to be managed and the issue needs attention.

Since frequent data transmission is the most energy-consuming operation and can bring to network congestion, operations on the sensed data (e.g. data aggregation) can be performed locally to the sensing nodes, which can send larger packets at lower frequency, instead of small sets of possibly redundant values. However timeliness constraints might be strong and, in this case, the transmission protocol should ensure a good compromise to obtain proper real-time behaviour (e.g. some key data about road events should always be transmitted as soon as they are available) (Cappiello and Schreiber 2009).

To manage the data produced by the sensors, we use the *PerLa* (*Per*vasive *La*nguage) system (Schreiber et al. 2012a): PerLa supports locally managed operations on data in a finely controllable and tunable fashion: the framework provides a declarative SQL-like language and a middleware infrastructure suitable for collecting data from different nodes of a pervasive system containing sensors as well as all kinds of generic data-gathering peripherals. The management of the gathered data is performed hiding the complexity of the possibly high heterogeneity of the underlying devices, which can span from RFID(s) to ad hoc sensor boards or even portable computers and smartphones. Moreover, PerLa supports context-awareness for sensors (Schreiber et al. 2011) and thus is easily integrated within a context-aware system based on the CDT framework.

In our scenario, the data-gathering process starts from the moment Mr. Verde unlocks the doors of the assigned vehicle and continues until he releases the vehicle making it available for the next reservation (the data-gathering process restarts for the next user). The whole process is context-mediated by means of PerLa, collecting only the data useful for the current user and vehicle context. The data gathered locally from the sensors positioned on the vehicle (GPS position, speed, actual power consumption, …) are pre-processed by the Green e-Box (on which a PerLa module runs) and part of the computation (possibly aggregation) is done by this component. From Green e-Boxes, data are pushed to the GM server using the PerLa middleware infrastructure for further processing and storage.

The reader may have noted that some of the functions offered by PerLa can similarly be achieved by using the T-Rex system and the TESLA language presented in Chap. 8. In fact, for simple requests, PerLa and TESLA are almost equivalent, but some important differences deserve mentioning. The T-Rex engine is a tool for collecting data and managing data streams based on the Complex Event Processing (CEP) paradigm; the two approaches are based on different modes as to receiving and handling data—asynchronous for T-Rex, synchronous for PerLa—and on the very different premises they are based on—T-Rex is event-based, Perla is data-oriented; therefore, they can only be compared as to language expressiveness.

Due to the non-storing data policy, TESLA must know the time intervals in which to work and this could be a shortcoming if the amplitude of the needed time window is not known in advance. Moreover, the impossibility of getting information from a static storage—such as ZTL zones or routes closed to traffic—makes answering some questions difficult, if not impossible.

PerLa, on the other hand, seems to fit many requests involving both static storage and data streams, and has context management capabilities, but it often needs two queries to produce the result (a low-level one, to get data, and a high-level one to process it) and could show a slightly higher answer delay for hard real-time applications.

Therefore, in the Green Move system we made the natural choice of using T-Rex for the event-driven functionalities described in Chap. 8, while PerLa is the elective tool for data-intensive context-aware applications such as those described in this chapter. A thorough comparison of the two approaches can be found in (Crotti 2013).

The system information distribution module (*GMID*) works in a synchronous way: it receives a request from a client, containing its GPS position, and sends back to the client useful data filtered on this position. Different user contexts need different information retrieval frequencies also in order to avoid congestion of the transmission channel; therefore, PerLa also feeds sensors data to the GMID. Moreover, the PerLa context language helps us by allowing different settings in different contexts (e.g. different sampling frequencies).

After declaring the contexts as described in (Schreiber et al. 2012b) PerLa allows the user to declare the activities that the system must perform at run time when these contexts become active. In order to show how the PerLa context language is used, we introduce the following example.

Mr. Verde can drive in different areas of the city: downtown, battery charging stations are close to one another, while in the suburbs they are located farther away. Whether Mr. Verde is driving downtown or not is detected by his GPS position:

if the city centre (identified by its GPS coordinates) is farther than a predefined distance *max distance* from the user's actual GPS position, then he is considered as driving in the suburbs, otherwise he is driving downtown. To give him the needed information, we define in Listing 1 and 2 two different contexts:

Driving in the suburbs (Listing 1) this context will be enabled only if the precondition specified by the `ACTIVE IF` clause is true; in this case, the system will sample GPS position and battery charge every 60 s if the battery charge is <= 50% (`SAMPLING EVERY … WHERE` clause), only if the vehicle is moving and the sensor provides GPS, speed and battery charge data (`EXECUTE IF` clause); if the battery charge is <= 35% an alarm is set (`SET PARAMETER … WHERE` clause) and thus the system will display the nearest charging station.

Driving downtown (Listing 2) if this context is enabled, the system will sample GPS position and battery charge every 120 s if the battery charge is <= 50%, only if the vehicle is moving and the sensor provides GPS, speed and battery charge data; if the battery charge is <= 35% an alarm is set and thus the system will display the nearest charging station.

Furthermore, in both contexts the system checks every 5 min if a context switch is necessary (`REFRESH EVERY` clause), modifying the sampling frequency as a consequence.

Do note how the computation can be distributed to the system components: all the processing involving battery charge is executed locally to the *Green e-box*, sending data to the GM *server* if and only if all the required conditions are satisfied (*speed* > 0 AND *batt charge* <= 0.35), thus preserving battery charge that might be wasted in frequent, unnecessary transmissions. The results of the PerLa queries are also used by the prototype described in Sect. 7 to retrieve data from sensors, whenever needed.

Listing 1 Suburb context

```
CREATE CONTEXT Suburbs_Driving
ACTIVE IF lat > center_lat + max_dist AND
long > center_long + max_dist ON_ENABLE:
SELECT lat, long, batt_charge
SAMPLING EVERY 60 s
WHERE batt_charge <= 0.5
EXECUTE IF EXIST lat, long, speed, batt_charge
AND speed > 0
SET PARAMETER'alarm' = TRUE
WHERE batt_charge <= 0.35; ON_DISABLE:
DROP Suburbs_Driving;
SET PARAMETER'alarm' = FALSE;
REFRESH EVERY 5 m;
```

Listing 2 Downtown context

```
CREATE CONTEXT
Downtown_Driving
ACTIVE IF
lat <=center_lat + max_dist
AND long <=center_long + max_dist
ON_ENABLE:
SELECT lat, long, batt_charge
SAMPLING EVERY 120 s
WHERE batt_charge <= 0.5
EXECUTE IF EXIST lat, long, speed,
batt_charge AND speed > 0 s
SET PARAMETER'alarm' = TRUE
WHERE batt_charge <= 0.35;
ON_DISABLE:
DROP Downtown_Driving;
SET PARAMETER'alarm' = FALSE;
REFRESH EVERY 5 m;
```

6 Pervasive Information Delivery for the Green Move Drivers

Since the set of possible advices stored on the server can be large, the system should balance the computational load between the server, the instances of the GMadvisor installed on GEBs and the GMadvisor client apps, described in Sect. 7.2, and also avoid sending too many suggestions to GEBs, thus exhausting the available bandwidth. To achieve this, the information to be sent to GEBs is pre-filtered at the server level based on the user position, the time and the user's data that is associated with her registration with the Green Move system (non-sensitive information such as age, gender, etc.). The pre-filtered advice received from the server is further filtered on the client app installed on the user's smartphone using the sensitive profile information stored there.

To tailor and distribute information coherent with the users' whereabouts and interests we need a powerful and customizable, yet privacy-safe, distribution service: the GMID. To realize such aim we adopt the *PervAds* framework (Carrara et al. 2013), which, in its original terms, defines a pervasive and privacy-respectful approach to advertising. The framework has been customized to obtain a general distribution channel retaining key privacy aspects. The distribution service provides messages, classified as *service messages* or *ads*. A service providing customized advice should be tailored to the needs of its users, yet granting them privacy: otherwise, users might be inclined to give inaccurate information about their preferences, which is of little use for personalization purposes. In PervAds, privacy control remains (literally) with the user of the system: (sub)contexts composed from the local CDT elements remain stored in the user devices and are used to filter locally the data that come from the GM server. In general, the distribution process comprises three steps:

1. on the central server the GMID system performs a *pre-filtering step* of interesting messages for the client using the part of context obtained from the primary CDT (e.g. age, gender, time and distance among client GPS position and ad/message geo-localized descriptor);
2. the set of pre-filtered messages is sent to the client (e.g. user's personal device), which performs the *filtering step*—the private part of the matching—using user interests configured at the local CDT level;
3. finally, the client displays the subset of the received messages matching the local CDT criteria: overall, the information has been filtered according to the combined CDT.

The message (e.g. an ad or traffic data) is composed of three parts: (i) a short caption, (ii) an (optional) image and (iii) a data structure (e.g. an XML-like file) describing the topics related to this specific ad or information (chosen among the ones described in the local CDT). The party who wants to broadcast a context-aware message (e.g. a shopkeeper or a municipal traffic information service) simply uploads it to an appropriately conceived GM web page and provides metadata about time duration, geospatial information and other possible topics, chosen among the ones mentioned in the CDT (b) in Fig. 3 and displayed by the GM advertisers interface. Interest topics help to tailor visualizations of the ads over the customer base, in order to target each advertisement campaign on a set of specific, possibly interested users.

Resuming the running scenario, Mr. Verde has configured his local client selecting the local context, e.g. personal interest topics among the ones described in the local CDT of his user category, like "I am interested in Chinese restaurants" (**`{cuisine`** = *Chinese***`}`**) or "I am interested in cloth shops which offer children assistance" (**`{Shop_type`** = *clothing*, **`Shop_facilities`** = *children***`}`**) or "I am interested in traffic news" (**`{General_info`** = *traffic***`}`**).

Do recall that the matching between the users' local contexts (stored locally in the client) and message metadata is done by the user client, without sending any confidential information to the GM server: the GMID service is only allowed to pre-filter messages on the basis of the primary context, and send them over by means of anonymous data associated with client devices.

7 Context Management and Information Distribution

Coherently with the system architecture described in Sect. 2, this part of the GM prototype is composed of a main GM context-aware component, the *GMCA*, and an information distribution component, the *GMID*. The *reservation component*, by interacting with the main GM context-aware component, realizes vehicle assignation and vehicle availability forecasts. As seen in Sect. 5, context management at the level of sensors is directly performed by PerLa.

7.1 Context-Aware Data Management Component (GMCA)

This component supervises all the sharing services provided by the system. For instance, the reservation process provides functionality like checking available vehicles, foreseeing vehicles' scheduling, proposing additional services to the users, all taking into account their actual context and historical contextual data. The GMCA component is organized into six modules:

CDT definition, containing the specification of the CDT;

- **Application constraint definition**, through which the designer limits possible context instances excluding incorrect context-element combinations;
- **Database access**, which accesses the GM database shown in Fig. 2 to subsequently build the contextual views of the data;
- **Partial view definition**, allowing the association of each context element with the related portion of data at design time;

- **Context-instance recognition**, which uses the context data that have been collected either explicitly from the user (e.g. current interest), or from the sensors (e.g. traffic info) and from mining historical data (e.g. shopping tastes);
- **Run time contextual-view generation**, which builds the context-aware view by composing the partial views associated with the context elements that compose the current context.

As an example, context data, together with data about vehicles, users and reservations become the input of the module that manages the reservation process (henceforth the reservation system), which evaluates all information at its disposal and generates the vehicle reservation schedule; at the end, reservations are fixed and should not be modified without user intervention. In order to do this, the reservation system evaluates all the vehicles' current states (a vehicle could be *available*, *reserved*, *out of service*, *in charge* or *under maintenance*) and tries to satisfy all reservation requests, although sometimes it might not be possible. The system generates all the possible assignments of vehicles to reservations, sorting the alternatives according to their ability to satisfy all the constraints (e.g. start and end time, nr. of seats of the requested car, etc.). At the end of the process, the best alternative is stored in the database and vehicles are assigned accordingly. These choices may be further optimized by means of sophisticated operations research algorithms.

In addition, the reservation system infers, from the user's context data, a set of possibly useful services to suggest him/her during reservation confirmation.

7.2 *Information Distribution Component (GMID)*

The GMID component takes care of distributing ads and service messages. The architecture of the GMID includes three submodules: (i) a web interface (*mgmtGUI*), to manage service messages and ads, (ii) a dedicated web-service (the *GMID core service*) that coordinates the client-server interaction and (iii) a client application (*client App*) that provides local filtering capabilities and an interface to the web-service. The mgmtGUI and the GMID core service use Java EE technologies, while the information (ads, information messages) storage solution relies on an ad hoc geo-localized NoSQL DB.

Among the GreenMove Applications (*GMA*s) introduced in Chap. 9, the *GM Advisor GMA* exploits the mechanisms available in dynamic applications to provide users with customized advice through context-aware procedures, without requiring that user preferences be known to the rest of the Green Move system.

Based on the notions presented in Sects. 3 and 6, the *GM Advisor* supports privacy-enforced ads and the distribution of service-related information from sellers to customers. It coordinates both the user personal device (e.g. a smartphone, where it has to be installed) and the Green e-Box (where it is provided by default) overseeing the interaction with the GMID core service.

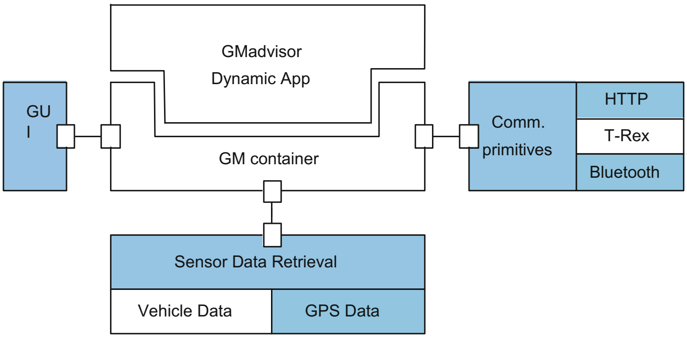

Fig. 4 Features offered by the GMcontainer used by the GMadvisor GMA

The *GM Advisor* relies on the following features of the dynamic applications framework, as shown in Fig. 4:

- **access to the GEB GUI**, to show suggestions on the GEB display (if this is available);
- **communication with the user smartphone** through the Bluetooth channel, to exchange messages between the user device (which selects the advice to show, according to the PervAds framework) and the GEB;
- **communication with external servers** through the HTTP channel, to interact with the central server containing the advice to be distributed;
- **retrieval of vehicle data**, to determine, for example, the current position of the user.

Besides the already described privacy reasons, the choice to adapt the PervAds framework into a GMA is driven by two more factors. First, not all users may be willing to receive additional information during their trip; this might also depend on the purpose of the trip, as a user might be willing to receive commercial ads during a leisure trip, but not during a business one. Second, by exploiting the HTTP channel provided by the GEB, the user avoids consuming her own internet traffic, with its related costs.

The web-based mgmtGUI provides users who want to publish information (ads designers, shop owners) with a simple interface to manage information messages and ads; it acquires the target interest topics from the CDT to be matched and attaches such metadata to messages and ads for subsequent filtering.

Figure 5 shows the steps performed and the interactions among the different components in a usage scenario. As previously mentioned, the *GMAdvisor* is split into two main components on the client side:

- The component installed on the GEB; this part sends the user id and position to the server, receives the advices and displays those that match the user preferences as determined by the client app.

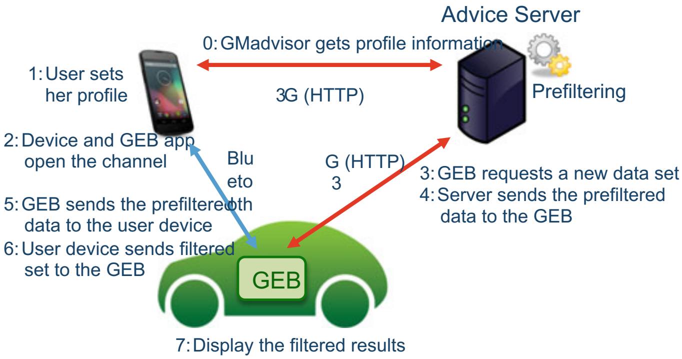

Fig. 5 Schematic description of the GMadvisor GMA and service

- The component installed on the user device; it is responsible for storing the private user preferences that should not reside on a remote server; depending on them, it filters the advices received by the GMA; it can also display advices to the user if the GEB does not have a GUI.

First, the user installs the client app on her device and selects her preferences according to a CDT retrieved from the central server. During the trip, the client app exploits the Bluetooth channel to interact with the GMadvisor GMA installed on the GEB. In response to the GMA sending the id and position of the user, the advice server sends back a set of pre-filtered advice, whose metadata is relayed by the GMA to the client app for further filtering. Finally, the selected advice is displayed on the GEB if a GUI is available there (otherwise the advice is shown on the user's smartphone).

8 Conclusions

Urban mobility and energy saving are among the driving factors in future smart-city planning and development. In this chapter, we have given an account of its context-and-preference-aware information collection and dissemination service based on the Context Dimension Tree, the PerLa sensor language, and the personal advertising platform PervAds, which cooperate in Green Move to providing the right information to the right person at the right time and place.

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References

Beretta D, Quintarelli E, Rabosio E (2011) Mining context-aware preferences on relational and sensor data. In: F Morvan, AM Tjoa, R Wagner (Ed.), DEXA Workshops IEEE Computer Society, pp 116–120

Bolchini C, Curino C, Quintarelli E, Schreiber FA, Tanca L (2007) A data-oriented survey of context models. SIGMOD Record 36(4):19–26

Bolchini C, Curino CA, Orsi G, Quintarelli E, Rossato R, Schreiber FA, Tanca L (2009a) And what can context do for data? Communications ACM 52(11):136–140

Bolchini C, Curino CA, Quintarelli E, Schreiber FA (2009b) Context information for knowledge reshaping. Int J Web Eng Technol 5(1):88–103

Bolchini C, Quintarelli E, Tanca L (2013) CARVE: Context-aware automatic view definition over relational databases. Information Systems 38(1):45–67. doi:10.1016/j.is.2012.05.004

Cappiello C, Schreiber FA (2009) Quality- and energy-aware data compression by aggregation in WSN data streams. Proceedings of the 2009 IEEE International Conference on Pervasive Computing and Communications pp 1–6 Washington DC: IEEE Computer Society

Carrara L, Orsi G (2011) A new perspective in pervasive advertising. Technical Report, Department of Computer Science, University of Oxford, Oxford

Carrara L, Orsi G, Tanca L (2013) Semantic pervasive advertising. Web Reasoning and Rule Systems—7th International Conference (RR). Springer, Mannheim, pp 216–222 doi:10.1007/978-3-642-39666-3_18

Cheng BH, de Lemos R, Giese H, Inverardi P, Magee J, Andersson J, Whittle J (2009) Software engineering for self-adaptive systems: A research roadmap. Software engineering for self-adaptive systems. Berlin, SpringerVerlag, pp 1–26 doi:10.1007/978-3-642-02161-9_1

Colace F, Santo MD, Moscato V, Picariello A, Schreiber FA, Tanca L (2015) Data Management in Pervasive Systems. Springer International Publishing

Crotti S (2013) Comparison and evaluation of some stream processing languages. B. Sc. thesis, Politecnico di Milano, Milan

Dey AK (2001) Understanding and using context. Personal Ubiquitos Computing 5(1):4–7

Liu K (2008) Pervasive informatics in intelligent spaces for living and working. International Conference on Service Operations and Logistic, and Informatics IEEE, pp 18–19

Miele A, Quintarelli E, Tanca L (2009) A methodology for preference-based personalization of contextual data. In: ML Kersten, B Novikov, J Teubner, V Polutin, S Manegold (Ed.), ACM International Conference Proceeding Series. 360, pp 287–298. ACM

Panigati E, Rauseo A, Schreiber FA, Tanca L (2012) Aspects of pervasive information management: An account of the green move system. *CSE*, IEEE, pp 648–655

Rauseo A, Martinenghi D, Tanca L (2011) Context-aware data tailoring thorugh answer set programming. Proceedings of the 19th Italian Symposium on Advanced Database Systems, pp 131–138

Rauseo A (2013) Context aware data management: a full fledged system based on answer set programming. Ph. D. thesis, Politecnico di Milano, Milan

Schreiber FA, Tanca L, Camplani R, Viganò D (2011) Towards autonomic pervasive systems: The PerLa context language. Proceedings of the 6th International Workshop on Networking Meets Databases (co-located with SIGMOD 2011)

Schreiber FA, Camplani R, Fortunato M, Marelli M, Rota G (2012a) PerLa: A language and middleware architecture for data management and integration in pervasive information systems. IEEE Trans Software Eng 38(2):478–496

Schreiber FA, Tanca L, Camplani R, Viganò D (2012b) Pushing context-awareness down to the core: more flexibility for the PerLa language. Proceedings of the 6th PersDB 2012 Workshop (co-locacated with VLDB 2012), pp 1–8

A Smartphone-Based Energy-Oriented Driving Assistance System

Simone Formentin, Carlo Ongini and Sergio Matteo Savaresi

Abstract Recent studies showed that one of the major environmental problems is the transport-related air pollution and road transport alone is expected to be the largest contributor to anthropogenic climate forcing in 2020. The development of more efficient vehicles, the use of alternative energy sources, and the deployment of intelligent transportation systems (ITS) are all solutions toward the decarbonization of the sector. In this chapter, an energy-oriented driving assistance system focusing on the assessment of the current driving style is proposed. In fact, it has been observed that a change of the driving style may provide savings from 5 to 40% of the total energy expenses, as well as reductions of the air pollution. The proposed system is fully integrated in a smartphone application, which acquires the signals related to the vehicle dynamics (e.g., velocity and acceleration) and computes three power-related indices containing significant information about the current driving style. Based on such indices, a feedback communication can be given to the driver (if needed) to induce a change in the driving style, which in turns would result into an energy saving. Differently from the existing studies, the proposed application is vehicle-independent and does not require any connection to the vehicle CAN-bus or OBD-interface. The effectiveness of the proposed approach is assessed via an experimental campaign carried out on urban and extra-urban routes by different drivers. Experimental results show that the proposed driving assistance system may reduce the vehicle consumption up to 30%.

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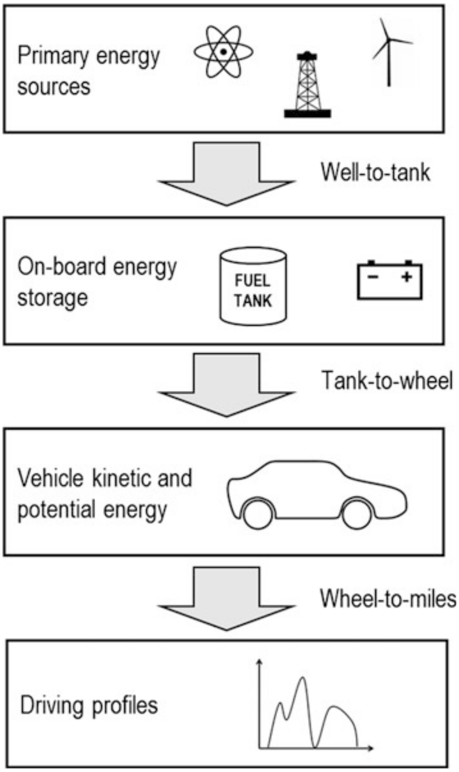
1 Introduction

The complete energy conversion chain related to vehicle energy consumption is depicted in Fig. 1. A first step, commonly referred as “wheel-to-tank”, is the conversion of the primary energy carries (e.g., chemical energy in fossil hydrocarbons or kinetic energy in wind, etc.) to an energy carrier that can be stored on-board (e.g., gasoline, electricity, hydrogen, etc.). Then, the energy stored inside the vehicle is converted by the propulsion system into mechanical energy, in the so-called tank- to-wheel conversion. Finally, the “wheel-to-miles” step refers to the dissipation of mechanical energy used to move a vehicle with the speed and the acceleration profiles chosen by the driver.

In order to optimize the total vehicle energy consumption, all the three step efficiencies need to be improved: the “Well-to-tank” conversion by optimizing the upstream processes, the “tank-to-wheel” by optimizing the power train components, architectures, and control strategies, and the “wheel-to-miles” step by reducing vehicle mass and frictions or by influencing the driver’s profiles and behavior.

Several research studies in this field have been focused on optimizing the “well-to-tank” and the “tank-to-wheel” energy conversions. The former has been

Fig. 1 Energy conversion chain



enhanced by improving the refinery and transportation of fossil oil. The latter has been improved by optimizing the power train components, architectures, and control strategies.

However, the so-called wheel-to-miles has been less considered until the last decade. This energy conversion step depends on the vehicle characteristics (mass, frontal surface, drag, etc.) and on the vehicle's speed and acceleration imposed by the driver's commands: the so-called driving style. The driving style itself depends on driver's behavior and experience but also on external factors such as traffic and car performance (Brundell-Freij and Ericsson 2005). It is well known that the driving style has a huge impact on vehicle consumption.

Driving style systems can be classified in two subcategories (Corti et al. 2013): active and passive (see Fig. 2).

Active driving style systems (Fig. 2a) control directly the driving style by imposing constraints on the vehicle performance. As an example, (Dardanelli et al. 2011a, b, 2012) propose to limit the acceleration and velocity of a light electric vehicle to manage the battery discharge rate. As shown by these works, the active control of the driving style can decrease the energy consumption and increase the range. However, these systems override driver commands and introduce some drawbacks. First of all, active driving style systems introduce safety issues. For example, they could limit the vehicle performance also in case of an emergency maneuver when the vehicle has to move fast to avoid collision or crash.

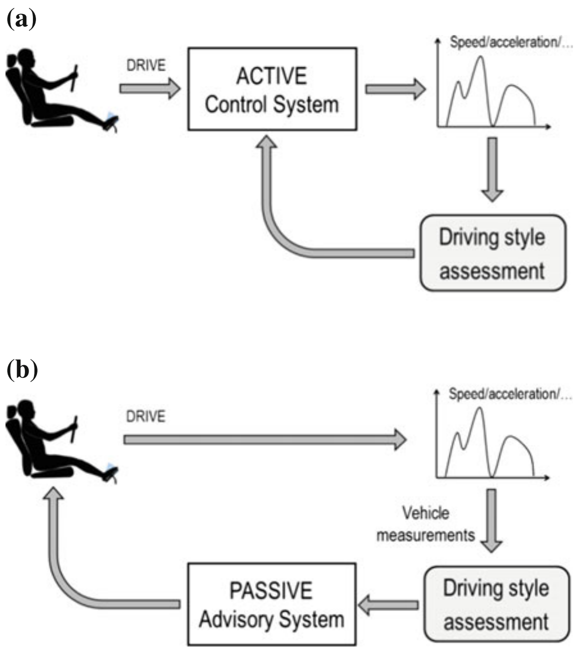


Fig. 2 Driving style systems classification: **a** Active driving style system, **b** Passive driving style system

Furthermore, an ad hoc installation of additional electronic control unit is required for existing vehicles.

An alternative approach is represented by passive driving style systems (see Fig. 2b). This kind of systems does not act directly on vehicle control system but provides a suitable feedback to the driver in order to change his driving style. The interaction between the system and the driver can be performed through different human–machine interfaces (HMIs). Indeed, the main drawback of such an approach is that the effectiveness of the system cannot be guaranteed, as the user may ignore the feedback or not pay attention to the HMI. A huge research effort has been devoted to passive driving style systems, and most of existing studies try to classify the behavior of a driver.

The work in (Murphey et al. 2009) presents a method to classify the driver's style by means of the analysis of the online jerk profile combined with the knowledge of the road type. In (Won and Langari 2005), the driving style is classified in three categories (aggressive, normal, and calm) according to the ratio of the standard deviation and the average acceleration within a specified window and they use the information for the power management system. Likewise, (Tricot et al. 2002) classify the driving behavior into three driving styles applying data classification techniques to vehicle position and driver's actions. Fuzzy systems are used in (Kamal et al. 2007) to determine the driver behavior from noisy data. In (Araujo et al. 2012), a driving style mobile application based on fuzzy system is proposed. The smartphone application gathers vehicle's data through an OBD–Bluetooth interface. In (Lin et al. 2006), Lin and co-authors present a method to classify the driving style in a virtual reality as aggressive or gentle by analyzing the driver's electroencephalogram. In the papers (Syed et al. 2007, 2008, 2009), an advisory system which provides visual and haptic feedback to the driver to change his driving style behavior and reduce the fuel consumption is proposed. Haptic interfaces for improving fuel economy through driving style classification have also been patented (Coughlin 2009). Although all existing systems focus on driving style assessment, they all have two main limitations: (i) the classification of the driver behavior is limited to a finite set of discrete label; (ii) a complete knowledge of vehicle efficiency or the vehicle-dependent measurements is required.

The second limitation is due to the fact that the works are developed just for a particular model of car. The algorithms rely on a deep vehicle knowledge (engine map, gear ratio, gear used by the driver, throttle position). For this reason, the proposed works are not flexible and reusable on different vehicles. Moreover, additional interfaces (like the OBD) are required to read signals from the vehicle CAN-bus.

An alternative is to rely upon inertial measurements. The main advantage of developing driving style application by relying on only such data is the system flexibility. The same system can be used on different categories of vehicles just by adapting few parameters without any vehicle-dependent connection. The first attempt in assessing the driving style via inertial measurements is proposed in (Manzoni et al. 2010; Savaresi et al. 2010). The authors design a method to evaluate the performance of a bus driver. Every time the driver stops, its velocity profile is compared to a realistic reference from an energetic point of view. A synthetic result is provided with a feedback on the bus HMI display. The system was implemented on the buses of Udine in Italy. However, this approach shows some limitation from the user interaction point of view. The feedback is generated only when the vehicle stops so that the driver does not receive any feedback for a long period of time when the vehicle travels without stopping (e.g., highway).

In this chapter, we propose a smartphone-based driving style system based on real-time feedback. A continuous evaluation of the driving style based on inertial measurements is shown to the driver. Differently from the previous works, the proposed system estimates in real-time three indexes related to vehicle power over-consumption instead of classifying the driving style in a finite set of categories. The proposed system is implemented on a low-cost, vehicle-independent device, a smartphone. In this way, we take advantage from an existing pervasive device that integrates all the required hardware (CPU, GPS, accelerometers, and HMI).

An experimental campaign has been carried out with five drivers on a test route for evaluating the performance of the system.

Experimental results show that it is possible to save up to 30% of the total energy.

2 Three Model-Based Indexes

To start with, the considered vehicle model is briefly presented. Then, three model-based indexes to evaluate the driving style are introduced and motivated, as described in Sect. 2.2.

2.1 Vehicle Model

The vehicle longitudinal dynamics of interest can be modeled as

$$P_{iner}(t) = P_{wheel}(t) - (P_{brake}(t) + P_{aero}(t) + P_{roll}(t) + P_{slope}(t)) \tag{1}$$

where $P_{iner}(t) = Ma(t)v(t)$ is the inertial power, M is the vehicle mass, $v(t)$ is the longitudinal speed, and $a(t)$ is the longitudinal acceleration. Further, P_{wheel}(t) is the net power at the wheel, $P_{brake}(t)$ is the braking power, $P_{slope}(t)$ is the power generated by the road gradient, and $P_{aero}(t)$ and $P_{roll}(t)$ represent the power dissipated by the non-conservative aerodynamic and rolling friction forces acting on the vehicle, respectively. Two simplifications will now be made, by neglecting the following terms:

$P_{slope}(t)$, as the system has been conceived for urban environment and the test site is assumed to be flat. It should be noticed that the road gradient may be estimated with a longitudinal accelerometer and/or inferred by road maps made available via Internet connection, see (Dai and Lee 2002; Vahidi et al. 2005).

$P_{brake}(t)$, as it is not measurable and will be treated as a disturbance from now on.

Therefore, one has

$$P_{wheel}(t) = P_{iner}(t) + P_{aero}(t) + P_{roll}(t) \tag{2}$$

The parameters of this model are the vehicle mass M, the rolling drag C_r, the aerodynamic drag Cd, and the frontal surface S. They are approximated as constants (C_r and C_d may in fact vary according to vehicle speed and tires pressure) and depend only on the specific vehicle. Thus, once the vehicle has been fixed, P_{wheel} is a nonlinear function of speed and acceleration, i.e.,

$$P_{wheel}(v(t), a(t)) = P_{iner}(v(t), a(t)) + P_{res}(v(t)) \tag{3}$$

with resistance power $P_{res}(t) = P_{aero}(t) + P_{roll}(t)$ depending on vehicle speed only. The parameters of such a nonlinear dependence can be experimentally estimated by appropriate identification experiments that require measuring only the wheel speed (Dardanelli et al. 2012).

The driver's commands translate into vehicle speed and acceleration, and these are the variables that one must act upon to reduce the energy consumption.

2.2 Cost Function Definition

The cost functions selected to assess the driving style aim at capturing all aspects of power consumption, while being computable in real-time based on inertial measurements only.

The first index $\gamma_1(t)$ is generated as indicated in Fig. 3. It is the high-pass filtered version of P_{wheel}. This cost function stems from considering that $P_{wheel}(t)$ can be split into two parts: a low-frequency one, $P_{LPF}(t)$, which is really needed to move the vehicle, and a high-frequency one, $P_{HPF}(t)$ that represents unnecessary inertial power that is wasted during the process.

The filter order and the cutoff frequency must be tuned to correctly separate the two contributions according to the signal characteristics and to the measurement noise, which are vehicle-dependent. Thus, $\gamma_1(t)$ can be interpreted as the power

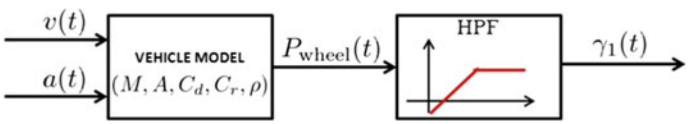


Fig. 3 Block diagram for the computation of γ_1

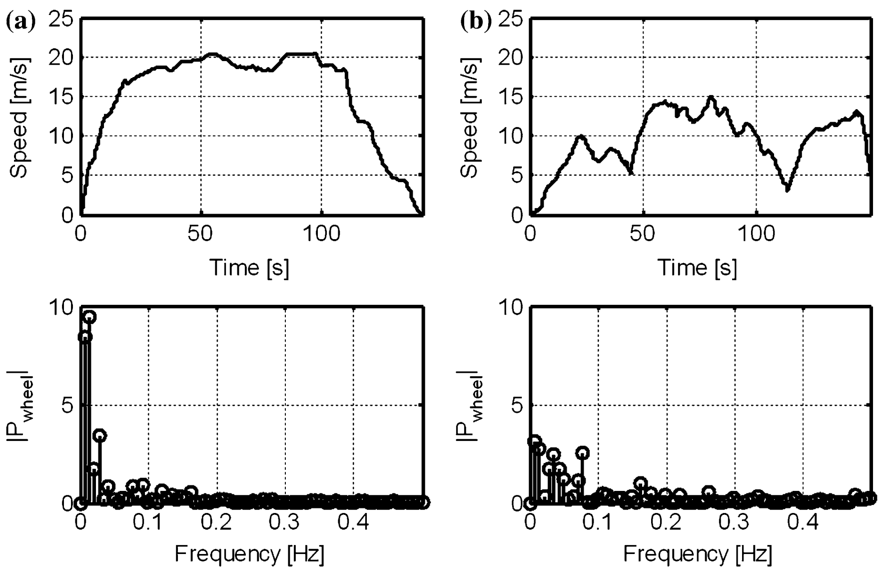


Fig. 4 Examples of two driving profiles. Top plots: time histories of the vehicle speed; bottom plots: spectral content of the signal $P_{wheel}(t)$. Notice that, when the speed is constant, there are no contributions at high frequency

wasted by a fast variation of the vehicle power, a "measure" of the driver aggressiveness. Based on this rationale, the ideal driving style would make the vehicle travel at constant speed (see Fig. 4).

The cost function $\gamma_1(t)$ is, in practice, a measure of the smoothness of the velocity profile imposed by the driver. However, $\gamma_1(t)$ is always equal to zero when the vehicle is proceeding at constant speed (e.g., on a highway).

To increase the driver's awareness about the energy losses due to the cruising speed value, the cost function $\gamma_2(t)$ is introduced as:

$$\gamma_2(t) = P_{res}(v(t)) = 0.5\rho A C_d v(t)^3 + MgC_r v(t) \tag{4}$$

which takes into account the power losses due to friction effects and depends on the cruising speed value $v(t)$, the vehicle mass M, the frontal surface A, and roll and drag coefficients C_r and C_d.

Note that both γ_1 and γ_2 depend on the instantaneous driving style (velocity v(t) and acceleration a(t)). In order to keep track of the driver's behavior over a time window of, say, M seconds, the cost function γ_3(t) is defined as

$$\gamma_3 = \sum_{t=i-M}^{i} \delta^{(M-t)} \frac{P_{res}(t)}{P_{wheel}(t)} \tag{5}$$

where δ is a forgetting factor parameter which allows attributing more importance to most recent data, see (Ljung 1999). Letting $\delta = 1$, γ_3 is the ratio between the power spent by resistance dissipative forces $P_{res}(t)$ and the total power $P_{wheel}(t)$.

Ideally, in this case, an efficient driving style keeps $P_{res}(t) = P_{wheel}(t)$, that is, the energy consumed by the vehicle is due to the chosen speed value and the inertial power dissipated by acceleration/deceleration is minimal.

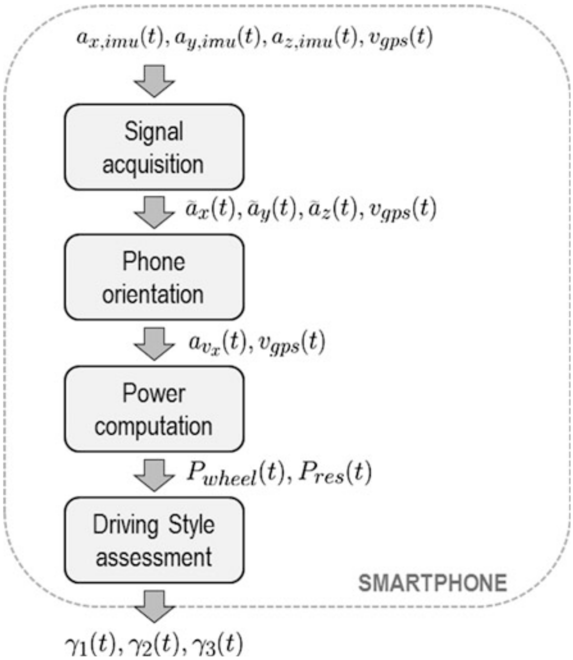
2.3 System Architecture

The proposed driving style system is entirely developed as a mobile phone application. Using a mobile device is particularly intriguing, due to its pervasiveness and user's acceptance, see also (Dardanelli et al. 2012; Manzoni et al. 2010; Corti et al. 2012). Furthermore, modern smartphones already integrate all the hardware required for a driving style application.

The algorithm has been developed to read the smartphone sensors, process the signals, compute the three cost functions, and provide a visual feedback to the driver. The block diagram of the driving style algorithm is depicted in Fig. 5. The main blocks are the following:

- signal acquisition block is responsible of the acquisition of inertial sensors and GPS;

Fig. 5 Block diagram of the driving style algorithm



- phone orientation block performs the estimation of the mobile device orientation, since smartphone acceleration measurements depend on the specific orientation the driver choice in setting the device in the car;
- vehicle power estimation block computes the vehicle power consumption from previous measurements by using data fusion techniques;
- driving style assessment block computes the driving style cost functions and implements suitable interfaces to provide a visual feedback to the driver.

2.4 Experimental Results

The aim of the experiments is to evaluate if the proposed mobile application can improve the energy consumption in a possible mixed urban and extra-urban route.

The test has been performed on a real route in Milan, and it involves a small set of different drivers. The test track, shown in Fig. 6, is 8.8 km long, and it is composed of 5.3 km-long urban route and of a 3.5 km-long extra-urban route. The two parts are generally characterized by different acceleration and speed profiles. In particular, the former is full of traffic because of the presence of several traffic lights and roundabouts, while higher speed and large streets characterize the latter.

The acquisition campaign has been performed with a Tazzari Zero Evo1 (see Fig. 7.

Fig. 6 Map of the experimental track

Fig. 7 Tazzari Zero Evo used in the experimental campaign

Table 1 Tazzari Zero Evo specifications

Weight	540 kg
Frontal surface	2.1 m^2
Max speed	100 km/h
Range	105 km
Battery	lithium-ion 12.8 kWh 80 V
Max power	15 kW
Charging time	Approx. 9 h

See http://www.tazzari-zero.com/ for further details.

The Tazzari Zero Evo is a two-seat, four-wheeled electric car with a driving range of about 140 km and a maximum speed of 100 km/h. The vehicle has a nominal power of 15 kW, a mass of 540 kg, and a frontal surface of 2.1 m^2. The lithium-ion battery pack (160Ah@80 V) requires about 9 h for a full charge (0–100%). Since the heater is powered by the traction battery and its use significantly reduces the range (about one-fourth the total range), it has been switched off for the entire duration of the tests. The main vehicle specifications are synthetically reported in Table 1).

The vehicle is part of a fleet of EVs used for the Green Move vehicle-sharing project and has been equipped with an electronic unit, the Green e-Box (see Fig. 8) which can read signals from the vehicle electronic boards and log them into a micro-SD support. In particular, the considered data are the battery voltage $V_{batt}(t)$ and current $i_{batt}(t)$, sampled every 0.2 s. From these two signals, the power extracted from the battery has been computed as $P_{batt} = V_{batt}(t)\, i_{batt}(t)$. Wheel speed values are also logged and the vehicle speed is computed by simple averaging the wheel speeds over the time. Note that the use of an EV allows an easier and more precise computation of the consumption at the tank, given by the electric power.

Fig. 8 Test vehicle: the iPhone with the driving style application (*left*) and the electronic control unit, Green e-Box (*right*)

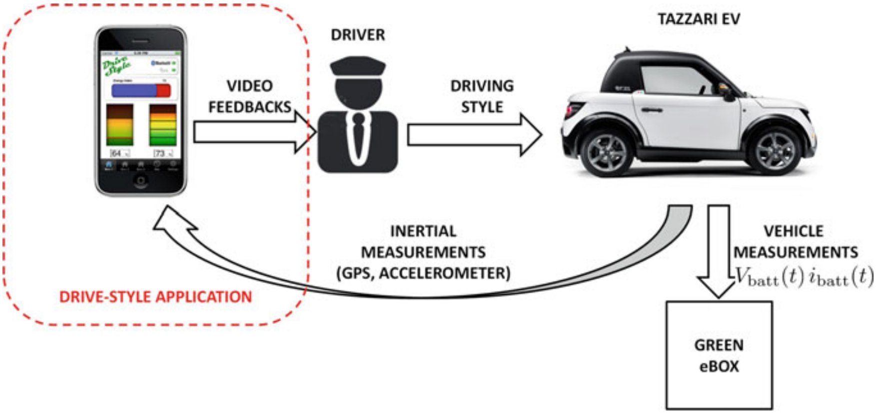


Fig. 9 Block scheme of acquisition campaign setup

Figure 9 shows the block scheme of acquisition campaign setup. The vehicle has been equipped with a smartphone (an iPhone 4) running the driving style application that preprocesses the inertial data, runs the algorithm, and provides visual feedback through the device screen. The electronic box logs the real vehicle measurements.

Three user interfaces (HMIs) will be considered and evaluated separately to assess the amount of energy savings: the first interface (Fig. 10a) reports all the three indexes, the second interface (Fig. 10b) has a single bar with a cumulate γ_1 plus γ_2 indication, whereas in the third interface (Fig. 10c) only γ_1 is shown.

The experimental campaign involved five different drivers (25–30 years old). Each driver performed five different trips on the same route: the first is aimed only at taking confidence with vehicle and route. Another one was carried out without

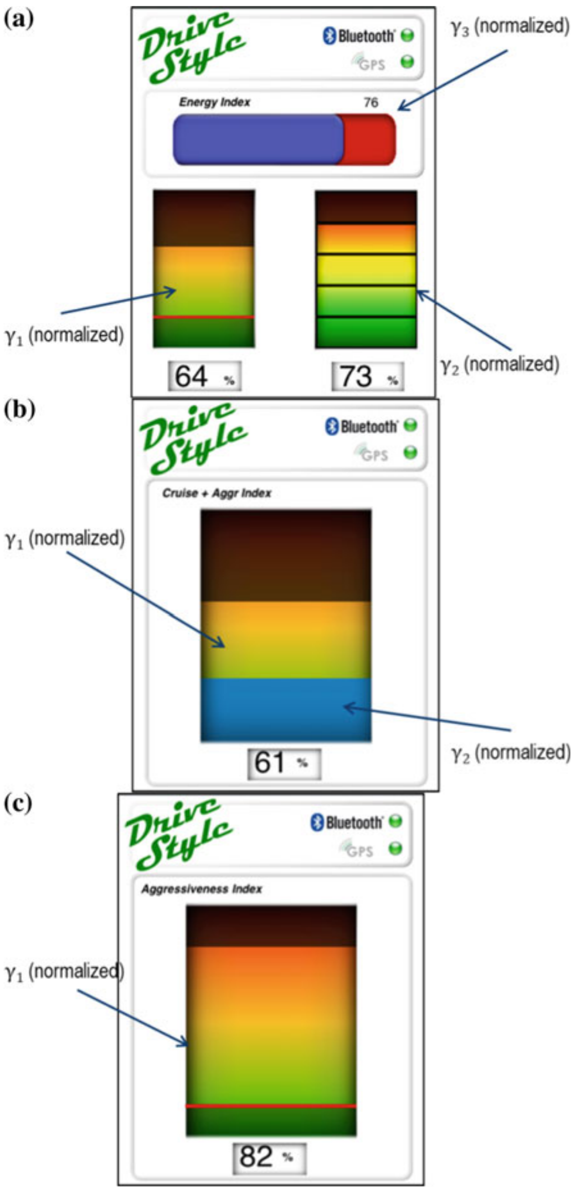


Fig. 10 Three interfaces of the driving style application tested by the different drivers

any interaction with the driving style application. Such a trip is labeled as blind and used as a benchmark to quantify the power consumption associated to the single driver. During the remaining three trials, the volunteers have been driving using all the three interfaces available, one at a time (see again Fig. 10). The order of the blind trial and of the three ones with the driving style application was randomly chosen for each driver, so as to minimize systematic errors in the evaluation of the results.

The experimental results are now illustrated, starting by analyzing those obtained with a single driver and then showing the aggregate results for all volunteers.

2.5 Wheel-to-Miles

Figures 11 and 12 show the vehicle speed and the longitudinal acceleration, as functions of distance, imposed by Driver 2 on the test route (the first test is omitted as it served only to explore the route). It can be easily noticed that Driver 2 imposes higher acceleration and speed when no feedback is active (blind trial): in the extra-urban area at approximately 2.5 km, the maximum speed decreases from 23 to 20 m/s, and the same happens between km 7 and km 8 of the urban part of the test route.

Figure 12 shows a similar pattern for the acceleration: in the blind trial, a peak of more than 2 m/s^2 is reached after 2 km. When the same driver gets feedback from the application, this value decreases to less than 1.5 m/s^2.

Further, Fig. 13 shows the energy spent at the wheel, computed using Eq. 3.1. Indeed, since the vehicle, the route, and the distance are the same, the energy spent at the wheel E_{wheel} depends only on speed and acceleration profiles. The energy spent at the end of the trip in the blind trial is 1.12 kWh, while it ranges from 0.78 kWh with version C to 0.75 kWh with version A of the driving style application, therefore assessing the effectiveness of the proposed approach.

To concisely and quantitatively express the results obtained with all drivers, let us define ϕ_i as the percentage of energy savings at the wheel with respect to the blind trial, namely

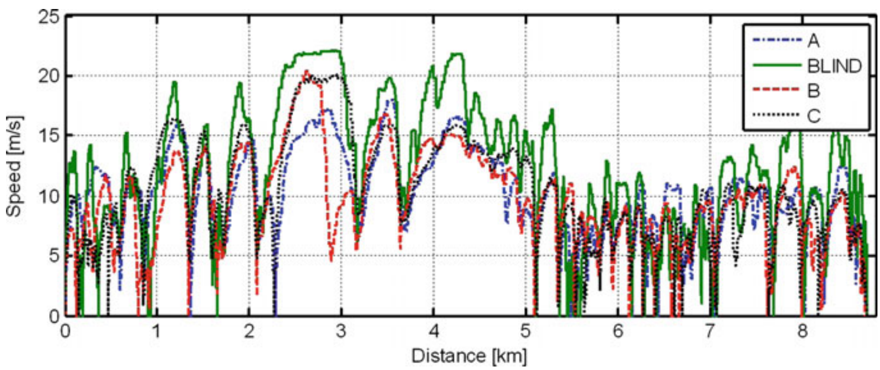


Fig. 11 Speed measured during the four trials of Driver 2 as a function of the travelled distance

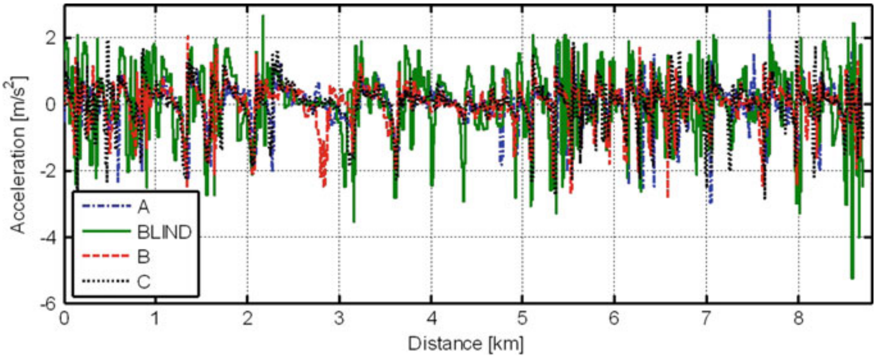


Fig. 12 Acceleration measured during the four trials of Driver 2 as a function of the travelled distance

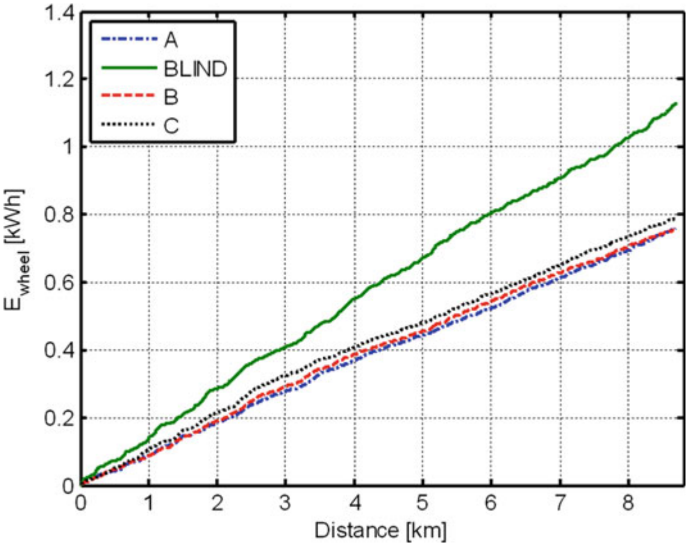


Fig. 13 Energy spent at the wheel by the vehicle with the different versions of the user interface

$$\varphi_i = \frac{E_{wheel,blind} - E_{wheel,i}}{E_{wheel,blind}} \tag{6}$$

where i ∈ A, B, C is the version of the HMI used.

As reported in Table 2, Driver 2 has $\phi_A = 32.8\%$, $\phi_B = 32.9\%$, and $\phi_C = 30.1\%$ during the campaign; consequently, more than 30% of energy has been saved with all three user interfaces. Moreover, note that the savings on the extra-urban area are mainly due to the reduction of the average speed. Without any driving style application, the average speed is 15.5 m/s, while it decreases from 11.2 to 12.6 m/s

Table 2 Synthetic results for Driver 2

	Urban	Extra-urban	Total
ϕ_A[%]	32.2	34.0	32.8
ϕ_B [%]	33.8	31.3	32.9
ϕ_C [%]	29.2	31.8	30.1
Avg. speed A [m/s]	7.5	11.4	8.5
Avg. speed B [m/s]	6.6	11.2	7.7
Avg. speed C [m/s]	6.8	12.6	8.2
Avg. speed BLIND [m/s]	7.2	15.5	8.9

with the different application versions. In the urban area, savings are not related just to velocity; for instance, with version A the driver saves more than 32.2% of energy, but he proceeds with an average velocity (7.5 m/s) of 0.3 m/s greater than with blind version.

It should be remarked here that the average velocity might be influenced also by traffic condition. A driver could take less time to finish a trip just because the traffic was lower during the trial. In order to avoid this bias, we explicitly ignore the idle time in computing the average speed.

2.6 Tank-to-Miles

The “tank-to-miles” energy conversion is not influenced just by speed and acceleration profiles, but also by the engine efficiency, which in turns depends on several variables such as the engine type, the gear shift, the clutch dynamics. However, the savings at the tank are the most important ones from the user’s perspective, since they have a direct economic impact related to fuel/electricity consumption.

To analyze this aspect, Fig. 14 shows the energy extracted from the battery pack of the test vehicle during the trials of Driver 2. Note that in the blind trial, the vehicle consumes 1.69 kWh of electric energy, while, when feedback is active, E_{batt} significantly decreases (1.20–1.17 kWh).

Further, let ξ_i represent the percentage of energy savings at the battery with respect to the blind trial, given by

$$\xi_i = \frac{E_{batt,blind} - E_{batt,i}}{E_{batt,blind}} \tag{7}$$

where again i ∈ A, B, C is the version of the HMI used. For Driver 2, ξ_A = 30.9%, ξ_B = 30.8%, and ξ_C = 29.0%. Note that the savings at the battery are slightly less than the ones achieved at the wheel, nevertheless the user saves 30% of electric energy on average.

This proves that optimizing the driving style in the wheel-to-miles phase also enhances the overall fuel consumption.

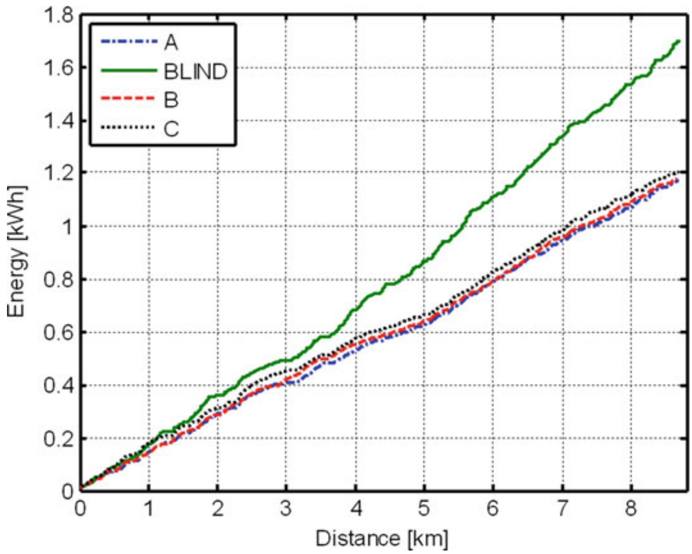


Fig. 14 Energy spent at the battery by the vehicle with different versions of the user interface

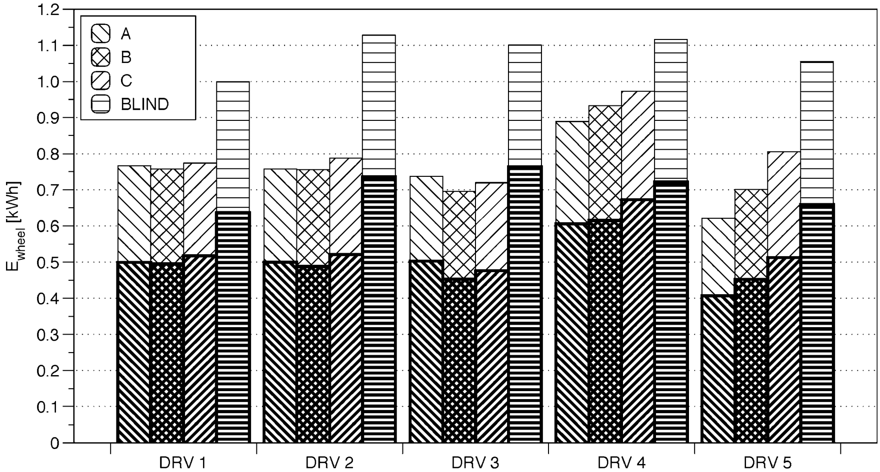


Fig. 15 Comparison between the mechanical energy E_{wheel} consumed by the five drivers. The thicker line represents the energy consumption in the urban area; the thinner one is related to the extra-urban part of the test route

2.7 Aggregate Results

To compare the results considering all five drivers, Fig. 15 shows the mechanical energy consumed at the wheel by all of them. The ticker line represents the urban consumption, while the thinner one represents that obtained on the extra-urban part

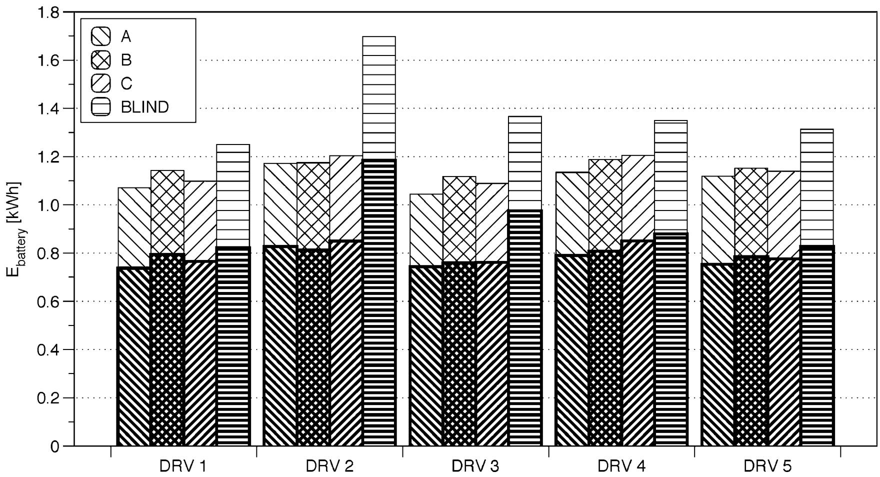


Fig. 16 Comparison between the energy extracted from the battery pack $E_{battery}$ for all drivers. The thicker line represents the urban energy consumption; the thinner line refers to the extra-urban consumption

of the route. By comparing the blind trials, it can be noticed that the five drivers behave quite differently. As an example, Driver 1 saves 100 Wh ($\approx -10\%$) to complete the test route with respect to what done by all the others.

Note that these experimental results demonstrate the effectiveness of the proposed driving style system, as with all user interfaces (A, B, C) the energy consumption is at least 0.2 kWh less than in the blind trial. Nevertheless, it is worth noticing that the percentage of energy savings is: (i) user interface-dependent: Driver 2, Driver 4, and Driver 5 perform better with the more informative interface A, while Driver 1 and Driver 3 perform better with the user interface B; (ii) driver-dependent: different drivers react in different ways to the visual feedback provided by the application. As an example, it can be noticed that Driver 4 saves less energy with respect to the others. Figure 16 reports the energy extracted from the battery pack.

The complete results are summarized in Table 3 which highlights the suitability of the proposed approach. In fact, the system induces all five drivers to save energy when interacting with the driving style application. Driver 2 saves about 30% of the electric energy, while for other drivers the percentage of saving ranges from 10 to 23%. All of them save more energy with the user interface labeled as A. Such HMI can then be considered as the best interface (overall) for the application at hand. This is not surprising, in that it describes a more detailed figure of the driving condition with respect to the others.

Table 3 Energy savings achieved with the three user interfaces by all drivers

	E_{wheel} [%]			$E_{battery}$ [%]		
	ϕ_A	ϕ_B	ϕ_C	ξ_A	ξ_B	ξ_C
Driver 1	23.3	24.1	22.5	14.3	8.6	12.2
Driver 2	32.8	32.9	30.1	30.9	30.8	29.0
Driver 3	33.0	36.8	34.6	23.6	18.2	20.3
Driver 4	20.3	16.4	12.8	15.9	12.1	10.7
Driver 5	41.1	33.6	23.7	14.9	12.3	13.2

3 Conclusions

In this chapter, a novel approach for reducing the vehicle energy consumption by means of a quantitative driving style assessment system has been proposed. The system is constituted by a smartphone application based on inertial measurements, which is vehicle-independent and interacts with the driver by means of visual feedback. Validation results are presented using three human–machine interfaces on an experimental campaign with five drivers. The experiments show that the system improves the driving style and reduces the vehicle energy consumption from about 10 up to 30%.

References

Araujo R, Igreja A, de Castro R, Araujo RE (2012) Driving coach: a smartphone application to evaluate driving efficient patterns. In: Intelligent Vehicles Symposium (IV), June 2012. IEEE, pp. 1005–1010. doi:10.1109/IVS.2012.6232304

Brundell-Freij K, Ericsson E (2005) Influence of street characteristics, driver category and car performance on urban driving patterns. Transportation Research Part D: Transport and Environment 10(3):213–229 ISSN 1361-9209

Corti A, Manzoni V, Savaresi SM, Santucci M, Di Tanna O (2012) A centralized real-time driver assistance system for road safety based on smartphone. In: Meyer G (ed) Advanced Microsystems for Automotive Applications 2012. Springer, Berlin, pp. 221–227

Corti A, Ongini C, Tanelli M, Savaresi SM (2013) Quantitative driving style estimation for energy-oriented applications in road vehicles. In: IEEE International Conference on, Systems, Man, and Cybernetics (SMC), pp. 3710–3715

Coughlin B (2009) Haptic apparatus and coaching method for improving vehicle fuel economy, 2009. United States Patent no. US 7,603,228 B2

Dai FC, Lee CF (2002) Landslide characteristics and slope instability modeling using gis, Lantau Island, Hong Kong. Geomorphology 42(3):213–228

Dardanelli A, Tanelli M, Picasso B, Savaresi SM, di Tanna O, Santucci M (2011a) Control-oriented energy-profiling and modelling of urban electric vehicles. In: IEEE International Conference on Control Applications (CCA), pp. 332–337

Dardanelli A, Tanelli M, Picasso B, Savaresi SM, di Tanna O, Santucci M (2011b) Speed and acceleration controllers for a light electric two-wheeled vehicle. In: 50th IEEE Conference on Decision and Control and European Control Conference (CDC-ECC), pp. 2523–2528

Dardanelli A, Tanelli M, Picasso B, Savaresi SM, di Tanna O, Santucci M (2012) A smartphone-in-the-loop active state-of-charge manager for electric vehicles. IEEE/ASME Trans Mechatron 17(3):454–463 (ISSN: 1083-4435)

Kamal MAS, Kawabe T, Murata J, Mukai M (2007) Driver-adaptive assist system for avoiding abnormality in driving. In: IEEE International Conference on Control Applications (CCA), 2007, pp. 1247–1252 (ISBN: 1085-1992)

Lin C-T, Liang S-F, Chao W-H, Ko L-W, Chao C-F, Chen Y-C, Huang T-Y (2006) Driving style classification by analyzing eeg responses to unexpected obstacle dodging tasks. In: Systems, Man and Cybernetics, 2006. SMC '06. IEEE International Conference on, 6:4916–4919

L. Ljung (1999) System identification. Wiley Online Library

Manzoni V, Corti A, De Luca P, Savaresi SM (2010a) Driving style estimation via inertial measurements. In: Intelligent Transportation Systems (ITSC), 2010. 13th International IEEE Conference on, pp. 777–782. IEEE

Manzoni V, Corti A, Spelta C, Savaresi SM (2010b) A driver-to-infrastructure interaction system for motorcycles based on smartphone. In: Intelligent Transportation Systems (ITSC), Sept. 2010. 13th International IEEE Conference on, pp. 1442–1447

Murphey YL, Milton R, Kiliaris L (2009) Driver's style classification using jerk analysis. In: IEEE Workshop on Computational Intelligence in Vehicles and Vehicular Systems, pp. 23–28

Syed FU, Filev D, Ying H (2007) Fuzzy rule-based driver advisory system for fuel economy improvement in a hybrid electric vehicle. In: Fuzzy Information Processing Society, 2007. NAFIPS '07. Annual Meeting of the North American, pp. 178–183

Syed FU, Filev D, Ying H (2008) Real time advisory system for fuel economy improvement in a hybrid electric vehicle. In: Fuzzy Information Processing Society, 2008. NAFIPS 2008. Annual Meeting of the North American, pp. 1–6

Syed FU, Filev D, Tseng F, Ying H (2009) Adaptive real-time advisory system for fuel economy improvement in a hybrid electric vehicle. In: Fuzzy Information Processing Society, 2009. NAFIPS 2009. Annual Meeting of the North American, pp. 1–7

Savaresi SM, Manzoni V, Corti A, De Luca P (2010) Estimation of the driver-style economy and safety via inertial measurements. Adv Microsyst Automot Appl 2010:121–129

Tricot N, Sonnerat D, Popieul JC (2002) Driving styles and traffic density diagnosis in simulated driving conditions. In: Intelligent Vehicle Symposium, 2002. IEEE 2:298–303

Vahidi A, Stefanopoulou A, Peng H (2005) Recursive least squares with forgetting for online estimation of vehicle mass and road grade: Theory and experiments. Veh Syst Dyn 43(1):31–55

Won JS, Langari R (2005) Intelligent energy management agent for a parallel hybrid vehicle-part ii: torque distribution, charge sustenance strategies, and performance results. IEEE Trans Veh Technol 54(3):935–953

Automatic Fleet Balancing in One-Way VSSs via Closed-Loop Dynamic Pricing

Simone Formentin, Andrea G. Bianchessi and Sergio Matteo Savaresi

Abstract Vehicle sharing systems (VSSs) are typically divided into two categories, defining distinct trip models. In round-trip VSSs, users must drop off the reserved vehicles at the pick-up station; in one-way VSSs, pick-up and drop-off stations may be different. In round-trip VSSs, the fleet is balanced over the stations by definition, whereas in one-way VSSs, the distribution of the vehicles tends to be unbalanced. Due to this fact, there are situations where no vehicle is available and some reservations must be rejected by the system. Moreover, the VSS organization usually incurs the additional cost of the fleet-balancing operations. Then, even though one-way VSSs are more attractive for the users, they are often not preferred by the service providers. Nevertheless, the scientific literature, which addresses the problem, is quite poor. In this chapter, the problem is addressed from a novel perspective, i.e. it is reformulated as an automatic control problem. The key point is to show that, based on the only (mild) assumption that human decisions are sensitive to changes in the price of the service, a VSS can be accurately modelled as a stochastic dynamical system. The obtained dynamical model is then used to devise a complete feedback control architecture. At the end of the chapter, a thorough simulation campaign shows that the performance of the closed-loop configuration may largely overcome that of the existing VSSs. Such results make this direction of research a promising challenge for both control engineers and people working on intelligent transportation systems (ITSs).

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1 Introduction

In the last decades, economic, environmental and traffic congestion problems have led to a large variety of activities aimed at finding new sustainable mobility solutions. In the last decade, the number of vehicle sharing systems (VSSs) has rapidly increased since they represent an effective solution to the above issues. VSSs are typically divided into two categories, each one defining a distinct trip model:

- round-trip VSSs: users must drop off the reserved vehicles at the pick-up station;
- one-way VSSs: pick-up and drop-off stations may be different.

In round-trip VSSs, the vehicles are balanced over the stations by definition, whereas in one-way they tend to be concentrated around the most visited locations. Moreover, the daily movements of people are typically inbound in the morning and outbound in the evening. It follows that, during the day, there are stations with a large number of vehicles (e.g. attraction points such as hospitals, stations and airports or offices and city centre) and, on the opposite, stations with a small number (even zero) of vehicles. This fact yields two main consequences: (i) the number of rejected reservations increases; specifically, all the reservations having an empty station as pick-up station or a full station as drop-off station cannot be accepted by the system; (ii) the VSS organization has to afford an additional cost to balance the distribution of the vehicles.

So far, VSS organizations have addressed this problem in several ways:

- by avoiding one-way trips;
- by increasing the price of one-way trips;
- by paying an additional staff moving the vehicles along the stations (e.g. Bikemi,[1] see Fig. 1).

In the latter case, there are two approaches to move vehicles from one station to the others. If vehicles are bicycles or small vehicles, they can be towed all in a time by a single person (see e.g. the Bikemi case in Fig. 1). Otherwise, either one staff member is devoted to one vehicle or the vehicles must be moved through a fleet of tow trucks (Dror et al. 1998). The latter solution has several drawbacks, e.g. the vehicles may be parked in station not easily reachable by tow trucks. Moreover, loading and unloading vehicles in tow trucks are costly and time-consuming. It follows that the relocation approach based on tow trucks may be not well suitable for an urban setting.

In the following, a different approach called *Feedback Dynamic Pricing* (FDP) for automatically tackling the problem of fleet balancing in one-way and free-floating VSSs is presented. This approach was first presented by Bianchessi et al. (2013). In the proposed method, the VSS is modelled as a dynamical system, and a balancing strategy is derived by formulating the problem as a real-time control issue.

[1]See http://www.bikemi.com/ for further details.

Fig. 1 Tow truck used to relocate the bicycles of Bikemi, the bike sharing service in Milan

In such a technique, the balancing of each station is regulated online by interacting with the users using the trip fee as a control variable. Such a solution eliminates the need for expensive, time-consuming and complicated staff operations for towing or driving vehicles from one station to another.

FDP functions are as follows: different trip fees (each of which is associated to a different drop-off station) are displayed to the user while she/he is driving. The higher the number of idle vehicles at the station, the higher the price and vice versa. To control in real time the balancing of the stations, the definitive price is given to the user only when she/he is at a pre-specified distance (e.g. 500 m) from the nearest of the drop-off stations, but not earlier.

In this chapter, it will be shown via simulations that such a feedback architecture naturally balances the fleet, thus leading to a much cheaper relocation cost. Four indices synthesizing the service quality from both the users and the VSS organization perspectives will be considered.

The sensitivity of the closed-loop system dynamics with respect to the two most significant design parameters of a VSS (i.e. the number of total vehicles and the proportional gain of the controller) will be investigated. The final performance from both a user perspective and a service provider perspective will be finally assessed.

2 State of the Art

In the following, a panoramic view of the scientific literature which addresses the problem of balancing vehicles among stations in one-way VSSs is given.

In Uesugi et al. (2007), users corresponding to different reservations can be forced to share the same vehicle or, on the contrary, a group of users belonging to the same reservation can be split into many groups, each of which has its own vehicle. Thus, three different reservation modes are available: (i) in *normal assignment*, a group of n user may pick up only *one vehicle*; (ii) in *divided assignment*, a group of n user may pick up up to m vehicles ($2 \leq m \leq n$); thus, the original group is divided into m subgroups; (iii) in *combined assignment*, k user groups (belonging to different reservations) which have the same drop-off station share the same vehicle.

Then, the number of vehicles to be assigned is computed based on the minimization of the following objective function T:

$$T = \sum_{i=1}^{K} (\alpha_i - \|V_i\|)^2 \tag{1}$$

where α_i is the number of parked vehicles at the station i, V_i is the optimum number of parked vehicles at the station i, and K is the number of stations of the system.

Although it has theoretically proven to be an effective technique, it may not be of practical use because users are usually reluctant in sharing a vehicle with strangers or, on the contrary, an entire family may not want to be divided in different vehicles.

In de Almeida Correia and Antunes (2012), the problem of balancing vehicles among stations is addressed by the definition of three trip selection schemes, each of which is formulated as a mixed-integer programming (MIP) problem with the objective of minimizing a generalized cost (e.g. the sum of relocation costs and rejected reservations costs). The schemes are as follows: (i) *controlled service*—it assumes that the car sharing organization has total control over the selection of trips from a list of requests made by clients. In this scheme, the organization is free to accept or reject trips in the period they are requested according to the profit-maximization objective. This may lead to great discontent as some clients may find themselves in a situation where they are aware of the existence of vehicles at a desired pick-up depot and still have their requests rejected; (ii) *full service*—it assumes that all trips requested by clients will be accepted. Note that this is not the same as to say that all potential car sharing trips in a city will be met. Indeed, this scheme only guarantees that trips between existing depots will be satisfied, not trips which are missing a depot near their origin and/or destination; (iii) *conditional service*—it is a hybrid one, in which there is no obligation of satisfying all the requests between existing depots but they can only be rejected if there are no vehicles available at the pick-up station.

For each of those schemes, a MIP problem is defined with the objective of maximizing the VSS organization profits T, defined as

$$T = P - C_{m1} - C_r - C_{m2} - C_v \tag{2}$$

where P is the price rate per time step driven, C_{m1} is the cost of maintaining one vehicle per time step driven, C_r is the cost of relocating a vehicle per time step driven, C_{m2} is the cost of maintaining one parking space per day, and C_v is the cost of the depreciation of one vehicle per day.

The simulations reveal that the scheme with higher profits when considering the same price rate charged to the client is the one where the car sharing organization has full control over the trip selection (controlled service). This was expected since it is the scheme with the higher number of degrees of freedom.

In Kek et al. (2009), the objective is to minimize the number of relocations and staff movements. Staff activities are then collected into four categories: (i) *waiting*—the staff waits at a station for the next activity; (ii) *maintenance*—the staff inspects or cleans vehicles at a station, drives a vehicle to a gasoline station for refuelling or drives a vehicle to a workshop for maintenance; (iii) *movement*—the staff travels between two stations without driving a vehicle; (iv) *relocation*—the staff drives a vehicle from one station to another. A cost is assigned to each of the previously introduced activities. Then, the problem is formulated as a MIP problem for a time–space network wherein nodes are stations and arcs are the staff operations.

In Mukai and Watanabe (2005), a relocation algorithm for waiting vehicles is proposed. Vehicles and stations are virtually connected by springs and, for each station and vehicle, equivalent "forces" and "energies" are computed. The movement energy of a car c is given by:

$$E_c = (w^{cc} \times F_c^{cc}) + (w^{cb} \times F_c^{cb}) \tag{3}$$

where F_c^{cc} is the virtual spring force between car c and other waiting cars, F_c^{cb} is the virtual spring force between car c and borderlines of the service area, and w^{cc} and w^{cb} are weight functions of virtual spring forces. Then, based on this virtual springs network, a location controller selects the car with maximum energy and the station with minimum energy and relocates the vehicle.

The problem of keeping vehicle balance among stations gets more complicated in the case of electrical vehicle sharing, where the travel range depends on the level of charge of the vehicles (recharging times range from 2 up to 8 h). This problem has been faced in Bruglieri et al. (2013) in which vehicles are moved by service operators to keep the system balanced. The workers may move easily and in an eco-sustainable way from a delivery station to a pick-up station by using a *folding bicycle* that can be loaded in the trunk of the EV which needs to be moved. The problem has been formulated as a mixed-integer linear programming problem, the objective function to maximize being as

$$T = \sum_{k=1}^{K} \sum_{(i,j)\in A: i \neq 0} x_{ijk} \tag{4}$$

where K is the total number of workers, A are the arcs of the network, and 0 is the depot node. The binary routing variable x_{ijk} equals 1 if the k^{th} worker visits node $j \in N$ immediately after node i, 0 otherwise. Thus, the objective function (4) represents the total number of served requests which must be maximized.

In Di Febbraro et al. (2012), a user-based methodology has been proposed on the basis of an optimal relocation policy in a rolling horizon framework. A VSS has been modelled as a discrete event system (which allows an easy representation of such complex systems) together with linear integer programming techniques.

Then, the whole system is an automaton made of states and events. Ideally, infinite states might be reached by the system (in practice, they are limited). Conversely, the event space is limited and gathers the following five events: vehicle booking, booking modification, booking cancellation, vehicle pick-up and vehicle drop-off. The objective is to minimize the reservation rejection ratio by minimizing the following cost function:

$$T = \sum_{i=1}^{nz} \left| T(i) - \sum_{v=1}^{nv} x_{i,v} \right| \tag{5}$$

where $T(i)$ is the mean number of bookings during a period of time τ that occurs in the origin zone i towards any destination, nz is the number of zones, nv is the number of vehicles, and $x_{i,v}$ is a variable that indicates the position of each vehicle ($x_{i,v} = 1$ if the vehicle v is in i, $x_{i,v} = 0$ otherwise). Then, by solving the relocation problem, the best position in which users should drop off vehicles is determined. This information is transmitted to users (about ten minutes before the estimated drop-off time), together with the offer of a fare discount for returning the vehicle to the proposed destination. Obviously, each user decides whether to accept the proposal or not.

Like the technique proposed in this chapter, the above contribution uses the trip fare as a control variable. However, FDP relies on a dynamic representation of the system and not on a static model of the balancing phenomenon. This property allows to use modern control theory to guarantee real-time properties.

3 The One-Way VSS as a Dynamical System

To start with, the main assumptions behind the method are briefly outlined.

A.1 *Human beings are price sensitive*

A.2 *Full knowledge of all stations balancing levels is available*

A.3 *Vehicles must be endowed with simple, technological infrastructures, which communicate fees variations to the users*

A.4 *Vehicles are endowed with a GPS antenna*

Notice that all of the previous statements are not restrictive at all. Most of the VSSs vehicles are just endowed with on-board screens and input devices. Moreover, 3G communication channel with the control centre and GPS antenna are a *must have* for VSSs. The GPS antenna together with the 3G communication channel allows the system to know the number of parked vehicles in each of the VSS stations. The human price sensitivity can be empirically observed.

Starting from the above assumptions, it is possible to model a VSS as a dynamical system and control its behaviour by using the trip fee as a control variable.

From a system-theoretic perspective, a VSS is very similar to a network of connected water tanks: vehicles move on roads as water flows in pipes and vehicles are stored in stations as water is stored in tanks. The main difference is that water follows physics, whereas vehicles follow their drivers' minds which are unknown non-deterministic systems.

Then, the equations of the system are as follows:

$$x(t+1) = x(t) + \sum_{i=1}^{M} S_j(t) f\left(U_j(t)\right) - r(t) \tag{6}$$

where, M and N are the number of vehicles and the number of stations, respectively; $x(t) = \{x_i(t)\}$ is a column vector of length N, and $x_i(t)$ is the number of vehicles at the i^{th} station at the instant t; $S(t) = \{s_{i,j}(t)\}$ is a selection matrix: $s_{i,j}(t) = 1$ if vehicle j may arrive to the i^{th} station in the instant t, 0 otherwise; $U(t) = \{u_{i,j}(t)\}$ is a matrix of $N \times M$ elements: $u_{i,j}(t)$ is the attitude of vehicle j to go to the i^{th} station; $r(t) = \{r_i(t)\}$ is a vector of N elements: $r_i(t)$ is the number of reserved vehicles at the i^{th} station that will leave before $t+1$; f is the (unknown) user action: the user evaluates all the information and makes his/her choice.

Moreover, the system defined in (6) must satisfy the following constraints:

$$x(t) \in \mathrm{N}_0^+$$

$$u_{i,j}(t) = p_{d_{i,j}} p_{c_{i,j}}(t)$$

where $p_{d_{i,j}}(t) = \frac{max(d_{i,j}) - d_{i,j}}{max(d_{i,j}) - min(d_{i,j})}$ and $p_{c_{i,j}}(t) = \frac{\bar{c} - (c_{fix} + c_{i,j})}{\bar{c}}$, $d_{i,j}$ and $c_{i,j}$ are the trip distance and the trip fee variation for vehicle i reaching station j, respectively; $\bar{c}$ is the maximum applicable trip fee; c_{fix} is the fixed trip fee; Moreover,

$$-c_{fix} \le c_{i,j}(t) \le \bar{c} - c_{fix}, \forall i, j, t;$$

$\bar{c} \gg c_{fix}$ (to have a wide range of controllability);

$$\sum_{i=1}^{N} u_{i,j}(t) = 1, \forall j.$$

A high-level view of such a system is depicted in Fig. 2.

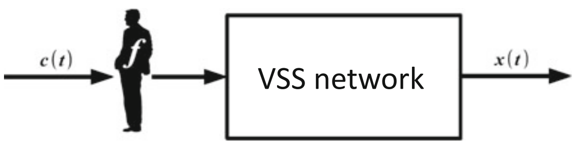

Fig. 2 System-theoretic view of a VSS: *f* is the decision process of the users based on the applied fees *c(t)*. The VSS network is composed by vehicles and stations. The system output, corresponding to the state *x(t),* represents the number of vehicles at the time *t* for each station

The human decision-making process has not a unique mathematical formulation, and it is still largely unknown. It has been empirically observed that people may respond with different decisions to the same situation. Moreover, because of some particular boundary conditions, people are not always free to choose. For instance, if the user is late for an important business appointment, it is very unlikely that the vehicle will be left far from the station nearest to the appointment point, no matter the price.

However, the *Feedback Dynamic Pricing* (*FDP*) method allows one to consider a probabilistic description of the overall decision process, thus leading to a realistic framework.

Therefore, for sake of generality, the function f has been defined as a stochastic function as follows: for each user j, a vector $u_{i,j}$ is computed, which represents the attitude of the user j to go to the i^{th} station (as previously described); $u_{i,j}$ is used to sort all the stations based on the estimated user preferences (from the best to the worst). Here, we assumed that only the first n stations may have a reasonable chance of being chosen by the users; for each one, a probability is computed by placing each one of the stations over a normal distribution with variance σ^2. It is to be noticed that increasing the value of σ makes users less price- and distance-sensitive. Therefore, all the proposed stations look almost the same to users. To the contrary, lowering the value of σ makes users more price- and distance-sensitive.

The probability corresponding to stations further than the n^{th} one are all set to zero, to represent the fact that only a small additional walking distance can be accepted by the users.

The attitude vector $u_{i,j}$ depends upon two contributions which are treated as independent probabilities, so $u_{i,j}$ is the joint probability of:

- $p_{d_{i,j}} \in [0; 1]$ is the probability (attitude) of user i to drop off the vehicle at the station j, it only depends upon the distance between station j and the chosen station at the reservation time;
- $p_{c_{i,j}} \in [0; 1]$ is the probability (attitude) of user i to drop off the vehicle at the station j; it only depends upon the applied trip fee.

A schematic representation of the function f is depicted in Fig. 3.

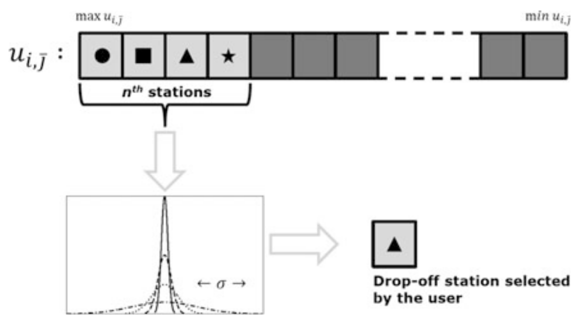

Fig. 3 Schematic representation of the human decision making process function f

A similar formulation for the attitude vector $u_{i,j}$ can be found in Di Febbraro et al. (2012) where the utility vector (herein the attitude vector) is modelled as a binomial logit model which depends, as in the previous formulation, upon distance and time.

4 Feedback Control of Fleet Balancing

The whole control architecture can be described as depicted in Fig. 4, where the VSS is the solid line block which includes users, vehicles and stations (see again Fig. 2 as an insight of this block). The output of the block is $x(t)$.

By hypothesis, it is possible to actively control the VSS through a regulator, namely R, by dynamically changing the trips fees $c_{i,j}(t)$. $\bar{x}_i(t)$ are the desired set points, i.e. the desired number of vehicles at the station i in the time instant t. The state elements $x_i(t)$ are supposed to be measured for each time instant t.

In this work, a static decoupled regulator with components

$$c_{i,j} = K_i \left(x_i - \frac{M}{N}\right), \; i = 1..N, \; \forall j \in M \tag{7}$$

is considered and empirically tuned over a set of different simulations. The regulator is characterized by the constant gain K_i (namely R in Fig. 4), while the term $\left(x_i - \frac{M}{N}\right)$ is the control error ($e(t)$ in Fig. 4). For simplicity (and without loss of generality) in Eq. (7), all the set points are equal (and corresponding to $\frac{M}{N}$), but distinct values for each station may also be used.

Remark. *Notice that the simple controller structure above is sufficient to achieve good results because VSSs can be seen, at a first approximation, as integral systems like water tanks. Therefore, analogously to water tanks, they can be easily controlled using a suitable proportional action. Indeed, more complex control strategies can be investigated that might lead to better performance.*

To evaluate the system performance, four indices are herein defined and divided into two subsets: system-side indices and user-side indices. More specifically, the indices are as follows:

- system-side indices:
  - Rejected reservations $= \frac{\textit{rejected reservations}}{\textit{all reservations}}$ [%];
  - Mean balancing error $= \frac{1}{N}\sum_{i=1}^{N}\frac{1}{T}\sum_{t=t_0}^{t_{end}}\left|x_i(t) - \frac{M}{N}\right|$ [*vehicles*];

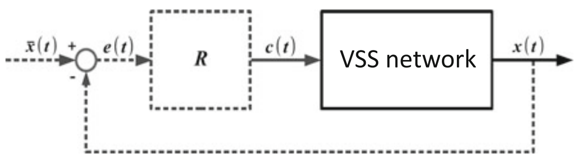

Fig. 4 Control system architecture: open-loop (*solid*) and closed-loop (*dashed*) configurations

- user-side indices:
  - Mean user fee $= \frac{\sum_{t=t_0}^{t_{end}} fees}{\sum_{t=t_0}^{t_{end}} reservations}$ $[euros]$;
  - Additional walking distance $= d(s,e) - d(s,\bar{e})$ $[m]$, where $d(a_1, a_2)$ is a function that computes the distance between two addresses a_1 and a_2; s is the pick-up station; $\bar{e}$ and e are the *preferred user's station* (the nearest to the destination address) and the selected drop-off station.

Similar indices, mainly related to the VSS network state, can be found in Barth et al. (2001)

5 Simulation Results

A simulator of the Model (6) has been developed in order to evaluate the previously introduced performance indices both in an open-loop VSS (namely the existing VSSs with fixed prices) and in a closed-loop VSS (the new approach presented here).

The simulator has been developed from scratch using MATLAB and its graphical user interface development environment GUIDE. Then it has been integrated with the Google Maps APIs for computing travelling times and distances, and for graphically showing the system evolution and results. The simulator allows to:

- generate a daily reservation profile or load a previously saved one;
- define or load a VSS network topology;
- assign a weight to each station which defines the station pick-up and drop-off rates;
- specify many parameters (e.g. the number of vehicles of the fleet and the controller gain);
- simulate the whole network by the use of Google Maps APIs for evaluating travel times and distances.

The main simulator interface with all the editable parameters is shown in Fig. 5. The parameters are as follows:

- the simulation time step size;
- the simulation duration;
- the number of the vehicles of the VSS fleet;
- the vehicles' mean speed;
- the maximum fee;
- a switch to enable or disable the control action;
- the number of simulations to be performed (a statistical analysis of all the simulations results will be automatically provided at the end);
- the controller parameters;

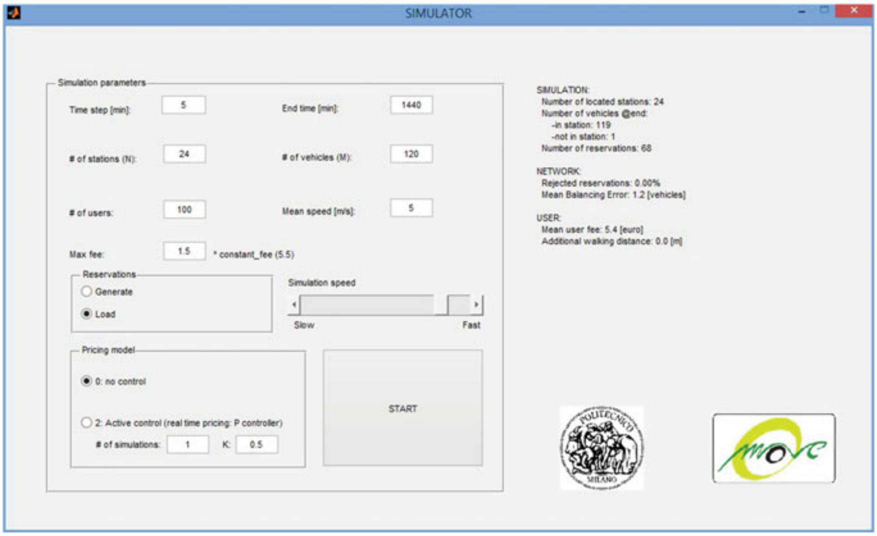

Fig. 5 Main simulator interface, the editable parameters are the simulation time step, the simulation duration, the number of the vehicles, the vehicles mean speed, the maximum fee, a switch to enable or disable the control action, the controller parameters, the number of simulations to be performed and the simulation speed

- the simulation speed (a low speed allows users to visually inspect the system time evolution; a high speed immediately provides the simulation results).

The map of the stations used in this work is the one of the A2A SpA e-moving project in Milan[2] (currently 30 stations). The number of daily reservations is randomly generated by using two distinct uniform distributions: one for the day and one for the night (alternatively daily reservation profiles may be loaded from a data file). The destination of each reservation is chosen by the use of a discrete distribution obtained by previously assigned stations' weights (which define the station pick-up and drop-off rates). In the simulations herein, three attraction points are placed on the map. Attraction points are defined by the use of high weights: a weight is a strictly positive integer, which defines the station drop-off and pick-up rates. For instances, when a vehicle leaves its station, the destination address (black stars in Fig. 6) will be selected by the simulator nearby the station i with the following probability:

$$P_i = \frac{W_i}{\sum_{j=1}^{N} W_j} \tag{8}$$

[2]See www.e-moving.it for further details.

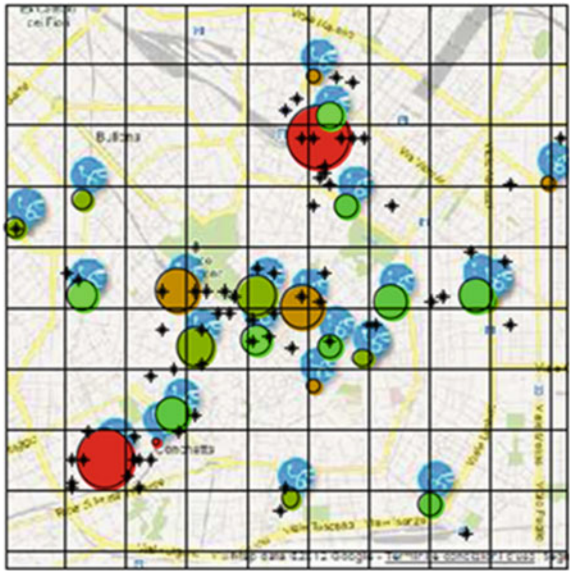

Fig. 6 Snapshot of the real-time visual feedback UI: the *circles* represent the number of vehicles in the stations, and the *black stars* are the destination addresses (which may differ from stations addresses). Three attraction points can be recognized in this network: one in the *middle* and the other two nearby the two big *red circles* (being attraction points, they are full)

Table 1 Simulation results

	No control action	Control action
Rejected reservations [%]:	4.41	1.47
Mean balancing error [vehicles]:	1.1	0.9
Mean user fee [$]:	5.4	4.4
Additional walking distance [m]:	0	220

where P_i is the probability of the station i to be selected as the nearest to the destination address and W_j is the weight of the station j. In Fig. 6 are depicted the locations of all the stations and the daily-generated reservations.

While running, the simulator displays the stations map drawing over each of the stations a circle, which represents the station state. The circles radius is proportional to the number of the parked vehicles, while the colour is related to the mean balancing error (red colour means unbalanced station, green colour means balanced station). In Table 1, the simulation results obtained with open- and closed-loop systems are compared.

Figure 7 shows the balancing of the network at the end of the day (end of the simulations).

To provide a fair comparison between the cases with and without control, simulation results for the controlled system are obtained over one hundred simulations, because of the statistical nature of function f describing the user's behaviour.

Then, the results shown in Table 1 for the *control action* column are obtained by averaging the indicators of all the runs. The results of the simulation without control

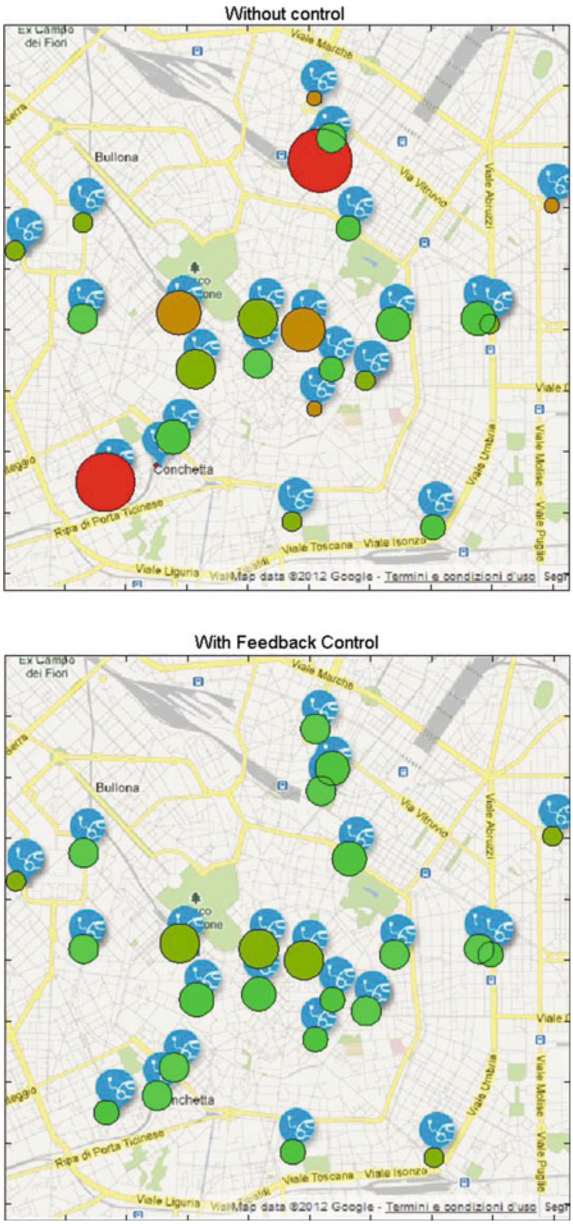

Fig. 7 Snapshots of the fleet balancing at the end of a 24h simulation with (*bottom*) and without (*top*) control action. The *balls* represent the number of vehicles in the station: the radius is proportional to the number of vehicles, while the *colour* (fading from green to yellow to orange to brick red to red) is related to the mean balancing error, unbalanced stations are *red* while balanced ones are *green*

action (*no control action* column) are not stochastic because users are not pushed by the control system to change their drop-off station (no discount or increase is applied), and therefore, users drop off their vehicles at the station closer to their destination.

Table 2 Nominal case parameters

Parameter	Value
Number of stations:	24
Number of vehicles:	72
Constant trip fee [Euros]:	5.5
Max trip fee [Euros]:	11
Simulation time [h]:	24
Simulation time step [min]:	5
K:	0.5
σ:	1

The nominal case parameters used for the presented simulations are reported in Table 2. The average execution time for a 24h-simulation is about 100 s a MacBook Pro 2.53 GHz Core 2 Duo (P8700) with 4 GB RAM running MATLAB R2012b 64-bit.

6 Sensitivity Analysis

A sensitivity analysis has been performed by changing the number M of total vehicles of the VSS, the parameter K in Eq. (7) and the parameter σ of the human decision-making process model. The considered range for M is from 24 (which means 1 vehicle per station) to 192 (which means 8 vehicles per station). The parameter K has been varied from 0.5 to 12. The parameter σ has been varied from 0.5 to 10. In Fig. 8, the results obtained with and without control action are compared and, for both of the cases, the four indices considered in this work are computed.

Notice that the controlled system behaves always better than the uncontrolled one, concerning the first three indices. There is an obvious trade-off between these indices and the additional walking distance. However, notice that good performance can be achieved even by accepting to walk for short distances.

Furthermore, increasing the value of σ lowers the control variable effect on the system. For high values of σ, the system is poorly (or even not) controllable. As a consequence, the percentage of rejected reservations and the MBE indices tend to the uncontrolled system values. On the contrary, both the mean trip fee and the additional walking distance indices do not tend to the values of the uncontrolled system because of fee variations and proposal of more than one drop-off station. The mean trip fee index tends to a value which is slightly lower than the uncontrolled system value. The additional walking distance index tends to a value which is between the minimum (0 m in the uncontrolled system) and the maximum distance value (about 800 m in the controlled system).

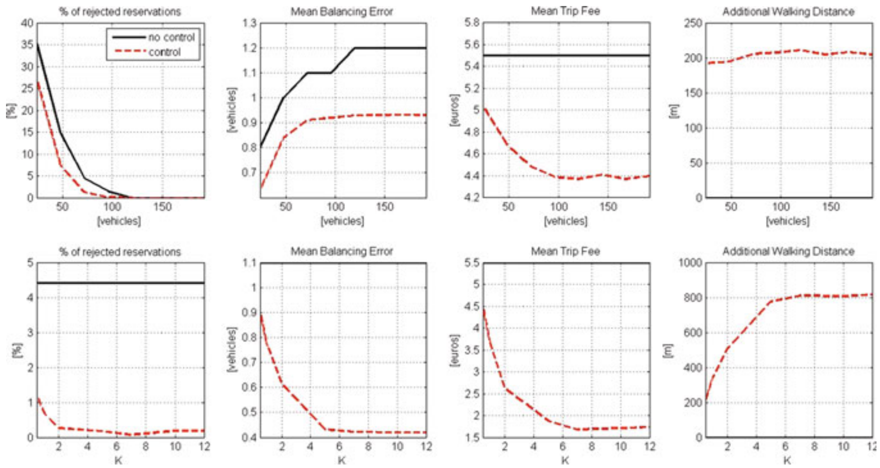

Fig. 8 Sensitivity analysis to the number of total vehicles (*first row*), to the control action (*second row*) and to the σ parameter of the human decision-making process model (*third row*). The behaviour of the uncontrolled (*solid line*) and controlled (*dashed line*) system is compared by computing the indices introduced in this work. From the left: percentage of rejected reservations, mean balancing error, mean trip fee and additional walking distance. The trade-off between the additional walking distance index and the other indices is evident

7 Conclusions

Concerning the network topology, it can be firstly noticed that isolated stations are hard to control and therefore to keep balanced. If a user wants to reach one of those stations, she/he will unlikely decide to change the destination due to the large additional walking distance.

This observation creates a link between fleet balancing and optimal distribution of the stations over the city. It follows that a backward formulation of the balancing problem via FDP would yield a novel way to locate new stations to the VSS. The simulator which has been developed for the balancing problem can be extended to this use by simulating the system behaviour with different network topologies.

Notice that even though simulation results are very good with a simple controller, it is also true that some available information, like drop-off times of currently reserved vehicles, future reservations, future pick-up times, traffic evolution, saturation values, weather forecast, is not used here to optimize the closed-loop system behaviour. This fact makes such a direction of research a very promising challenge for both control engineers and people in the field of ITSs. It follows that this novel formulation of fleet balancing can be seen as the groundwork for many interesting future research projects.

In addition, this new method is environmental sustainable. Vehicles are, in the best-case scenario, only driven by customers, and no additional vehicle trips without customers (i.e. performed by the staff for keeping the number of vehicles balanced over the stations) are conducted.

Future work on this project will follow several directions, among which the analysis of complex control strategies considering more information than the present state, e.g. future reservations and traffic evolution. Moreover, this control architecture will be tested on a real vehicle sharing system in order to analyse in depth the actual reaction of users to real-time changes of the service price.

References

Barth M, Han J, Todd M (2001) Performance evaluation of a multi-station shared vehicle system. In Intelligent Transportation Systems, IEEE

Bianchessi A, Formentin S, Savaresi S (2013) Active fleet balancing in vehicle sharing systems via feedback dynamic pricing. In IEEE ITSC 2013–16th Conference on Intelligent Transportation Systems. Intelligent transportation systems for all transport modes, 1619–1624

Bruglieri M, Colorni A, Luè A (2013) The vehicle relocation problem for the one-way electric vehicle sharing. ArXiv e-prints, July 2013

de Almeida Correia GH, Antunes AP (2012) Optimization approach to depot location and trip selection in one-way carsharing systems. Transp Res Part E: Logistics and Transportation Review, 48:233–247 (Select Papers from the 19th International Symposium on Transportation and Traffic Theory)

Di Febbraro A, Sacco N, Saeednia M (2012) One-way carsharing. Transp Res Rec: J Transp Res Board 2319(1):113–120

Dror M, Fortin D, Roucairol C (1998) Redistribution of self-service electric cars: a case of pickup and delivery. Rapport de recherche RR-3543, INRIA. Projet PRAXITELE

Kek AGH, Cheu RL, Meng Q, Fung CH (2009) A decision support system for vehicle relocation operations in carsharing systems. Transp Res Part E: Logistics and Transportation Review 45:149–158

Mukai N, Watanabe T (2005) Dynamic location management for on-demand car sharing system. In: Khosla R, Howlett RJ, Jain LC (eds) Knowledge-based intelligent information and engineering systems, vol 3681 of Lecture Notes in Computer Science. Springer, Berlin, pp 768–774

Uesugi k, Mukai N, Watanabe T (2007) Optimization of vehicle assignment for car sharing system. In Apolloni B, Howlett RH, Jain L (eds) Knowledge-based intelligent information and engineering systems, vol 4693 of Lecture Notes in Computer Science. Springer, Berlin, p 1105–1111

Information System: Georeferenced Database

Maria Brovelli, Marco Negretti and Ludovico Biagi

Abstract The goal of the implemented system is to provide useful tools to monitor in real time the positions of the vehicles that share the Green Move system. Data can be accessed in two different ways: by the Green Move WebGIS, for browsers; by the geoweb service that delivers the data accordingly to the Web Map Service and Web Feature Service standards that are defined by Open Geospatial Consortium (OGC), for OGC Web Services clients. Static information, like vehicles identifiers or registrations numbers, is published. Moreover, real-time data are published and updated every 5 s: vehicles positions or other data from onboard Global Navigation Satellite System as well as useful data from others sensors, like speed and battery charge level and static information, like vehicle identifier, registration number. Furthermore, delivered vehicles positions are processed to correctly georeference them in correspondence of roads. Free and open-source software has been used to implement the service: MapServer, OpenLayers, and PostGIS/PostgreSQL provide the GeoDB, and OpenStreetMap service is used for road maps.

1 Introduction of the Delivery Data Service

We can easily model the service like in Fig. 1: Data are sent from vehicles and are stored in a database, and then a delivery service provides them to the users.

To obtain a high level of data accessibility in the delivery data process, we have chosen to implement two different types of data access:

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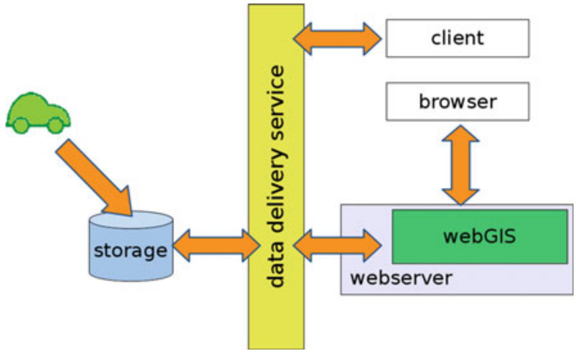
D.F. Bignami et al. (eds.), *Electric Vehicle Sharing Services for Smarter Cities*,
Research for Development, DOI 10.1007/978-3-319-61964-4_13

Fig. 1 Data flow diagram



- WebGIS. A generic user can use a common browser to access the WebGIS Internet page: He can navigate and query the map using the tools that are available in the Web site.
- Geoweb service. It is a web service oriented to geographical data; in this case, the data are accessed by a client software able to communicate with the Web service. In a framework oriented to geographical data, the standards to share and deliver data defined by the Open Geospatial Consortium (OGC) should be considered.

The main data that we have to deliver are the time variable vehicles position and charging stations fixed positions.

Regarding the vehicles, a Global Navigation Satellite System (GNSS) device on board is used to determine position in time, and, in our test case, we have considered also to publish other data related to the cars: identifier number, speed, number of satellites used to determine the position, accuracy of estimation; generally, we can include every kind of information available from the GNSS device or also from any other kind of device on board. For the charging stations, we have considered to publish also the number of the available charging places.

In the next sections, we shall discuss how we implemented services, the used software, and the data organization; a complete description of the built system will be given in the following to better detail the schema of Fig. 1.

2 Targets that Drove the Implementation Process and Consequent Technological Choices

All of our choices were aimed at achieving the highest possible level of interoperability, in terms of both data and software. To define how to deliver the data, we also considered the need to respect existing standards, also at the national level, to provide a really user-friendly service.

2.1 Interoperability: Make Data Accessible

Data interoperability is very important to allow a data access that is independent of the operating system, the geographic information system (GIS) software, or any other local configuration or property. In this way, interoperability data access and mutual independence between client and server environment are assured.

In this context, as mentioned in the previous paragraph, a leading role is played by the Open Geospatial Consortium (Reed 2011): OGC is an international not-for-profit organization with more than 400 members from different areas and with different skills, such as private companies, government agencies, academic, nongovernment organizations.

The main goal of OGC members is to share the development of standard interfaces to support exchange of geographical data and data interoperability.

Delivering geospatial data using a geoweb service, therefore, allows everyone to access the data, provided that the geoservice and the client adopt the same standard: Generally, all the GIS software use the standards defined by OGC.

OGC has defined different standards, generally named OGC Web Services (OWS), according to the data type and service that are provided.

For example, we have:

- Web Coverage Service (WCS), to publish multidimensional raster data;
- Web Feature Service (WFS), to publish and edit (transactional server) vector data;
- Web Map Service (WMS), to publish map image;
- Web Processing Service (WPS): rules for geospatial processing, to standardize inputs requests and outputs responses;
- Catalog Service (CS-W), supports metadata for data and services, and standards to publish and search them;
- Sensor Observation Service (SOS), to acquire and publish data from sensors.

These are just the main standards: many others exist for specific purpose.

We chose to model data as vector points using GNSS coordinates to define positions; all other information is modeled as point attributes. For these kind of data, we chose to adopt WMS and WFS standards.

The WMS standard (De La Beaujardiere 2006) defines an interface to manage map images. A user makes a request defining the geographic layers, the area of interest, reference system, and image resolution. The server manages the request and returns the map image to the user in one of the formats defined by the standard, for example, JPEG or PNG.

We implemented the service using the version 1.3 of WMS because this version is commonly used by many public Italian administrations like, for example, *Geoportale della Lombardia*[1] and *Geoportale Nazionale*[2] (PCN), operated by Ministry of Environment; at the European level, INSPIRE[3] directive refers to this standard version.

Therefore, we framed our service in a wide group of geoweb services that already exist.

The WFS standard (Vretanos 2014) defines an interface to manage vector data, as the ones we use. The user makes a request like in WMS, but in this case the service delivers vector data. To be compliant to the WFS standard, a service shall be able to describe the vectors features using the GML[4] application scheme: Server may provide additional data formats, such as the ESRI[5] shapefile; however, GML is mandatory to be WFS compliant.

Also, this standard is widely used in Italy, for example, in already mentioned cases of PCN and Lombardy geoweb services.

Then, we have:

- a view service, following the WMS standard;
- a download service for the vector data, following the WFS standard.

2.2 Accessibility of Software

In order to be free of using, analyzing, modifying, and distributing our system, and to warrant the access without any kind of license problem (Stallman 2007), we used free and open-source software (FOSS) to build these services.

To deliver data, we used MapServer (McKenna et al. 2015), an open-source platform for publishing spatial data using OGC standards, and interactive mapping applications to the Web; it runs on all major operating system (Linux, Mac OS X, Windows), and the last release is the 7.0.1 in the February 2016.

To collect data, we used PostgreSQL (Riggs et al. 2015), one of the most important and powerful open-source object-relational database systems. It runs on all major operating systems, including Linux, UNIX, and Windows; it has full support for foreign keys, joins, views, triggers, and stored procedures (in multiple

[1]The map service of Regione Lombardia public administration: http://www.geoportale.regione.lombardia.it/.

[2]National map service: http://www.pcn.minambiente.it.

[3]INSPIRE (Infrastructure for Spatial Information in Europe—Directive 2007/2/EC) is an initiative launched by the European Commission, and it aims to ensure that the spatial data infrastructures of the Member States are compatible and usable in a Community and transboundary context.

[4]GML, or rather Geography Markup Language, is an XML encoding to represent geographic information; it is defined in ISO 19136:2007 standard.

[5]Environmental Systems Research Institute.

languages). It includes most SQL data types, including *integer*, *numeric*, *boolean*, *char*, *varchar*, *date*, *interval*, and *timestamp*.

Furthermore, very important for our operating purposes, there is a database extension named PostGIS (Corti et al. 2014) that implements additional supports for geographic objects in PostgreSQL, allowing it to be used as a spatial database for geographic information systems, much like ESRI's SDE or Oracle's Spatial extension.

PostGIS:

- adds new data types, such as *point*, *linestring*, *polygon*, *multipoint*, *multi-linestring*, *multipolygon*, *geometrycollection*, so you can define data as geographical;
- adds new functions to build geographical multidimensional queries;
- provides tools to easily import data in the database from the most common formats for geospatial data (like shapefiles);
- allows direct access to data from many GIS software, like MapServer.

To realize the browsing interface, we used OpenLayers (Gratier et al. 2015): It is a JavaScript library with many tools to insert interactive maps inside html pages, to navigate and query them.

By using OpenLayers, we can access and publish data from all the sources that deliver data according to the OGC standards: Then, we can publish both the pertinent data of the Green Move project and all the other data that we need to give to the user a full view, adding, for example, the WMS from Regione Lombardia map service, OpenStreetMaps, and Google Maps data as background data.

All the adopted software GIS are members of the OSGeo projects. The selection process to become a member of OSGeo Project is managed by the Open Source Geospatial Foundation (OSGeo), a not-for-profit organization whose mission is to support the global adoption of open geospatial technology. To be a member of this selected group of projects, many constraints must be respected: Firstly, a project must be open source, but this is not enough. For example, all the code should be compatible with open-source licenses to avoid future troubles, and each project should have also an active community, both of users and of developers, that warrants a sustainable future development of the project (OSGeo wiki 2016).

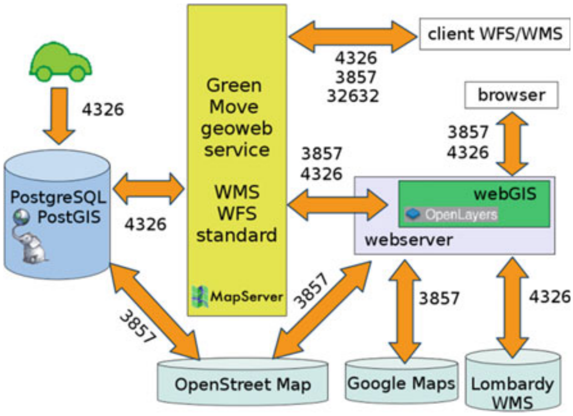
When a project asks to be added to the OSGeo projects, it remains for a while at the level of "incubating project"; at the end of the verification process, in the positive case, it can become an official "OSGeo project."

The membership at the OSGeo projects is not easy, and it gives us confidence about the reliability of these projects.

All these softwares are free and open source, but this does not mean that a license does not exist (St. Laurent 2004). In particular:

- MapServer is released under a *MIT-style license* (Massachusetts Institute of Technology 1988);
- PostgreSQL is released under *PostgreSQL License*, is a BSD-style license (PostgreSQL Global Development Group 2010);

Fig. 2 Scheme of implemented service



- PostGIS is released under the *GNU General Public License v2* (Free Software Foundation 1991);
- OpenStreetMaps is released *under BSD 2-clause license* (Regents of the University of California 1998).

3 Description of the Delivery Data Service

Figure 2 depicts the schema of the service that we implemented; note the double way to access data:

- using a common browser, through the webGIS page built with OpenLayers libraries;
- using any client that implements WMS or WFS standards.

Data from different sources and with different reference systems and coordinates are used: These data can be managed together, and their reference systems can be converted through PostGIS and MapServer tools.

In Fig. 2, the reference systems and coordinates are reported with their EPSG codes[6]; in detail, we have:

- WGS 84, geographic coordinates, code 4326: positions from GNSS car receiver and data from Regione Lombardia WMS;
- WGS 84/Pseudo-Mercator coordinates, code 3857, from OpenStreetMap and Google Map;

[6]EPSG Geodetic Parameter Dataset is a collection of definitions of reference systems and coordinates with the reciprocal transformations; there is also an online registry: http://www.epsg-registry.org/.

- WGS 84/UTM zone 32 N, code 32632: We choose to deliver data using also this coordinates, because they are widely used in Italy.

As it is shown in Fig. 2, the core of our service is the Green Move geoweb service, built using MapServer. It queries the database where the data from Green Move cars are stored, and it deliveries them using WMS and WFS standard in EPSG 4326, 3857, 32632.

The data of the Green Move geoweb service can be accessed in many different ways, for example, using a desktop GIS or by loading Green Move data through another Web service; anyway, we can combine data from different sources, local and remote, and see them all together.

In the example of Fig. 3, QGIS, a desktop GIS (QGIS Development Team 2014), is used to visualize data from Green Move geoweb service (cars positions and charging stations) together with locally stored data (urban area, roads, rivers, railways, municipally borders). In Fig. 4, Green Move data have been loaded with the online viewer of *Geoportale Nazionale*: We visualize them together with data of the *Geoportale* geoweb service (e.g., the orthophotos).

The user can browse and query the data, and to see, for example, how many places are still available in the charging points, the position, the battery charge remaining, or any other detail concerning a vehicle.

The Green Move webGIS (Fig. 5) is accessible with a common browser and publishes data from four different sources:

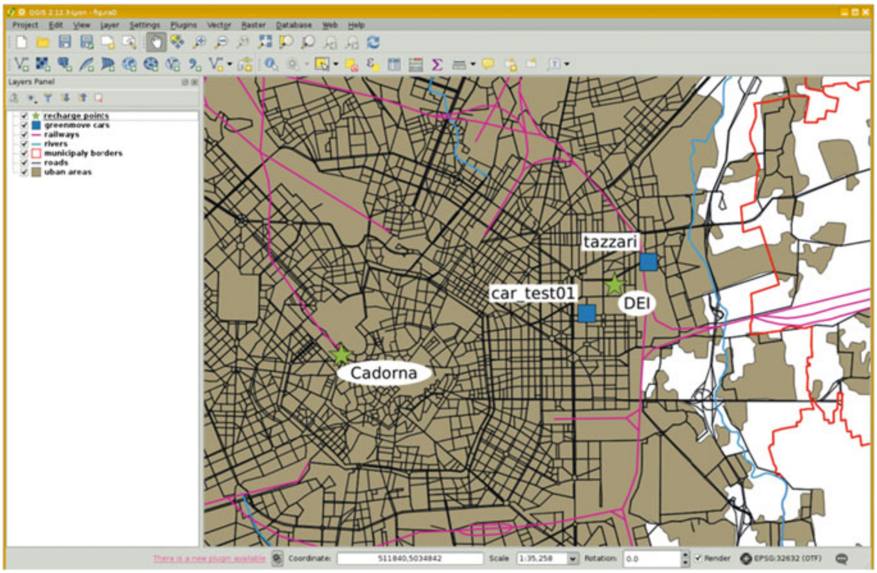


Fig. 3 Example of data access using a desktop GIS

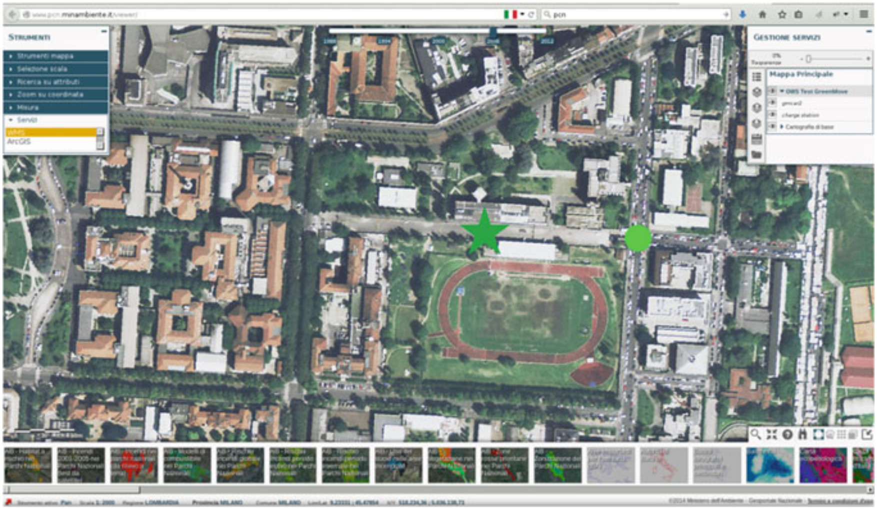


Fig. 4 Example of data access using a Web viewer

Fig. 5 Green Move webGIS

- data from Green Move WMS geoweb service;
- data from Regione Lombardia WMS (CTR[7] and orthophotos), OpenStreetMap and Google Maps services that the user can use as background map.

Furthermore, in a webGIS page a link to Google Street View[8] data is available that permits to navigate the location where the car is; moreover, all the car data can be accessed. Both data and images in the page are updated every 5 s, so we can follow the car during its movement like if we were aboard. Then, we can also access the Street View tools and explore the neighborhoods of the current position (Fig. 6).

A test version of these services is available at the following link:

- GreenMove webGIS: http://greenmove.como.polimi.it;
- GreenMove OWS service: http://greenmove.como.polimi.it/cgi-bin/owsgm.

In the demo version of the services, the data are freely available, but, to avoid privacy violations, access rules should be implemented according to the kind of data and the user profile.

4 Vehicles Data Processing

The coordinates estimated from the Green Move vehicles are not always correct: Indeed, the accuracy of the position estimates by the GNSS receiver varies and depends on the observation conditions; for example, in a narrow street, with high buildings (urban canyon), the satellites configuration is poor and this decreases the positioning accuracy. In Fig. 7, a possible result of this lack of accuracy is shown: The car is not always positioned on the road; sometime, it appears on the sidewalks and even inside buildings.

To correct these errors in the coordinates positions, first of all we need a vector map of the streets that shall be used as reference.

We chose OpenStreetMaps—OSM (Ramm et al 2010)—as reference map: OSM is a collaborative project to create a free editable map of all the world; it is like the Wikipedia project, but oriented to the geographic content. The data are released under Open Database License (Open Knowledge Foundation 2009) that allows to freely share and modify them.

We chose OSM data mainly because:

- OSM is an open project, so it is a choice consistent with the previous;
- the data can be downloaded, locally stored, and used as reference to provide position corrections;

[7]Carta Tecnica Regionale: regional topographic map.

[8]Google Street View provides panoramic views from positions along many streets in the world. It was launched in 2007 with images only from cities in the USA, but it grew quickly and now it includes images from many cities and rural areas worldwide, including Milan.

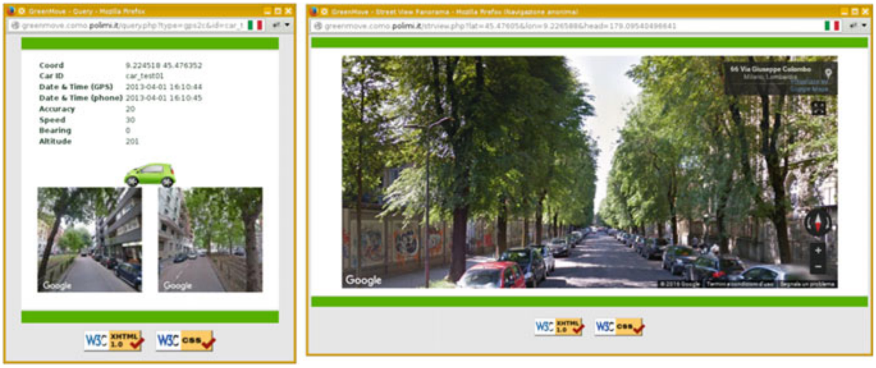


Fig. 6 Access to Google Street View image from Green Move webGIS

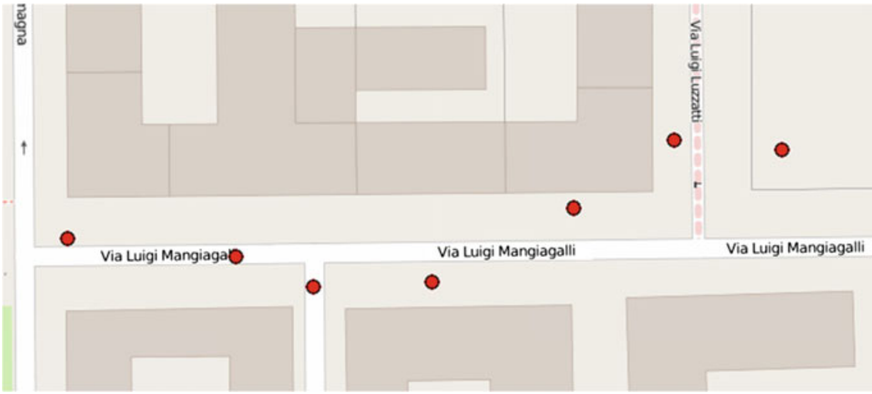


Fig. 7 Circles indicate the measured coordinates of a car test every five seconds

- OSM is continuously updated and, anyway, wrong data can be corrected by users;
- the corrections can be shared with all the community, contributing in this way to growth of OpenStreetMap project;
- we do not add other costs to the Green Move project, to buy and keep up to date the data.

We downloaded OSM data of the Milan area, and we imported them using the geographical tools available with the PostGIS extension.

Both OSM data and GNSS data coming from Green Move cars are stored in geographical structure in the database: An extract of these structures is shown in Table 1. Besides the usual data types (*integer*, *double*, *char*, and so on) used for scalar attributes (such as number of viewed satellites, cars speed, street identifier), a multidimensional data type, named *geometry*, is used in the database tables. It permits to store in a proper way, not trivially as simple list of couples of real

Table 1 Partial view of cars and OSM road tables

Field	Data type
Ts	Timestamp without time zone
Gb_id	Character varying(50)
Coord	*Geometry (Point, 4326)*
Speed	Double precision
Satellites	Integer
…	…
Field	Data type
Osm_id	Bigint
Way	Geometry (LineString, 4326)
Oid	Integer
…	…

numbers, points (GNSS car position), and lines (roads map) and defines the associated reference system (in Table 1, EPSG code 4326: WGS 84, geographic coordinates). This more complex data representation model permits us to build queries using geographic tools, for example, to extract the nearest point to a line, the point inside a building, and so on.

To correct the car position in real time, a trigger has been implemented that is automatically executed every time that an "update event"[9] happens in cars table. The trigger calls a function that pulls out all the road segments that are in the neighborhood of 20 m[10] from the estimated position. Then, we choose a segment that meets certain characteristics and, using PostGIS tools, the GNSS point is projected on this segment: The projected point is stored and published as true car position.

In the first version of our function, we simply chose the closest segment to the point, but, as it is shown in Fig. 8, when a crossroad exists the corrected point can jump from one segment to another one.

For this reason, another constraint has been introduced in the segment selection procedure. It computes also the bearing for all the available segments and the bearing of the movement of the car (using the current and previous positions); finally, the nearest segment is chosen that has a bearing similar to that of the car. In this way in the example of Fig. 9, the perpendicular segment to the car movement is rejected, while the segment with a bearing more similar to the car movement is chosen.

The different types of corrections and the original point positions can be compared on this page of the Green Move webGIS:

http://greenmove.como.polimi.it/pos-cor.php.

[9]This event happens when a new position has been sent from the GNSS receiver installed on the Green Move car to the database table.

[10]If the car position is farther than 20 m from any road segment, we assume that there could be an error in the road map and we avoid to make a so great correction.

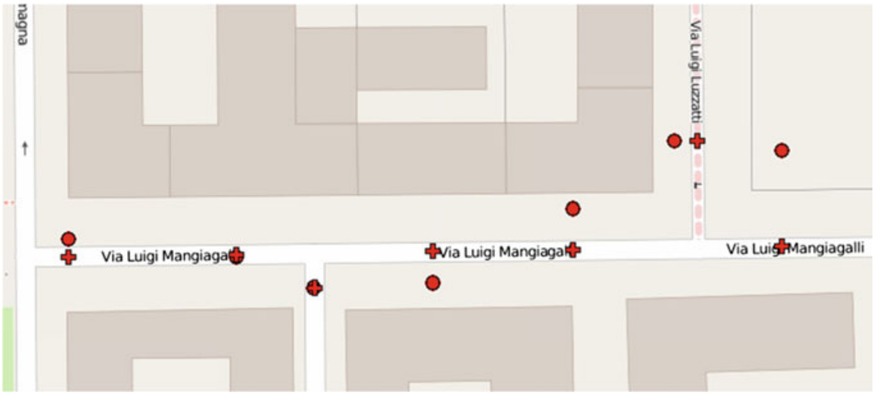


Fig. 8 Circles indicate the coordinates given by GNSS receiver, the crosses are the corrections made using as reference the nearest road segment. Note the error in the crossroads

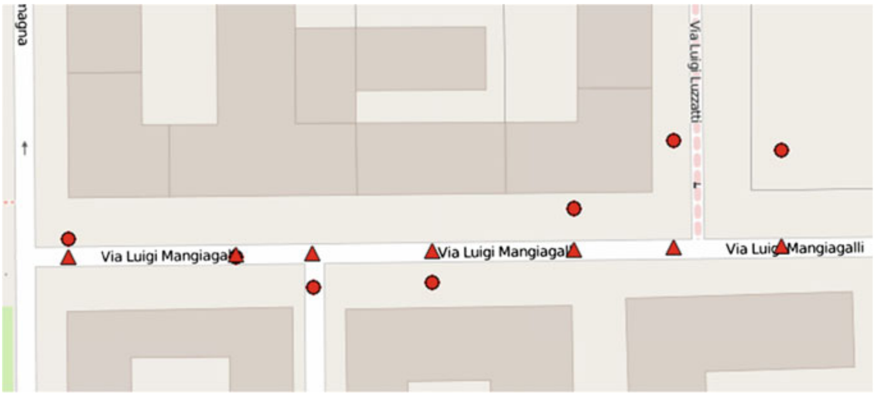


Fig. 9 Circles indicate the measured coordinates; the triangles are the correction made using as reference the nearest road segment with a bearing similar to the bearing of the movement

5 A Possible Future Evolution: City Monitoring

We can evolve the simple model used until now in another one that is more complex and can better model the system.

In the previous sections, we consider the Green Move cars as points with relevant attributes (level of battery charge, speed,…).

However, we can also consider cars as sensors in motion that collect data from the environment around them: We can image to install other devices on cars to collect data like pollution and so on.

These data should be interesting to monitor the city condition and to plan possible actions to improve life condition of its citizens (Brovelli et al. 2011).

Following this assumption, we can model the system in a different way: Instead of using the WFS standard to deliver generic vector data, we can adopt the Sensor Observation Service—SOS (Broring et al. 2012).

This OGC standard is thought to be used in cases in which sensor data need to be managed in an interoperable way. It defines a Web service interface which allows to manage temporal series of data and defines operations to insert new observations, register new sensors, and remove existing ones. We built a test Web service using the istSOS software (Cannata and Antonovic 2015) that has been developed by the Earth Science Institute (IST) at the University of Applied Sciences of the South Switzerland (SUPSI); it is free and open source, released under GPL v2 license.

The prototype worked fine, and it should be an idea to realize a system to continuously monitor the city and its conditions, using the rental car service.

References

Broring A, Stasch C, Echterhoff J (eds) (2012) OGC Sensor Observation Service Interface Standard, document number 12–006

Brovelli MA, Giori G, Mussin M, Negretti M (2011) Improving the monitor of the status of the environment through web geo-services: the example of large structures supervision. Trans GIS 15:173–188

Cannata M, Antonovic M (2015) istSOS-project documentation. http://istsos.org/en/trunk/doc/. Accessed 9 March 2016

Corti P, Kraft TJ, Mather SV, Park B (2014) PostGIS Cookbook. Packt Publishing, Birmingham

De La Beaujardiere J (eds) (2006) OpenGIS Web Map Server Implementation Specification, document number 06–042

Free Software Foundation (1991) GNU General Public License, version 2. https://opensource.org/licenses/gpl-2.0.php. Accessed 9 March 2016

Gratier T, Spencer P, Hazzard E (2015) OpenLayers 3. Packt Publishing, Birmingham

Massachusetts Institute of Technology (1988) The MIT license (MIT). https://opensource.org/licenses/MIT. Accessed 9 March 2016

McKenna J, Fawcett D, Butler H (2015) An introduction to mapServer. http://www.mapserver.org/introduction.html. Accessed 9 March 2016

Open Knowledge Foundation (2009) Open database license (ODbL) v1.0. http://opendatacommons.org/licenses/odbl/1.0/. Accessed 9 March 2016

OSGeo wiki (2016) OSGeo community projects. http://wiki.osgeo.org/index.php?title=OSGeo_Community_Projects. Accessed 9 March 2016

PostgreSQL Global Development Group (2010) PostgreSQL licence. http://www.postgresql.org/about/licence/. Accessed 9 March 2016

QGIS Development Team (2014) QGIS user guide. http://docs.qgis.org/2.8/en/docs/user_manual/index.html. Accessed 9 March 2016

Ramm F, Topf J, Chilton S (2010) OpenStreetMap: using and enhancing the free map of the world. UIT, Cambridge

Reed CN (2011) The open geospatial consortium and web services standards. In: Zhao P, Di L (eds) Geospatial web services: advances in information interoperability. IGI Global, Hershey, pp 1–16

Regents of the University of California (1998) The BSD 2-clause license. https://opensource.org/licenses/BSD-2-Clause. Accessed 9 March 2016

Riggs S, Krosing H, Bartolini G, Ciolli G (2015) PostgreSQL 9 administration cookbook. Packt Publishing, Birmingham

St. Laurent AM (2004) Understanding open source and free software licensing. O'Reilly Media, Sebastopol

Stallman R (2007) Why open source misses the point of free software. https://www.gnu.org/philosophy/open-source-misses-the-point.en.html. Accessed 9 March 2016

Vretanos PA (eds) (2014) OGC Web feature service 2.0 interface standard, document number 09-025r2

Part III
The Simulation Model

The Evaluation Model: Estimation of Economic, Social and Environmental Impacts of Car Sharing Services

Alessandro Luè, Roberto Nocerino, Valerio Paruscio, Diego Ciccarelli, Simone Vantini and Paolo Zanini

Abstract This chapter describes a model able to simulate car sharing configuration options, taking into account different dimension of sustainability (environment, economy, mobility and social). We studied the possible effects of such options on the mobility system. In order to identify and structure such effects, we used cognitive maps, elicited by means of interviews and workshops made with the researchers with different expertise of the Green Move team and territorial stakeholders. Such maps led to the development of a simulation model for the estimation of the options' effects. Different sub-models are briefly described in terms of inputs,

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outputs and operating logic. The model has been used in the design of a full-scale electric car sharing service for the city of Milano.

1 A General Overview of the Model

The assessment model has been elaborated starting with an analysis of the literature and case studies on existing car sharing systems. That enabled the identification of the main elements characterizing the existing systems (configuration parameters) and the main performance (indicators).

The realization of the model placed at our disposal a multi-attribute assessment system capable of evaluating the performances of various vehicle sharing alternatives. The assessment has pursued the logic of analysing several criteria. The implementation of the model in MATLAB language makes the assessment fully automated: once the input values have been set, in fact, it is able to calculate outputs automatically.

Based on a specific spatial distribution of the stations, through a logit model who receives in input some parameters related to the car sharing system features (e.g. closeness to the station, fee of the service), the MATLAB model estimates the probability that a generic citizen subscribes a car sharing service. Hence, we can derive an expected number of users subscribing to a specific service configuration. Then, a certain temporal interval (e.g. one week) is considered and at every minute a certain number (based on the evaluate probability and on the time slot) of trips is randomly generated. Destinations are also randomly generated using a source-destination matrix provided by AMAT, the mobility agency of the Municipality of Milan. Then, duration, length and number of trips, as well the expected number of users, are exploited to obtain environmental and economic outputs. In the rest of this section, a detailed description of inputs, models and outputs is provided.

The main configuration parameters (inputs) that characterize the alternative in question concern elements relating to size, rate and service level and type (Arena et al. 2015):

- Spatial localization of stations,
- Type of vehicle (% FEV),
- Spatial flexibility (1w 2w),
- Probability of finding a vehicle and
- Annual and hourly fees.

Other inputs concern data from external sources pertaining to the context of the city of Milan:

- source–destination matrixes provided by AMAT and
- demographic data from the census.

Relevant inputs consist in the coefficients and data useful to the models being fully defined and populated.

The main indicators (outputs) that describe environmental, transport and economic performances of the alternative are five:

1. Accessibility,
2. Congestion,
3. Emissions,
4. Parking spaces and
5. Economic sustainability.

The model is made up of various sub-models, listed hereunder, the relationships between which are illustrated in Fig. 1 and the operational logics of which are described in detail in the next paragraphs.

- Service demand model,
- Creation of O/D matrix,
- System sizing model,
- Accessibility model,
- Congestion model,
- Emission model,
- Public space occupation model and
- Economic and financial model.

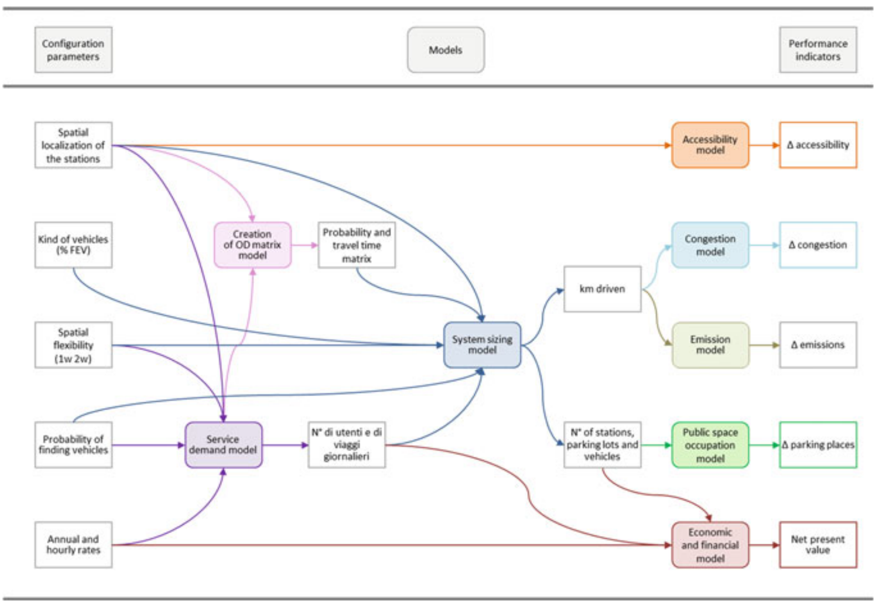


Fig. 1 General scheme of the assessment model. (Luè et al. 2012)

2 Service Demand Model

The model has been developed starting from an analysis of preferences indicated by the answerers. The logit model chosen for the elaboration of the replies is capable of providing, following the changes in configuration parameters and the distance from the nearest station, the probability of a user subscribing to the car sharing service, service characterized by the parameters themselves.

Therefore, the demand analysis has sought to:

- Deepen knowledge of Milan citizens' preferences, especially those citizens in possession of a car or at least a driver's licence, in respect of different models of car sharing service;
- Elaborate a logit model that makes it possible to estimate the probability of subscription by a single user to a car sharing system endowed with certain characteristics. To achieve that, the investigation has resorted to the technique of Stated Preferences (SP) based on the use of replies provided by a sample of individuals with regard to hypothetical contexts suitably put forward to them;
- Identify the interviewed persons' willingness to share their own cars.

2.1 *Input*

Definition	Source	Notes	Values
Capillarity	Configuration parameter	c: based on the location it is possible to define for each user the time needed to reach the nearest station on foot	Values expressed in minutes in terms of time needed to reach the nearest parking. Variable depending on the alternative
Spatial flexibility (1w 2w)	Configuration parameter	f: possibility of restitution of the car at any station (1w) or at the origin station (2w)	Values expressed as 1 (1w) or 0 (2w)
Annual and hourly rate	Configuration parameter	t_f = fixed annual service fee t_v = flexible hourly fee	Values expressed in €/year and €/hour Variable depending on the alternative

2.2 *Output*

Once the configuration parameters have been set, the model calculates, in respect of a generic citizen residing in the Municipality of Milan and residing around the nearest station to him, the **p** probability of his subscribing to the configured car sharing service.

2.3 Description

The elaboration of replies has been carried out through a specific software (Biogeme,[1] an open-source freeware designed for the maximum likelihood estimation of parametric models), whereby the preferences expressed by the answerers are used for estimating the value of parameters of a utility function, the arguments of which are the variables used in describing the alternatives.

The purpose of the model is to estimate, for each car sharing alternative, the probability of an individual subscription to a proposed car sharing service. The model used is called logistic regression and makes it possible to derive a functional form (identified through parameters to be estimated) that directly links the variables relating to the characteristics of the alternatives to the probability of subscribing to the car sharing service defined by such variables.

The general form of a logistic model is of the following type:

$$p(U) = \frac{e^{U}}{1 + e^{U}}$$

where in the case being examined here:

- p = probability that a user subscribes to a car sharing service with a U utility and
- U = Utility associated with the car sharing service under examination.

Moreover, in the logistic model the U utility results from the linear combination of different factors contributing to its definition. In general terms, U acquires in fact the form $U = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_r x_r$ in which x_j are variables relating to the characteristics of the alternatives and β_j are parameters that measure the relative importance of each variable. The estimate of the model consists in the estimate of the β_j parameters.

Estimating the model parameters produced by the replies to the questions on stated preferences means first of all to decide which variables to insert in the utility function, being in this instance variables of the car sharing alternative. In order to select the variables to include, several tests have been conducted in order to assess the relevance of variables to the determination of the U utility for users' and variables' relative weight in the choice. The utility function consists in the following expression:

$$U = \beta_0 + \beta_{tf} t_f + \beta_{tv} t_v + \beta_c c + \beta_f f + \beta_{sa} sa + \beta_g g + \beta_e e + \beta_o o + \beta_{nc} nc$$

[1] http://biogeme.epfl.ch/home.html.

where

- t_f = Fixed annual service fee.
- t_v = Flexible hourly fee.
- c = Capillarity of stations (measured in minutes taken to reach the nearest station).
- f = Possibility of restitution of the car at any station (1 way) or at the origin station (2 ways).
- sa = Availability of additional services to simple car sharing.
- g = Gender, 1 if the user is a woman otherwise 0.
- e = Age bracket the user falls under: 1 between 20 and 30 years, 2 between 30 and 40 years, 3 between 40 and 50 years, 4 beyond 50 years.
- o = Employment status, 1 if user employed, otherwise 0.
- nc = Number of cars owned by each family.

A reduced model has been identified, after the removal therefrom of both the configuration parameters not deemed significant (sa) and all the regressors setting out users' individual characteristics (g, e, o, nc) as they cannot be used in relation to the AMAT data subsequently used to build the hourly matrices of trips. The AMAT data, in fact, are not stratified by gender, age, employment status and number of cars within a family nucleus.

The reduced model acquires therefore the following form:

$$U = \beta_0 + \beta_{tf} t_f + \beta_{tv} t_v + \beta_c c + \beta_f f$$

where the values of the coefficients have been estimated through the method of weighted maximum likelihood (i.e. the unknown parameters have been assigned the value that better fit with the answers provided by interviewed persons). Such a likelihood is calculated by assigning a different weight to the interviewed subjects that is exactly proportional to their representativeness in the universe of Milan population with drivers' licences.

In conclusion, the estimated configuration parameters are fixed rate (€/year), flexible rate (€/hour), capillarity (minutes) and spatial flexibility (1 = one way, 0 = two way) with the following values:

Coefficient	Configuration parameter	Value of β_j	Significance
β_0	Intercepts	−2,291623	9,76e-15
β_{tf}	Fixed rate	−0,009772	6,68e-09
β_{tv}	Flexible rate	−0,123986	0,00204
β_c	Capillarity	0,234164	0,11350
β_f	Spatial flexibility	−0,037040	0,06736

The comparison of significant factors from the list of regressors shows how the economic factor, both in the fixed rate and in the flexible rate, seems to be the most relevant one, followed by the spacial flexibility, likewise (although less) significant.

The capillarity, though less significant from a statistical viewpoint, has been retained in the model in the light of its influence on users' actual behaviour.

In order to compare the impact of the various factors on the percentage of persons subscribing a car sharing service, we should note that these factors have the same influence in the probability of a user to subscribe a car sharing service than the change from 1w to 2w: a rise of 23,96 € in the annual fee or a 1,89 € rise in the hourly fee or a 6,32 min increase in the time needed to reach the station.

Once the parameters have been estimated, it is possible to use them in the logit model so as to estimate the percentage of individuals who would subscribe a car sharing service characterized by certain parameters. In order to calculate the probability of an individual subscribing the car sharing service, we calculate the product between the values of the β_j constants and the values acquired by the x_j configuration parameters.

Starting from the parameter values thus obtained, we move to the calculation of the *p* probability that a person might decide to make use of the car sharing service offered by Green Move:

$$p = \frac{e^{\beta_0 + \beta_{tf} \cdot t_f + \beta_{tv} \cdot t_v + \beta_c \cdot c + \beta_f \cdot f}}{1 + e^{\beta_0 + \beta_{tf} \cdot t_f + \beta_{tv} \cdot t_v + \beta_c \cdot c + \beta_f \cdot f}}$$

where

- β_0 (fixed parameter) = −2.29162.
- β_{tf} (coefficient relating to the fixed fee) = −0.00977.
- t_f (value of the fixed fee [€/year]).
- β_{tv} (coefficient relating to the variable fee) = −0.12399.
- t_v (value of the variable fee [€/hour]).
- β_c (coefficient relating to the capillarity) = −0.03704.
- c (capillarity [minutes]).
- β_f (coefficient relating to spatial flexibility) = 0.234164.
- f (spatial flexibility: 1 = 1 way, 0 = 2 ways).

3 Creation of O/D Matrix Model

The model has been implemented in the MATLAB programming language. The algorithm receives as input the population and traffic flow data, the demand matrices and the spatial configurations of stations. Thanks to the parameters for analysing the demand implemented in a logit function that provides the percentage of service users out of the total pool of potential users, the algorithm calculates the number of potential users who move from one station to the other (origin/destination matrix). The calculation has been done by apportioning the data gathered from the sources between regular square mesh spatial grids of 500 m/side, on the assumption that they are uniformly distributed within the polygons of original data sources (census sections and O/D areas of circulation flows). The number of output files of the model is 864, a value obtained from the product of the combinations of input configurations: eight fee configurations, two flexibility configurations, 18 spatial configurations and three time slots (morning peak hours, evening peak hours, off-peak hours). Model is fully described in Chap. 15 **Model of the O/D Matrix—Grid driven estimate of the O/D matrices for a car sharing service.**

4 System Sizing Model

The task of this model is to estimate:

- The number of vehicles that should make up the fleet with a view to fulfilling a scheduled percentage (set through the parameter called "probability of finding a vehicle") of the envisaged reservation requests ($N_{vehicles}$);
- The number of bays necessary to ensure at any time the parking of temporarily unused vehicles (N_{bays});
- The number of km covered by the cars in the fleet (KM_{CS}).

The heart of the model, developed in MATLAB language, is capable of reproducing the temporal evolution of the service during a typical day, by simulating the users' requests at any station and the trip of any single vehicle from the origin station to the destination one; the model thus keeps track of the number of vehicles found at any given time at any station, being accordingly capable of calculating the minimum number of bays to be ensured for each station and the number of vehicles to be foreseen at the start of the service in order to meet the desired percentage of requests.

The main inputs of the model consist in the data relating to the spatial location of stations and in those resulting from the combination of modules of demand analysis and O/D matrices analysis. Model is fully described in Chap. 16 **System sizing model—Simulation model of the service.**

5 Accessibility Model

The model is based on the assumption that it may be possible to define a sphere of influence around each collective mobility stations (public local transport, railway link, bike sharing, car sharing, etc.) that rest on the city territory. Such spheres of influence are functions of attractiveness for each of the different types of stations and allow us to define the number of users potentially serviced by these stations. The introduction of a new car sharing system increases the area of the city territory covered by collective mobility services, thereby increasing the number of users potentially serviced and accessibility to the mobility system.

5.1 Input

Definition	Source	Notes
Spatial location of stations	Configuration parameter	Geographical data
Spatial location of local public transport stations	dati.comune.milano.it	Geographical data
Spatial location of railway stations	dati.comune.milano.it	Geographical data
Spatial location of bike sharing stations	dati.comune.milano.it	Geographical data
Spatial location of car sharing stations	dati.comune.milano.it	Geographical data

5.2 Output

The model calculates the variation of accessibility (%Acc) to local public transport for citizens, following the introduction of the proposed car sharing system.

5.3 Description

The model calculates in the first place accessibility to the mobility system without the GM car sharing alternative (Acc_{Us_SCS}), defined as number of potentially serviced users, located, in other words, within a given range of influence (variable for each type of existing stations), as illustrated in Fig. 2.

The model then calculates the accessibility of the mobility system with the GM car sharing alternative (Acc_{Us_CS}) defined, in this instance as well, as number of potentially serviced users (Fig. 3).

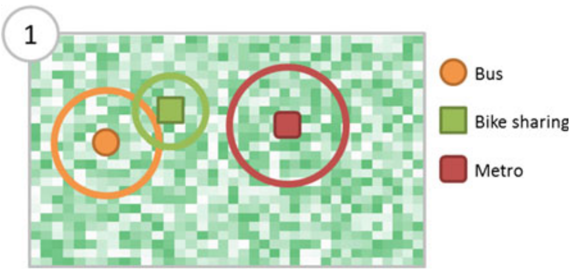


Fig. 2 Accessibility without GM car sharing

Fig. 3 Accessibility with GM car sharing

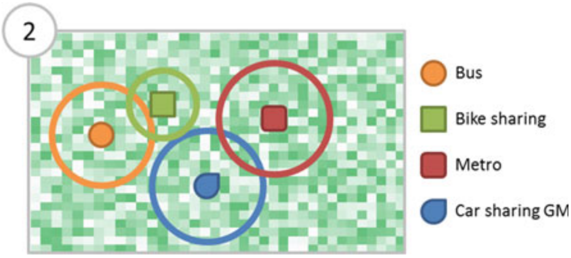
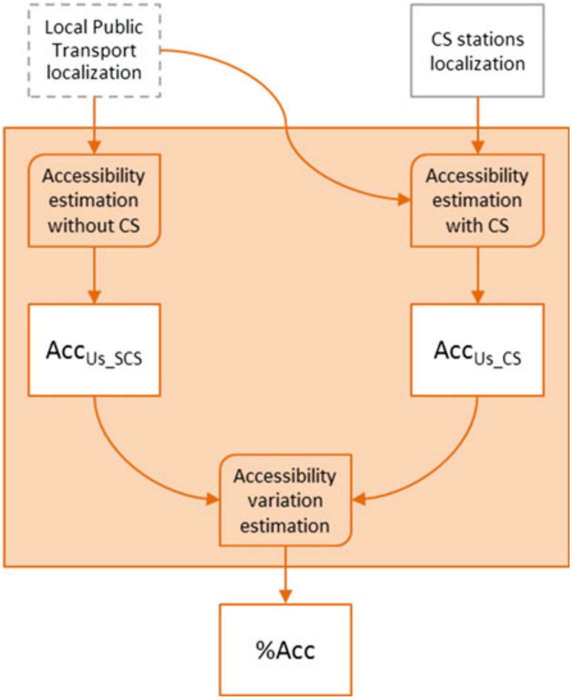


Fig. 4 Scheme of the model of accessibility variation (in *orange*)



The accessibility variation %ΔAcc is calculated as:

$$\%\mathrm{Acc} = (\mathrm{Acc}_{\mathrm{Ut\_CS}} - \mathrm{Acc}_{\mathrm{Ut\_SCS}})/\mathrm{Acc}_{\mathrm{Ut\_SCS}}$$

which represents the percentage of additional users potentially serviced thanks to the introduction of the GM car sharing system. Table 1 lists the public transport categories examined and the relative ranges of influence used.

Figure 4 shows the scheme of the model of accessibility variation.

Table 1 Public transport categories examined and the ranges of influence used

Type of station	Range [metres]	Time [minutes]
Bus	500	6
Tram	500	6
Bike sharing	500	6
Metro	700	8
Regional trains	1000	12
Car sharing	1000	12

6 Emission Model

The model is based on the assumption that car sharing users drive less than users that own a private car. Distances covered by car sharing users with and without service are calculated, and, as a result, the emissions produced in the two scenarios.

The emissions of the car sharing system, both polluting and greenhouse, depend on the type of vehicles adopted, ICE and FEV, and by the proportion of vehicles of the two engine types. The emissive factors for pollutants and greenhouse gases are considered the same for the private vehicle fleet and for the car sharing ICE vehicles. The polluting emissions of FEV vehicles are deemed equal to zero because they are local emissions, whereas greenhouse emissions, of a global character, are other than zero and depend on the energy mix used in the production of electricity.

6.1 Input

Definition	Source	Notes	Values
Km covered by users of the car sharing service	Sizing model		Values expressed in km (KM_{CS})
Coefficients of polluting gas emission per engine type: electric (FEV, full electric vehicle) and traditional (ICE, internal combustion engine)	Literature: **INEMAR (INventario EMissioni Aria), Lombardia, 2012**	They are applied to the polluting emissions of the current vehicle fleet and to the emissions of non-electric CS (car sharing) vehicles. The local polluting emissions of electric CS vehicles are set at 0	Values expressed in mg/km **ICE vehicles ($coeff_{pol\_ICE}$)** CO: 1000 C_6H_6: 33,8 NO_X: 417,5 PM10: 35 **FEV's ($coeff_{pol\_FEV}$)** CO: 0 C_6H_6: 0 NO_X: 0 PM10: 0

(continued)

(continued)

Definition	Source	Notes	Values
Coefficients of GHG emission per engine type (electric and internal combustion)	Literature: **Comparison of GHG emissions by different vehicle technologies, CIVES (Commissione Italiana Veicoli Elettrici Stradale a Batteria, Ibridi e a Celle a combustibile), 2012**	The CO_{2eq} emissions for electric vehicles are related to the energy mix used in the production of electric energy	Values expressed in g/km **ICE vehicles ($coeff_{GHG\_ICE}$)** CO_{2eq}: 120 **FEV's ($coeff_{GHG\_FEV}$)** CO_{2eq}: 60
Coefficient of decrease in km travelled by CS users in comparison with those that use private cars	Literature: **Carsharing: A Sustainable and Innovative Personal Transport Solution with Great Potential and Huge Opportunities, Frost & Sullivan Automotive Practice, 2010**	The car sharing users drive less than those using private cars. The difference is estimated to be around 30% km less driven	Value expressed in % −30%

6.2 Output

The model calculates the ΔE_{pol_CS} variation (local) and the ΔE_{GHG_CS} one (global) between the E_{pol_CS} polluting emissions and the E_{GHG_CS} greenhouse ones produced by car sharing users and the E_{pol_SCS} polluting and E_{GHG_SCS} greenhouse emissions produced by the same users without the car sharing service.

6.3 Description

The model calculates the km covered by car sharing potential users without a car sharing service (KM_{SCS}) in relation to the km driven by car sharing users (KM_{CS}), as calculated by the sizing model.

$$KM_{SCS} = KM_{CS}/(1-30\,\%)$$

6.3.1 Polluting Emissions

The model calculates the polluting emissions of car sharing (E_{pol_CS}) based on the km driven by car sharing users (KM_{CS}), taking into account the engine type of vehicles in the car sharing fleet.

For fully electric car sharing service:

$$E_{pol\_CS} = KM_{CS} \cdot coeff_{pol\_FEV}$$

For car sharing with traditional ICE vehicles:

$$E_{pol\_CS} = KM_{CS} \cdot coeff_{pol\_ICE}$$

For mixed fleet (Y% electric):

$$E_{pol\_CS} = Y\% \cdot KM_{CS} \cdot coeff_{pol\_FEV} + (1 - Y\%) \cdot KM_{CS} \cdot coeff_{pol\_ICE}$$

The model calculates the polluting emissions without car sharing (E_{pol_SCS}) based on the km driven by potential users without car sharing (KM_{SCS}).

$$E_{pol\_SCS} = KM_{SCS} \cdot coeff_{pol\_ICE}$$

The difference between E_{pol_CS} and E_{pol_SCS} gives us the variation of polluting emissions ΔE_{pol_CS} between the scenario without car sharing and the one with car sharing, with regard to potential car sharing users.

$$\Delta E_{pol\_CS} = E_{pol\_SCS} - E_{pol\_CS}$$

6.3.2 GHG Emissions

The model calculates the GHG emissions of the car sharing (E_{GHG_CS}), produced as a result of the generation of electric energy with the actual energy mix, based on the number of km covered by the car sharing users (KM_{CS}), taking into consideration the engine type of the vehicles in the car sharing vehicle fleet.

For fully electric car sharing service:

$$E_{GHG\_CS} = KM_{CS} \cdot coeff_{GHG\_FEV}$$

For car sharing with traditional ICE vehicles:

$$E_{pol\_CS} = KM_{CS} \cdot coeff_{GHG\_ICE}$$

For mixed fleet (Y% electric):

$$E_{GHG\_CS} = Y\% \cdot KM_{CS} \cdot coeff_{GHG\_FEV} + (1 - Y\%) \cdot KM_{CS} \cdot coeff_{GHG\_ICE}$$

The model calculates the greenhouse emissions without car sharing (E_{GHG_SCS}) based on the km covered by the potential users without car sharing (KM_{SCS}):

$$E_{GHG\_SCS} = KM_{SCS} \cdot coeff_{GHG\_ICE}$$

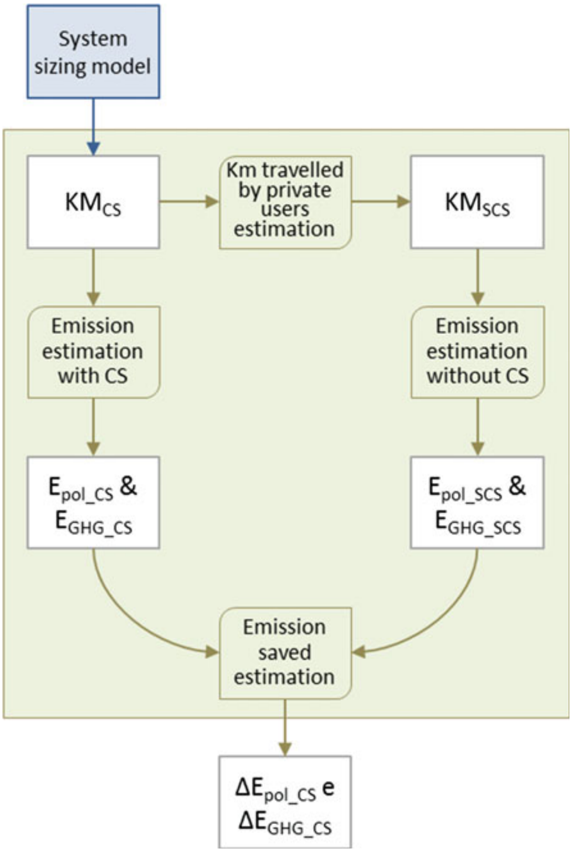


Fig. 5 Scheme of the emission variation model (in *green*)

The difference between E_{GHG_CS} and E_{GHG_SCS} gives us the variation in GHG emissions ΔE_{GHG_CS} between the scenario without car sharing and the one with car sharing for the potential car sharing users.

$$\Delta E_{GHG\_CS} = E_{GHG\_SCS} - E_{GHG\_CS}$$

Figure 5 sets out the scheme of the emission variation model.

7 Congestion Decrease Model

The model is based on the assumption that the car sharing users drive less than users who own a private car. Accordingly, calculation is made of the km covered by the car sharing users, with and without GM service and the difference between these two values.

7.1 Input

Definition	Source	Notes	Values
Km covered by users of the car sharing service	Emission saving model	KM_{CS}	Variable depending on the alternative
Km covered by users of the car sharing service if the service was not available to them	Emission saving model	KM_{SCS}	Variable depending on the alternative

7.2 Output

The model calculates the variation in km covered by users of the car sharing service compared to the km covered by users without car sharing (ΔKM_{CS}).

7.3 Description

The model calculates the difference (ΔKM_{CS}) between the km covered by the car sharing users (KM_{CS}) and the km covered by the users without the service (KM_{SCS}).

$$\Delta KM_{CS} = KM_{SCS} - KM_{CS}$$

Figure 6 sets out the scheme of the congestion decrease model.

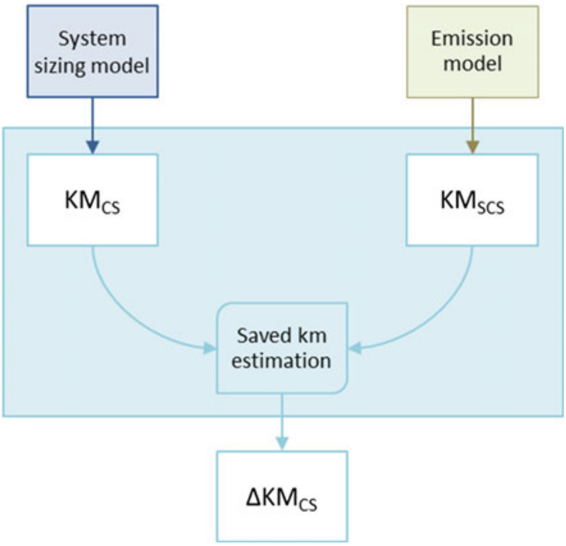


Fig. 6 Scheme of the model of congestion variation (in *blue*)

8 Public Space Occupation Model

The model is based on the assumption that a car sharing service enables some of the registered users to renounce to their own cars. In literature, the number is estimated to be between 8 and 15 private vehicles replaced by each car in sharing. The decrease in car ownership corresponds to a decrease in the space occupied by private cars.

8.1 Input

Definition	Source	Notes	Values
Number of stations, parking bays and vehicles	System sizing model		Value expressed in absolute number
Coefficient of reduction of the motorization rate in respect of car sharing users	Literature http://www.zipcar.com/is-it#greenbenefits	Each car of a car sharing service replaces between 8 and 15 private cars, thereby making available for other purposes the public space set aside for car parking	Value expressed in absolute number ($coeff_{\Delta MR}$) 8–15
Coefficient of occupation of public soil per vehicle	–	It denotes the square metres occupied on average by each vehicle	Value expressed in square metres ($coeff_{sqm\_car}$) 10 m^2

8.2 Output

The model calculates ΔOCC, i.e. the decrease in the space occupied by private cars because of the implementation of the car sharing system.

8.3 Description

The model calculates the number of replaceable vehicles thanks to the presence of a car sharing service (V_{s_CS}) as the product between the number of vehicles, calculated from the sizing model of the service (V_{CS}) and the coefficient of reduction of the motorization rate in respect of car sharing users ($coeff_{\Delta MR}$).

$$V_{s\_CS} = coeff_{\Delta MR} \cdot V_{CS}$$

By subtracting from the number of replaceable vehicles (V_{s_CS}) the number of service vehicles (V_{CS}), we get the lower number of vehicles owing to the introduction of car sharing (ΔV).

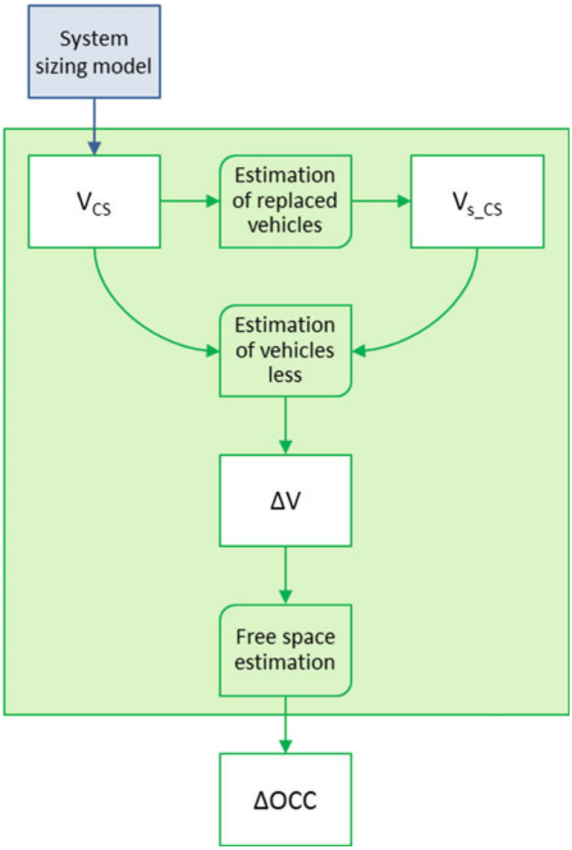
$$\Delta V = V_{s\_CS} - V_{CS}$$

The product between the variation of vehicles (ΔV) and the coefficient of occupation of public soil per each vehicle ($coeff_{sqm\_car}$) provides the public space potentially available for other purposes thanks to the introduction of car sharing (ΔOCC).

$$\Delta OCC = coeff_{sqm\_car} \cdot \Delta V$$

Figure 7 sets out the scheme of the model of variation in the occupation of public spaces.

Fig. 7 Scheme of the model of variation in the occupation of public spaces (in *green*)



9 Economic and Financial Model

The Net Present Value is a methodology for setting the Net Present Value (NPV) of an expected series of cash flows, not merely by adding them up algebraically but also by using them pursuant to a rate of return (i.e. the opportunity cost of capital). In the assessment in question, the net cash flow will be characterized by the difference between the incoming cash flow (consisting in revenues from subscriptions, hourly rate and telephone reservations) and the outflow (represented by fleet-related costs, operational costs and, lastly, structural overheads).

9.1 Input

Definition	Source	Values
Number of users and daily trips	*From system sizing model*	
Number of stations and vehicles	*From system sizing model*	
Annual and hourly rate	*From system sizing model*	
Time span and discount rate of cash flows arising from the project	*From literature* Feasibility studies for the implementation of a car sharing service Personal contacts with companies operating in the reference sectors	k (rate) = 4%–6% T (time span in years) = 5–8 years
Investment in infrastructure	*From literature* Feasibility studies for the implementation of a car sharing service Personal contacts with companies operating in the reference sectors	Cost of an e-box add-on = 400€ Cost of a charging point = 1,500€ Cost of a FEV vehicle = 30,000€ Cost of an ICE vehicle = 12,000€ Cost of purchasing software = 15,000€ Cost of renting a FEV vehicle = 6,000€/year Cost of renting an ICE vehicle = 5,000€/year
Costs associated with fleet management and with the efficiency of the vehicle sharing service	*From literature* Burlando, C., Mastretta, M. Il car sharing: un'analisi economica e organizzativa del settore. Vol. 342. Franco Angeli, 2007	Cost of charging electric vehicle = 0.025€/km Cost of petrol = 0.3€/km Cost of insuring a FEV vehicle = 1000€

(continued)

(continued)

Definition	Source	Values
		Cost of insuring an ICE vehicle = 1000€ Cost of car washing = 7€/week Cost of maintenance = 250€/week
Costs of call centre and structure	*From literature* Il servizio di car sharing nella provincia di Bergamo—Analisi di fattibilità. Bergamo, May 2009	Percentages of telephone reservations = 30% Cost of phone call = 0,5€/call Call profit = 0–0,5 €/call Annual overheads (in relation to the number of service stations) = 0–4: 100,000€ 5–90: 175,000€ 91–250: 300,000€ 251–450: 500,000€ 451–750: 800,000€

9.2 Output

Net Present Value of cash flows arising from the project.

9.3 Description

The Net Present Value criterion is based on the principle according to which it would be proper for an investment to be made only if the benefits it might yield (estimated in terms of financial flows) exceed the resources used. This method, in fact, makes it possible to compare the initial investment with the future cash flows generated by it and indicates therefore the financial performance generated by the service: if it is positive, it means that the investment is profitable.

For comparing the present costs with future flows, the latter are expressed net of the financial value at the time, i.e. duly expressed in the present value, hence essentially discounting at the same time moment. The sum of such discounted amounts represents the net present value of the project: "net" because it consists in the difference between incoming cash flows and cash outflows, both those of the initial investment and those associated with service management; “present” because it is referred back to a single reference year.

This method represents the net investment income expressed as absolute value and has the advantage of taking into account the financial value of time, even though a great deal of its reliability is linked to the correctness of the cash flow estimation that, wherever over- or underestimated, might lead to an erroneous assessment of the project. If we want to express this index through a formula, we would write:

$$\mathrm{NPV} = \sum_{t=0}^{n} \frac{\mathrm{NCF}_t}{(1+k)^t}$$

where

- t: time deadlines;
- NCF_t: financial flow (positive or negative) at time t;
- k: weighted average cost of capital (or WACC), an alternative rate of return for a similar risk according to the theory of CAPM (capital asset pricing model);
- $\frac{1}{(1+k)^t}$: discount factor as at time t.

The basic assumption underlying the procedure of discounting cash flows is that an investment project must be able to generate a higher return than the one that might be achieved on the capital market: if that is so, the Net Present Value will be positive and the investment will be deemed profitable.

As an assessment method, the Net Present Value is characterized by a series of strengths and weaknesses. Seen from the viewpoint of its strengths:

- It is a compact investment indicator and is expressed through the same unit of the measure as the one by which the items of cost and revenue are usually quantified. Precisely on account of this characteristic, it helps monitor the different value of the currency over time and pays heed to it at the stage of assessing investments;
- It is a method that records, in a simple manner, the presence of profitability compared to the selected discount rate;
- It represents a better capital budgeting technique than others, since it makes use of cash flows rather than book values.

Seen, instead, from the viewpoint of its weaknesses:

- It is a methodology that pays no regard to the relative size of several projects, but only to the absolute one, making thereby difficult to compare different investments, and tends, as regards them, to better evaluate large projects respect smaller ones;
- the calculation of the NPV is toilsome and necessitates the identification of the cost of capital, a factor of uncertain determination referred to a market characterized by a variety of financial instruments;

- account is taken, in the analysis of the NPV, of uncertain future revenues, the uncertainty of which ought to be taken in mind.
- Incoming cash flow: $T_v \cdot H_a + N_a \cdot T_f + N_a \cdot T_p \cdot P_t$, where
  - T_v: hourly rate of service;
  - T_f: annual rate of service;
  - T_p: telephone booking fee;
  - H_a: total annual hours of service on the part of subscribers;
  - N_a: total number of subscribers;
  - P_t: annual number of telephone bookings.
- Cash outflow: $I + C_f + C_o + C_s$ where
  - I: annual infrastructural investment;
  - C_f: annual costs associated with the vehicle fleet (purchase/rental of vehicle, energy, insurance, maintenance and washing);
  - C_o: annual costs associated with the call centre and with staff;
  - C_S: fixed overheads.

In the assessment in question, the incoming cash flows consist in the annual and hourly fees associated with the vehicle sharing service and in the revenues arising from telephone bookings. Concerning, instead, the cash outflows, they are linked to investment in the necessary infrastructure, the costs associated with the vehicle fleet and the operational management of the service and, lastly, the infrastructural overheads. Those values are, therefore, the model inputs and come from secondary sources, such as feasibility studies, through including primary sources as well, e.g. interviews with sector operators. More specifically (as reported in Fig. 8):

10 A Multi-Criteria and Multi-Stakeholder Rating of the Car Sharing Configurations

After describing the models and sub-models necessary for estimating the performances of different alternatives, the last step consists in the option evaluation, through the estimated evaluation indicators. The more detailed description of the Green Move evaluation activities are described by Luè (2015) and Luè et al. (2016). Evaluation indicators are able to give an estimation of the level of fulfilment of the different objective; in fact, through a more or less wide panel of indicators, different options can be compared based on their effects and the consequent level of satisfaction of the objectives. The problem of designing a vehicle sharing service is characterized by the coexistence of conflictual. For example, the increase of service area and of the level of service (an objective to be maximized) can be persuaded only with an increase of the investment and operational costs (an objective to be minimized). The main indicators, represented on the right part of Fig. 1, have been identified by the interaction with the experts and stakeholders: accessibility, congestion, local and global emissions, public area space, net present value. Project team decided not to consider congestion as a significant indicator because of the aleatory dependence of this aspect to the introduction of a car sharing service and because of high multi-factorial interdependences with political decisions regarding mobility in a city.

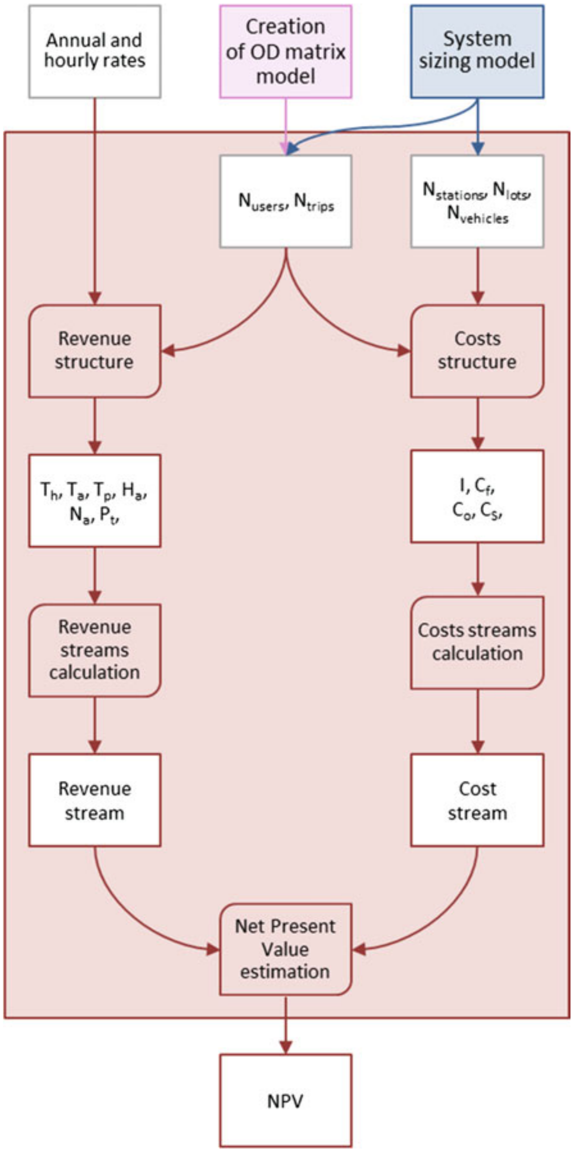


Fig. 8 Scheme of the economic-financial model (in *magenta*)

Hereinafter, the used indicators are listed:

- C1—Net Present Value (NPV), economic performance of the car sharing service;
- C2—global emissions, quantity of greenhouse gas emissions avoided;
- C3—public area space, reduction of the public space occupied by private cars;
- C4—daily requests of the users;
- C5—percentage of the satisfied requests.

Note that the last two indicators are considered also proxies to measure two different aspects of the level of accessibility to the urban mobility system.

In the following of this chapter, for clarity sake, the results of the modelling and the outcome of the multi-criteria rating will be shown for a set of 150 service configuration options. To construct such set, we considered three variable rate values (15€, 16.2€ and 17.4€), different relocation strategies (Bruglieri et al. 2014b) and a number of vehicles made available for users ranging from 100 to 1500 (note that we considered 15 possible values of the number of vehicles; therefore, in the following figures, the points are grouped along such values). All options consider a free-floating scheme in the municipal area. Note that two car sharing services in the city of Milano, Enjoy and Car2go, present, respectively, a rate of 15€/h and 17.4€/h. Figures 9 and 10 depict the outcome of the simulation modelling as regards two indicators, the *Daily requests* and the *Net Present Value (NPV)*. Note that there is a

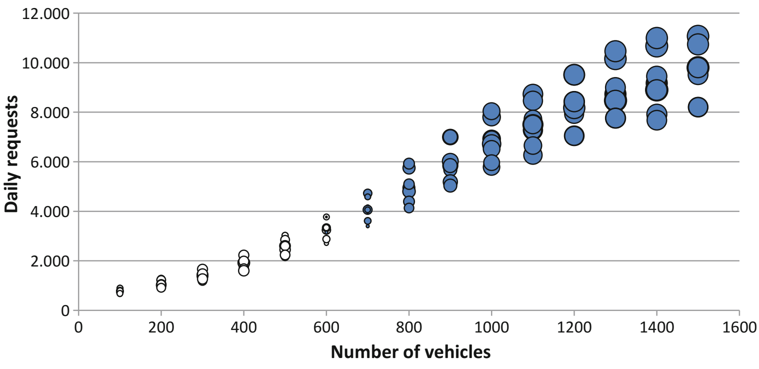


Fig. 9 *Number of vehicles* and *daily requests* calculated for the considered options. The *circle* is proportional to the *Net Present Value* (*blue filled circles* represent positive values, *empty circle* negative values); Luè (2015)

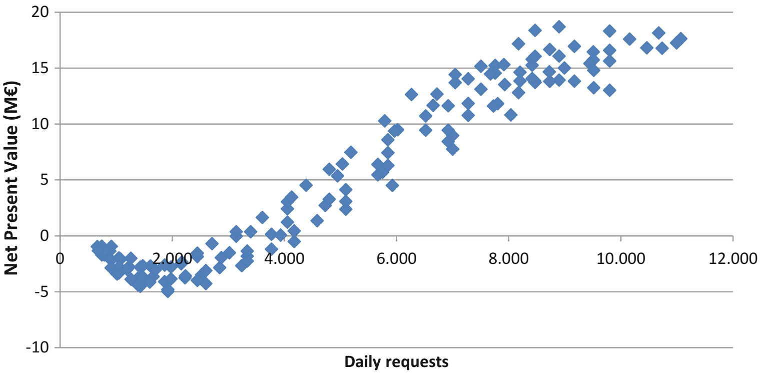


Fig. 10 *Daily requests* and *Net Present Value* calculated for the considered options; Luè (2015)

Table 2 Profiles P1 and P2, characterized by threshold values of the indicators

Indicator	Measure of unit	P1	P2
C1	M€	0	12
C2	ton CO_2 eq/y	400	1000
C3	m^2	40000	80000
C4	Number	3500	8000
C5	%	70	85

break-even point, at around 600–700 vehicles, where the service begins to become profitable. Moreover, the higher the number of vehicles, the higher the NPV because of a scale economy of the service.

The subsequent step consists is the option evaluation, which is carried out by means of a multi-criteria analysis, in order to take into account possible conflicting objectives. The service options are compared based on their (estimated) effects and the consequent level of fulfilment of the objectives. The purpose of the design process is not to provide a single optimal configuration of service for the decision-maker, but rather to support the decision-maker in a strategic assessment of different aspects. With this in mind, we decided to rate the options, according to their indicators' values. We implemented the *ELECTRE TRI* sorting method (Mousseau et al. 2000; Dias et al. 2002), in order to sort the options in categories and to elaborate a proposal. Moreover, the evaluation of the options is conducted taking into account the points of view of different stakeholders.

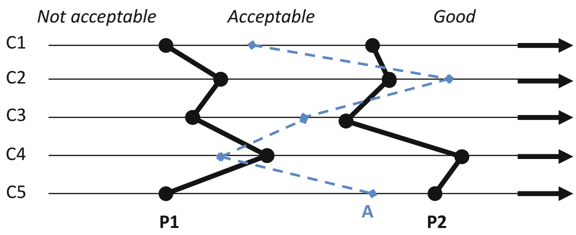


Fig. 11 Comparison of alternative *A* to profiles P1 and P2, in order to rate *A* in one of the three classes (*Not acceptable*, *Acceptable*, *Good*)

Three classes are defined (*Not acceptable*, *Acceptable*, *Good*), and two profiles (P1, P2) are identified to separate the classes using the evaluation indicators (Table 2). The threshold values are defined according to the judgment of the Green Move experts and, where possible, they are referred to "tangible" values. For instance, the P1 threshold for *public area space* corresponds to the area occupied by the Milan stadium, while the P1 threshold for *daily requests* of the users corresponds to present average rents of Car2go in Milano.

Each service option *A* is compared to the two profiles to identify their outranking relationships, that is if *A* outranks P1 (and P2) or not. The comparison is carried out considering the five criteria, according to the outranking methods ELECTRE TRI.

The analysis of such relationships attributes option *A* to one of the classes. Simplifying, the procedure is the following. If *A* does not outrank both P1 and P2, it belongs to the lower class (*Not acceptable*). If *A* outranks only P1, then it belongs to the intermediate class (*Acceptable*). If *A* outranks both profiles, it belongs to the class of *Good* solutions. Figure 11 shows an exemplification of the comparison between options and profiles. For more information on ELECTRE TRI, see Dias et al. (2002) and Mousseau et al. (2000).

As mentioned above, because we considered different stakeholders, we carried out a rating for each one of them, depending on their points of view, made explicit by the importance of the criteria. Figures 12 and 13 present the rating outcome of the considered 150 options, according to the point of view of *Municipality of Milan*, *Car sharing operator* and *Environmental association*. Note that, according to the results previously presented in Figs. 9 and 10, options with less than 600 vehicles are considered as *Not acceptable*, because they are not economically sustainable. Then, only for a higher number of vehicles, the options begin to generate positive effects (as regards the other criteria) and are evaluated as *Good*. Depending on the stakeholder preferences, such classification changes; for instance, *Environmental association* considered *Good* less options than the *Car sharing operator*, because it cares more about aspects such as the environmental effects that become relevant only for higher number of vehicles.

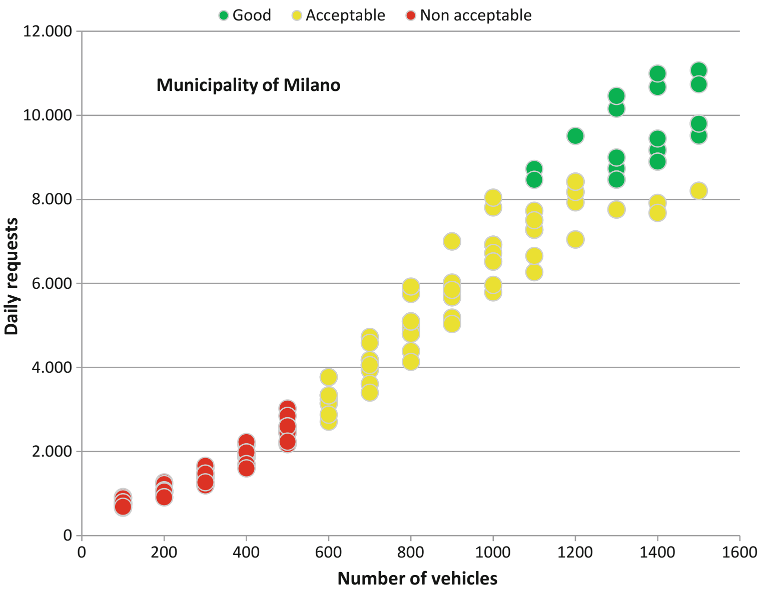


Fig. 12 Rating of the service configuration options, according to the point of view of the *Municipality of Milan* stakeholder; Luè (2015)

Let call *An* + the set of options classified as *Good* for stakeholder *n*. Of course, such options could be considered *Good* by other stakeholders. The higher the number of stakeholders that classify one option as *Good*, the higher the possibility that such option will be regarded as a suitable compromise. We define A^{min} the set of options that are considered Good by *all* stakeholders (i.e. identified by using the intersection operator) and A^{max} the set of options that are considered Good by *at least* one stakeholder (i.e. identified by using the union operator). See Fig. 14 for a graphical exemplification of the procedure.

The ultimate goal of this system is to support a decision process involving different stakeholders, in case of conflicting preferences. The information generated during the process may be made available to all and helps to provide elements to support decision-making.

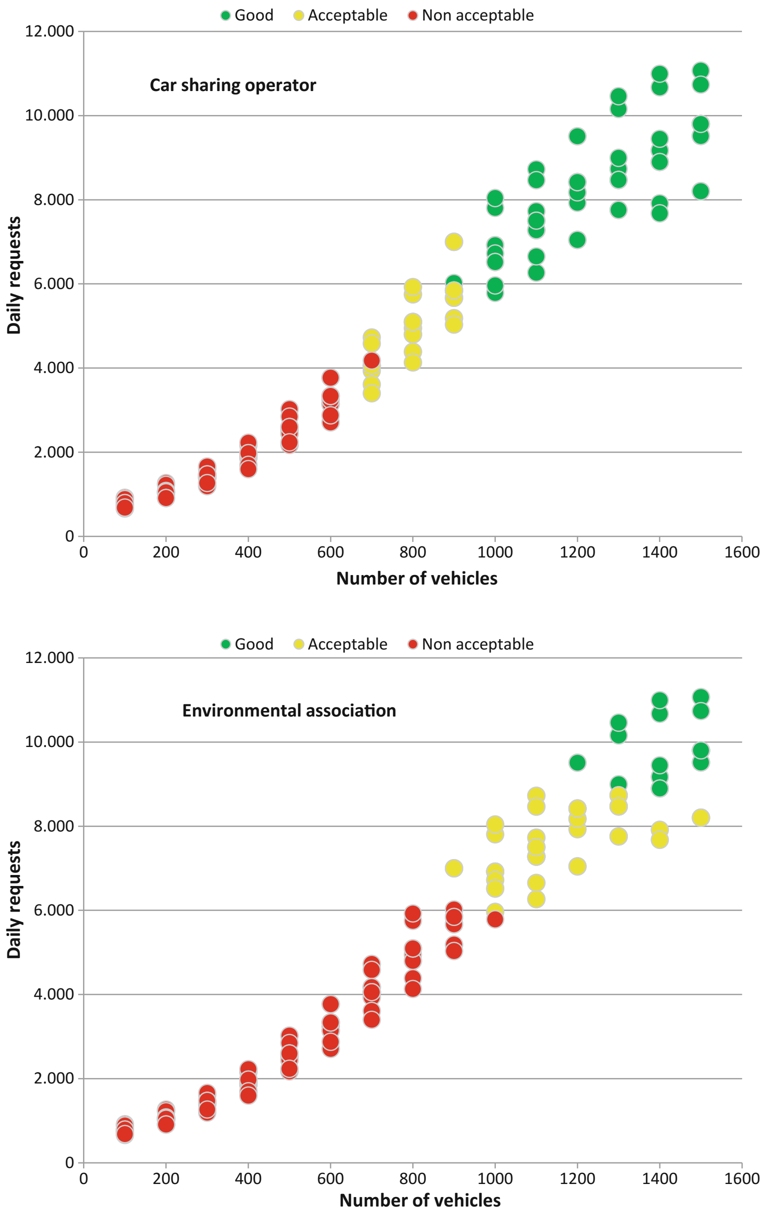


Fig. 13 Rating of the service configuration options, according to the points of view of the stakeholders *Car sharing operator (above)* and *Environmental association (below)*; Luè (2015)

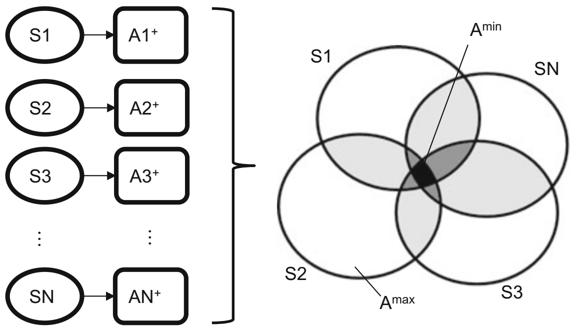


Fig. 14 Starting from the outcome of the rating process for each stakeholder, two sets of options, A^{min} and A^{max}, are defined; Luè (2015)

11 Conclusions

In this chapter, the different components of the simulation models have been described, underlying the connections and interactions between the different sub-models. The implemented model is able to design and size the main dimensions for a car sharing service, considering both internal combustion engine vehicles and electric ones. The model, starting from a limited number of significant configuration parameters, estimates a set of indicators and evaluates the economic, environmental and social performances of the designed service. The considered multi-criteria assessment is able to take into account the points of view of the territorial stakeholders, expressed mainly by their quantification of the importance of the different dimensions (criteria) and the possible support they may provide for the set-up of the service. The proposed method can be useful in general for design and planning of mobility service, especially at a strategic level.

Next two chapters are focused on the description of two relevant models: the model for the creation of origin/destination matrix and the model for the system sizing.

References

Arena M, Azzone G, Colorni A, Conte A, Luè A, Nocerino R (2015) Service design in electric vehicle sharing: evidence from Italy. Intel Transport Syst, IET 9(2):145–155

Burlando C, Mastretta M (2007) Il car sharing: un'analisi economica e organizzativa del settore, vol 342. Franco Angeli, Milan

CIVES - Commissione Italiana Veicoli Elettrici Stradale a Batteria, Ibridi e a Celle a combustibile (2012), Confronto delle emissioni di gas climalteranti di diverse tecnologie veicolari

Dias, L., Mousseau, V., Figueira, J., & Clímaco, J. (2002). An aggregation/disaggregation approach to obtain robust conclusions with ELECTRE TRI. *European Journal of Operational Research*, 138(2), 332–348

http://dati.comune.milano.it/

http://www.zipcar.com/is-it#greenbenefits

INEMAR - ARPA Lombardia (2016), INEMAR, Inventario Emissioni in Atmosfera: emissioni in Regione Lombardia nell'anno 2012 - dati finali. ARPA Lombardia Settore Monitoraggi Ambientali

Luè, A. (2015). *Design and decision aiding for mobility services and systems* (Doctoral thesis, Politecnico di Milano, Milano, Italy). Retrieved from http://hdl.handle.net/10589/113583

Lué A, Colorni A, Nocerino R, Paruscio V (2012) Green Move: an innovative electric vehicle-sharing system. Procedia - Social and Behavioral Sciences. 48:2978–2987

Lué, A., Colorni, A., Nocerino, R. (2016). *Cognitive Mapping and Multi-criteria Assessment for the Design of an Electric Car Sharing Service*. In: André, M., Samaras, Z. (eds.) Energy and Environment, John Wiley & Sons, pp 31–45

Mousseau V, Slowinski R, Zielniewicz P (2000) A user-oriented implementation of the ELECTRE-TRI method integrating preference elicitation support. Comput Oper Res 27 (7):757–777

Muoversi (2009). Il servizio di car sharing nella provincia di Bergamo - Analisi di fattibilità

Zhao, D. (2010). Carsharing: A Sustainable and Innovative Personal Transport Solution with Great Potential and Huge Opportunities, Frost & Sullivan Automotive Practice

Model of the O/D Matrix: Grid Driven Estimate of the O/D Matrices for a Car Sharing Service

Daniela Carrion, Guido Minini and Livio Pinto

Abstract To plan a car sharing service and, in particular, to design the positions of the stations, it is fundamental to know the number of potential users corresponding to different scenarios. In this work, to answer the question: "how many potential users will take the car in Station A and will leave it in Station B?" a model has been designed and implemented to estimate the potential users of the car sharing system and consequently the Origin/Destination matrices of the service. A large amount of data was available, including cartographic data, census information, demand matrices and traffic flows. To be able to combine the necessary information, available in different formats and structures, a common grid has been considered as a reference for the computation and some hypotheses have been assumed, e.g. the census data have been considered homogeneously distributed within a grid cell. The available information has been referred to the cell to estimate the Origin/Destination matrices for the car sharing service with respect to different scenarios. The spatial data have been managed and displayed in a GIS environment, and an ad hoc algorithm has been developed to integrate the input data.

1 Introduction

To be able to estimate the potential users of a car service (Arena et al. 2015), it is necessary to obtain the traffic fluxes from and to the stations planned with different scenarios, in order to single out the best solution for the stations placement.

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In most cases, the Origin/Destination (O/D) matrices are simulated (Toledo and Kolechkina 2013) or acquired with ad hoc surveying, as it can be found in the scientific literature. An interesting discussion on the state-of-the-art of O/D matrices determination and a discussion on the difficulties in acquiring the information for O/D matrices can be found in Bera and Rao (2011). They underline, in particular, the difficulty to find realistic models for large networks.

Considering the model determination, Yang and Zhou (1998) study how to optimally locate and count the traffic to obtain reliable O/D matrices. Also Boyaci et al. (2015) propose a model and give suggestions on how to obtain the demand information, they also suggest taking into account the public transport.

Usually models are calibrated iteratively to reproduce observed data, however Lo et al. (1996) approach considers the survey data as stochastic variables. Also Randriamanamihaga et al. (2014) apply a statistical analysis to O/D matrices, in this case to bike sharing, to find out clusters to analyse why and when people are moving.

Correia and Antunes (2012) propose an optimization approach to depot location, and they consider the case study of Lisbon. The potential trip matrix was provided by a private company, in this case the authors divide the territory into cells with 1000 m side, defining it as a rough simplification, in addition, they consider the Euclidean distance between origin and destination.

In the case study presented in this paper, the O/D matrices are estimated starting from available inputs for the Milan municipality. The basic information that has been used comes from census data (dating 2011) and traffic fluxes information acquired independently from the car sharing simulation. The availability of real data should allow for a realistic estimation. Nevertheless, some hypotheses have been assumed to fill some gaps in the input data with respect to the required purpose and to ease the computation process. All data have been referred to a regular grid to be able to overcome the differences in the spatial data distribution and to speed up the computation time.

2 Analysis of Available Data

The O/D matrix model has been developed considering, as input, data which were already available and acquired for different purposes. This led to some pre-processing and working hypotheses. In the following sections, the data used, summarized in following table, are presented.

Definition	Source	Notes
Milan Census zones	Milan Municipality Open Data (http://dati.comune.milano.it/dato/item/98)	Number of inhabitants (dating 2011) for each census zone, represented as a vector polygon with Gauss-Boaga coordinates.

(continued)

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Definition	Source	Notes
Demand matrices	AMAT Milano (*Agenzia Mobilità Ambiente Territorio*, Agency for Mobility Environment and Territory)	Circulation flows among AMAT zones (Milan areas defined by AMAT); values expressed in terms of equivalent vehicles, referred to time slots.
AMAT zones for traffic fluxes (reference zones for the demand matrices)	AMAT Milano (*Agenzia Mobilità Ambiente Territorio*, Agency for Mobility Environment and Territory)	Vector polygons.

2.1 Census Zones

Census zones data were available from ISTAT (*Isitituto Nazionale di Statistica*, Italian national statistics institution), dating 2011, for the Milan area (see Fig. 1 for the zones distribution). They had been downloaded from the Milan Municipality open data Web portal. The census data are in polygon vector format with the number of inhabitants for each polygon stored in the attribute table. The reference system of the data is the former official Italian one, namely Gauss-Boaga, a local adaptation of the UTM cartographic representation system.

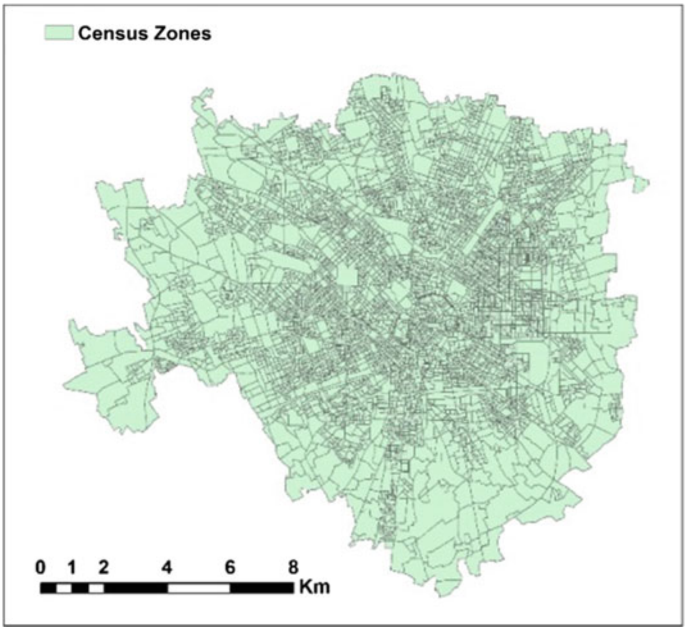

Fig. 1 Census zones over Milan Municipality

2.2 Demand Matrices

AMAT Milano (*Agenzia Mobilità Ambiente e Territorio*, Agency for Mobility Environment and Territory) provided demand matrices containing the traffic flows over Milan zones defined by AMAT itself (see Fig. 2 for the AMAT zones for traffic fluxes). For each couple of zones, the number of the so-called equivalent vehicles, moving from one zone to another, is given. The "equivalent vehicles" correspond to the weighted sum of cars and motorcycles, where motorcycles have been considered with a 0.5 weight. The time of the day is divided into time slots; all provided values are referred to a reference hour for each time slot. To obtain the number of equivalent vehicles for each time slot, the "reference hour" values must be multiplied by the coefficients provided by AMAT for each time slot (see Table 1).

In AMAT demand matrices, for each couple of O/D zones, the traffic flows are grouped with respect to the reason of the movement itself (work, going back home, study, etc.), however, for our purposes, this information has not been taken into account and all movements have been considered as equivalent.

AMAT does not provide any information about the night time slot. As it will be described in next section, the night equivalent vehicles have been deduced multiplying the number of equivalent vehicles of the mean hour of the off-peak time slot by a coefficient (defined by hypothesis).

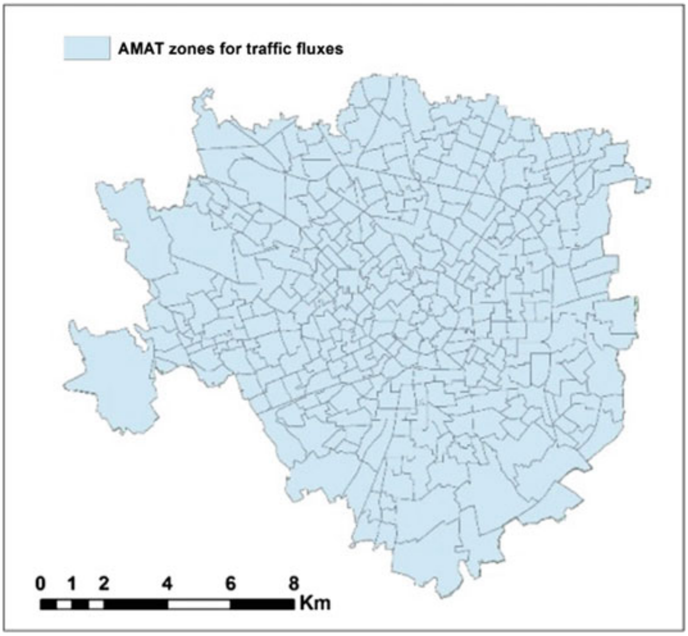

Fig. 2 AMAT zones for traffic fluxes over Milan Municipality

The demand matrices are provided together with the vector representation of the zones to which traffic flows are referred. They will be named in the following as "AMAT zones".

In Fig. 2, the AMAT zones are shown. Comparing Figs. 1 and 2, it is possible to observe that census and AMAT zones divide the territory differently. This problem will be dealt with in next section.

3 Working Hypotheses and Spatial Approach

An effective way to approach spatial analysis of heterogeneous data is to exploit the simplicity and effectiveness of a grid: indeed, a grid allows to divide the territory into cells and to treat each cell independently. To build the O/D matrix, the main difficulty is to combine all input data. For the case of this work, the input data are mainly the census data and the AMAT zones, for which the traffic fluxes are provided: these two inputs are referred to vector polygons, which do not match one to another (see Figs. 1 and 2). The census information, combined with the potential users' information coming from the demand analysis (Beria et al. 2017), given a proper area of interest for each station, provide the potential users of a certain Green Move station. Then, to compute the potential users which move to another station (given its own area of interest), the AMAT zones traffic fluxes are considered.

The overlay of three vector layers (census zones, AMAT zones and stations' areas of interest) is needed, but the vector data overlay is quite demanding from a computational point of view. With a grid-based approach, the computation area is automatically defined by the grid cell. Moreover, the shortest computation time allows the possibility to compute different scenarios. For these reasons, in this work the O/D matrices have been built following a grid-based approach. All input data have been referred to a grid, with a cell size of 500 m.

Some hypotheses have been necessary: they introduce some approximations, which have been considered as negligible with respect to other approximations considered in the project.

The hypotheses are:

- the population has been considered as homogeneously distributed into each census zone (Fig. 3);
- the traffic fluxes have been considered as homogeneously distributed into each AMAT zone.

Table 1 Time slots and their characteristics, provided by AMAT

Time slot	Reference hour	Coefficient
from 7 a.m. to 10 a.m.	8.00–8.59 a.m. morning peak hour	2.33
from 10 a.m. to 4 p.m.	Mean hour in the off-peak time slot	6
from 4 p.m. to 8 p.m.	17.00–17.59 p.m. evening peak hour	3.52

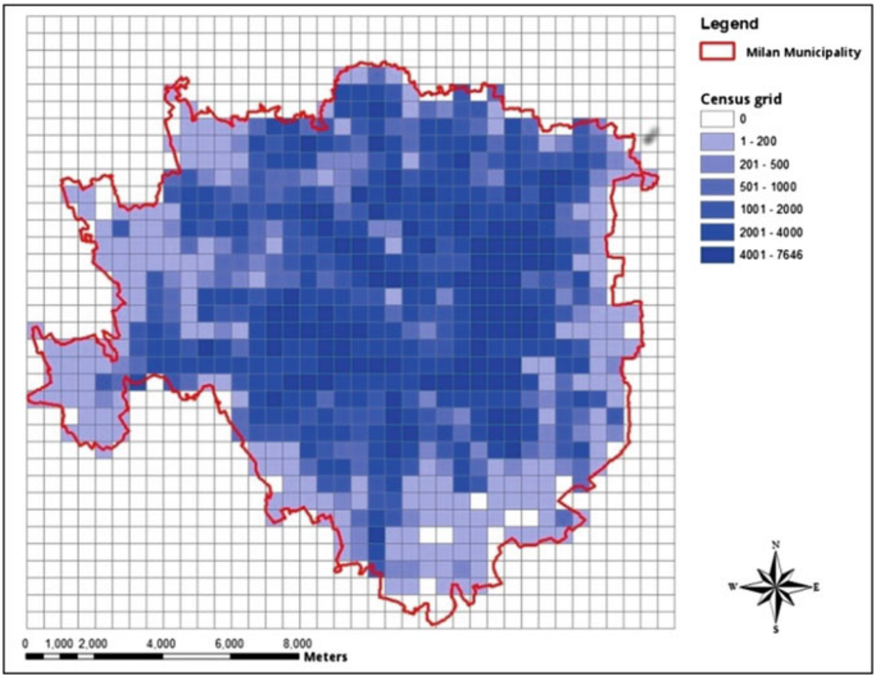

Fig. 3 Milan Municipality census on a regular grid with 500 m spacing

These assumptions can lead to some unrealistic results in areas where buildings and very congested roads are distributed in a very inhomogeneous way, like close to parks. However, these are not the most common cases in a highly urbanized area as the Milan municipality (see Fig. 4).

Other hypotheses have been taken into account to define the area of interest of each Green Move station:

- it has been considered that the mean walking speed of a potential user is 4 km/h;
- the potential user base (or area of interest) for each station has been considered within a 15 min walking distance;
- a grid cell has been assigned to a station if it is inside the station user base.

The research team has evaluated the 4 km/h walking speed as a reasonable estimation. Online, it is possible to find comparable values[1] which consider slightly higher walking speed; however, in our estimation, we have considered also the possible presence of crossings or traffic lights.

[1]e.g. https://www.newscientist.com/blog/shortsharpscience/2007/05/ quickstep-world-is-walking-faster.html.

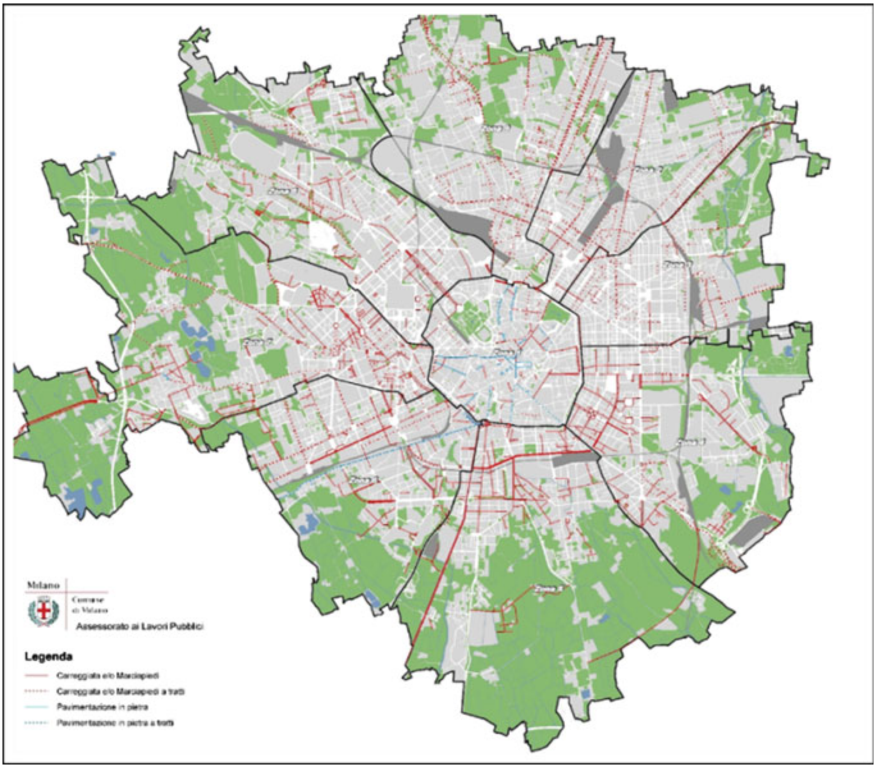

Fig. 4 Map showing the building density in Milan Municipality

These assumptions imply that the area of interest of each station is 1 km wide around the station itself.

For the car sharing service, different variables have been considered for the scenarios: different stations design and number, different charge rates, based on a fixed year rate (0 €/year, 50 €/year, 100 €/year) and on an hourly rate (3 €/h, 5 €/h, 7 €/h, 15 €/h), and different policies: direct trip (1way) or round trip (2ways).

To compute the number of potential users, with respect to each charge rate and spatial policy (1way or 2ways) combination, the number of inhabitants of each grid cell has been multiplied by a constant value obtained from a logit function (Ben-Akiva and Lerman 1985). The logit has been provided by the demand analysis model (Beria et al., Submitted and Chap. 5) and gives the probability p that a person wishes to use the Green Move car sharing service. In the following, the formula used to compute the probability p is shown:

$$p = \frac{e^{b_0 + b_{tf} * t_f + b_{tv} * t_v + b_c * c + b_f * f}}{1 + e^{b_0 + b_{tf} * t_f + b_{tv} * t_v + b_c * c + b_f * f}},$$

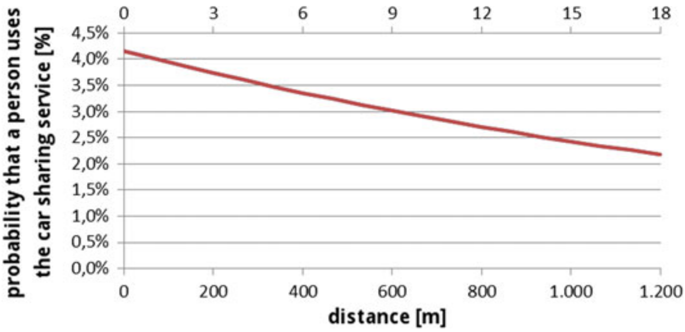

Fig. 5 Probability p in relation to the time provided by the logit function, in the interval between 0 and 15 min, with the fixed fee parameters = 50 €/year, flexible fee = 5 €/hour, spatial flexibility = 1 (1way)

where:

- β_0 (fixed parameter) = −2.29162;
- β_{tf} (coefficient relating to the fixed fee) = −0.00977;
- t_f (value of the fixed fee [€/year]);
- β_{tv} (coefficient relating to the variable fee) = −0.12399;
- t_v (value of the variable fee [€/hour]);
- β_c (coefficient relating to the capillarity) = −0.03704;
- c (capillarity [minutes]);
- β_f (coefficient relating to spatial flexibility) = 0.234164;
- f (spatial flexibility: 1 = 1way, 0 = 2ways).

In Fig. 5, the logit probability p is shown with respect to time, between 0 and 15 min, with the following parameters: fixed rate = 50 €/year, variable rate = 5 €/hour and spatial flexibility = 1 (1way). It is evident that, with the considered parameters, the logit has an almost linear behaviour, the same occurs with the other rate combinations considered, both in the 1way and in the 2ways cases. Thanks to this trend, to simplify the model implementation, the p probability has been assumed as a constant value corresponding to the mean value of the logit function between 0 and 15 min, within the user base of each Green Move station.

4 Building of O/D Matrices for Different Scenarios

The model outputs have been obtained implementing ad hoc code in MATLAB language. The same could have been done, for example, with python, and the MATLAB choice is not sensitive.

These are the inputs to the software:

- grid of population data;
- grid of AMAT zones;
- stations' scenarios;
- AMAT demand matrices (one for each time slot).

Input data depend on the model parameters, in particular the potential users change with respect to the demand analysis variables; the station distribution depends on the considered scenario; the AMAT demand matrices have been considered separately with respect to the time zones. Moreover, as previously discussed, all input data have been referred to grids, with a 500 m spacing.

If we consider the case study of this work, the actual inputs are:

- Sixteen files corresponding to the potential users grids, computed thanks to the logit function, which has been calculated for each one of the 8 rate combinations and for each spatial flexibility (1way or 2ways);
- Eighteen files corresponding to the grids of the stations' scenarios (for each station a different code is considered and in each cell the code of the closest station and the number of cells constituting its user basin are written). The user basin of each station is 1 km (this results from considering a potential user within a 15 min walking distance for a 4 km/h walking speed);
- One file containing the AMAT zones (for each cell the AMAT zone code and the number of cells assigned to each zone are reported);
- Three files obtained from the AMAT demand matrices, one for each time slot, corresponding to the reference time for each slot.

The software which computes the O/D matrices requires the percentage (% V_{eq}) corresponding to the number of vehicles moving from one zone to another; this is obtained from the AMAT demand matrices.

In Fig. 6, two different representations of the information included in the AMAT demand matrices are shown, with the morning peak time data: in the table on the left each row corresponds to a couple of Origin/Destination zones, and for each origin zone the value % V_{eq} is given; in the table on the right the same information is written as a double entry table. This format is more suitable to be used as input for the O/D algorithm.

AMAT demand matrices do not give any information about night traffic flows. To have an estimation about the night traffic and to be able to simulate car sharing demand along the day, the off-peak information has been considered as representative for the whole night slot (from 20 h to 7 h), considering that the traffic flux of the off-peak reference hour can be equivalent to the 11 night hours. With this hypothesis, each night hour has a traffic flow that is 1/11 of one hour during the off-peak. For the daytime, the original AMAT information has been kept.

ORIG	DEST	% V_{eq}
37	40	0.537
37	41	3.184
37	42	2.715
37	43	4.476
37	44	1.007
37	46	1.893
37	56	3.123
37	62	1.765
…	…	…

% V_{eq}	DEST							
ORIG	…	37	38	39	40	41	42	…
…	…	…	…	…	…	…	…	…
37	…	0.000	0.000	0.000	0.537	3.184	2.715	…
38	…	0.000	0.000	0.000	0.000	1.126	0.000	…
39	…	0.000	0.000	0.000	0.000	0.000	0.000	…
40	…	0.000	3.936	1.460	0.000	0.000	2.630	…
41	…	0.000	0.820	1.346	1.080	0.000	0.000	…
42	…	0.000	2.434	0.000	0.955	5.089	0.000	…
…	…	…	…	…	…	…	…	…

Fig. 6 Excerpt from the matrix of AMAT demand relating to the peak morning hour. In the left table, each line stands for a pair of AMAT Origin/Destination areas (vector form), whereas, in the right table, the source areas are listed on the lines and the destination areas inside the columns (matrix form)

Fig. 7 Scheme of the model for creating the O/D matrices (*in pink*)

In Fig. 7, the schema of the O/D model determination is shown.

The final outputs are 864 files corresponding to the 16 configurations rate-flexibility with respect to 18 stations scenarios and three time slots. This information has been useful in the framework of the Green Move project to analyse the applicability of the car sharing scenarios. Each output is a text file containing a double entry table showing the potential number of people taking the vehicle in one station and leaving it to another station.

5 Conclusions

In this chapter, a case study of O/D matrix determination for a car sharing service has been presented. The model for the O/D determination has been based on available data for the Milan Municipality, and the analysis has been grid driven. Indeed, the input layers' data, namely census and traffic fluxes data, were referred to polygons which did not match one to another. To speed up the computation time and to ease the spatial analysis, all data have been computed on a regular grid. This has allowed performing several simulations, which have been useful to evaluate the applicability of the Green Move car sharing service for the Milan Municipality (Luè et al. 2012).

The traffic fluxes have been acquired from already available data: the number of vehicles moving from and to specific polygon zones defined by AMAT has been considered as an input for the O/D model.

To refer all data to a grid, some assumptions have been necessary; in particular, the information has been considered as homogeneously distributed within the input polygons, both for census data and for traffic fluxes. In general, these hypotheses have been considered as reasonable for this case study. Some inconsistencies can occur when large census areas, with a large number of inhabitants, include areas where people do not live (such as parks). This inconvenience could be overcome excluding park areas from the analysis and including the road network in the analysis. This can be taken into account in future developments of this study. Another improvement could be to include also the public transport into the analysis. However, for the traffic fluxes the AMAT data considered in this work have been surveyed on the territory and not simulated, so the actual fluxes, which exist simultaneously to the public transport, have been taken into account for this paper.

Finally, also the parking spots could be included into the analysis, in combination with the road network, to improve the car sharing station positioning.

References

Arena M, Azzone G, Colorni A, Conte A, Luè A, Nocerino R (2015) Service design in electric vehicle sharing: evidence from Italy. IET Intell Transp Syst 9(2):145–155, 3. doi:10.1049/iet-its.2013.0034

Almeida Correia GH de, Pais Antunes A (2012) Optimization approach to depot location and trip selection in one-way carsharing systems. Transp Res Part E: Logistics and Transp Rev 48(1): 233–247. ISSN 1366-5545. http://dx.doi.org/10.1016/j.tre.2011.06.003

Ben-Akiva M, Lerman SR (1985) Discrete choice analysis: theory and application to predict travel demand. The MIT press, Cambridge

Bera S, Rao KVK (2011) Estimation of origin-destination matrix from traffic counts: the state of the art. Eur Transp Trasporti Europei 49:3–23

Beria P, Laurino A, Maltese I, Mariotti I, Boscacci F (2017) Analysis of Peer-to-Peer Car Sharing Potentialities, Electric Vehicle Sharing Services for Smarter Cities - The Green Move project, Research for Development, Springer

Boyacı B, Zografos KG, Geroliminis N (2015) An optimization framework for the development of efficient one-way car sharing systems. Eur J Oper Res 240(3):718–733. ISSN 0377-2217. http://dx.doi.org/10.1016/j.ejor.2014.07.020

Lo HP, Zhang N, Lam WHK (1996) Estimation of an origin-destination matrix with random link choice proportions: A statistical approach. Transp Res Part B: Methodological 30(4):309–324. doi:10.1016/0191-2615(95)00036-4

Luè A, Colorni A, Nocerino R, Paruscio V (2012) Green move: An innovative electric vehicle-sharing system. Procedia-Social Behav Sci 48:2978–2987

Randriamanamihaga AN, Côme E, Oukhellou L, Govaert G (2014) Clustering the Vélib′ dynamic origin/Destination flows using a family of Poisson mixture models. Neurocomputing 141 (2):124–138. ISSN 0925-2312. http://dx.doi.org/10.1016/j.neucom.2014.01.050

Toledo T, Kolechkina T (2013) Estimation of dynamic origin-destination matrices using linear assignment matrix approximations. Intel Transp Syst, IEEE Trans 14(2):618–626

Yang H, Zhou J (1998) Optimal traffic counting locations for origin–destination matrix estimation. Transp Res Part B: Methodological 32(2):109–126. ISSN 0191-2615. http://dx.doi.org/10.1016/S0191-2615(97)00016-7

System Sizing Model—Simulation Model of the Service

Giovanna Marchionni, Marco Ponti and Luca Studer

Abstract The model estimates the number of vehicles of a fleet that are necessary to meet the expected requests, as well as the estimated number of bays needed to ensure the temporary parking of the vehicles in use or charging at any time. The model allows to reproduce the service trend during a typical day, simulating the pickup requests at each station and the trip of each vehicle from the pickup to the return station; the model monitors the number of vehicles at every station, therefore allowing an estimate of the minimum number of bays per station and of the number of vehicles in order to satisfy the expected requests.

1 Context of the Model in the Service Configuration

This model aims at estimating some crucial values to measure the extent of the car sharing service, e.g. the number of vehicles required to set-up a fleet and the number of bays required for every pickup point (station), as a function of the characteristics to be given to the service (configuration parameters).

As explained in chap. 14, the values calculated from the present sizing model are then applied to the financial—economic model to evaluate the economic sustainability of the service. Furthermore, the sizing model allows to estimate the total number of km covered by the vehicles of the fleet. These data are essential for the subsequent sub-models to estimate the variation in vehicle congestion and in polluting and climate-altering emissions.

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The main model inputs are the number and location of stations and the O/D matrix of users, which is calculated from the previous sub-models of demand analysis and creation of O/D matrices, as well as some important service configuration parameters.

The core of the model, developed in MATLAB language, allows to reproduce the service time trend during a typical day, by simulating the pickup requests at each station and the trip of each vehicle from the pickup to the return station. The model monitors the number of vehicles at every station at any time, thus calculating the minimum number of bays per station and the number of vehicles necessary to satisfy the requests.

A prefixed percentage of electric vehicles to be included in the fleet can be imposed to input parameters: in this case, the model estimates the number of additional vehicles required with respect to the same service using traditional vehicles due to the time used for charging.

The increasing significance of the diffusion of electric vehicles required a variation in the base sizing model, as described in detail in Sect. 3. It considers an entirely electric fleet, and analytically and dynamically simulates the service operation with electric vehicles, also taking into account the dynamics of charging and running down of vehicle batteries.

2 Model Description

The fleet and bays sizing procedure consists of two sequential phases:

- a first preliminary phase, which calculates the O/D matrix of the actual trips to be simulated in the following phase. It starts from the users' O/D matrix and considers the number of average trips per user and the target share of pickup requests that the operator aims at satisfying. In this phase, the matrix of the distance between the several stations is also calculated;
- a second phase, which uses a dynamic and microscopic simulation model of the vehicle sharing service, in order to reproduce its daily operation and therefore to calculate the total km covered and the number of necessary vehicles and bays.

The simulation model of the second phase is dynamic and microscopic because:

- it can simulate the daily trend of the service over a typical day, with a time step of 1 min;
- it simulates the trip of each vehicle from one station to another (pickup from the station of origin and return at the station of destination), considering for each trip its starting and final position, the time taken and the km covered.
- each station is simulated separately by monitoring:

– the time trend of the number of vehicles available;
– the pickup requests (with a contextual check that a vehicle is available) and the return requests, which are stochastically extracted from a predefined demand pattern that is defined in the preliminary phase.

The next Sect. 2.1 describes in deeper detail final and intermediate inputs and outputs of the sizing model. Section 2.3 examines more closely the most significant methodological and procedural aspects of the model.

2.1 Input

The model mainly requires two input data sets, which characterize the service in terms of offer and demand. Data inputs are specified in detail in the following table.

Definition	Source	Notes	Values
Number ($N_{stations}$) and location of stations	Configuration parameter	Offer parameter: pickup and return points in the area that is covered by the service. These data greatly depend on the service comprehensiveness, in relation to the extent of the area where the service is offered	Variable based on the configuration alternative
Space flexibility (1w or 2w)	Configuration parameter	Offer parameter: possibility to return the car either to any parking area (1w) or only to the same pickup point (2w)	Values expressed as 1 (1w) or 0 (2w)
Average length of the route in 2w mode	Work hypothesis	Demand parameter: it is used to randomly generate the duration of a single trip	Only active in 2w mode
Average duration of intermediate stops in 2w mode	Work hypothesis	Demand parameter: it is used to randomly generate the stopping time of a single trip	Only active in 2w mode
Type of vehicles (%FEV)	Configuration parameter	Offer parameter: it represents the desired percentage of electric vehicles out of the total fleet	Percentage value, which varies based on the alternative
Probability to find a vehicle available (%VEH)	Configuration parameter	Offer parameter: it indicates the percentage of the demand of trips that the service manager wants to satisfy	Percentage value, which varies based on the alternative
Users' O/D matrix	Model of creation of O/D matrices	Demand parameter: potential users travelling between the several stations of the system	M_{O,D_users}
Users-trips coefficient	From the literature	Demand parameter: it represents the daily number of trips per user. It allows to estimate the number of users' trips	$coeff_{us/tr}$

2.2 Output

Model outputs may be divided into intermediate (obtained at the end of the preliminary phase and necessary to feed the actual service simulation model) and final ones, which can subsequently be used by other sub-models (economic–financial model, estimate of emissions and congestion).

Intermediate outputs are:

- **Matrix of distances** ($M_{distances}$): it represents the matrix of the distances between the stations of the configuration. It is calculated by means of an optimal routing algorithm;
- **Matrix of desired** ($M_{O,D\_desired\_trips}$) **and actual** ($M_{O,D\_carried\_trips}$) **trips**: the first matrix represents the demand of desired trips. It is calculated starting from the M_{O,D_users} matrix that is modified by means of the users-trips coefficient. The second matrix represents the number of actual trips: it differs from the previous one because not all the desired trips can be run, but only a share corresponding to the probability to find a vehicle available. The two types of matrices are hourly and the sum of the matrices defined for each time slot of the day gives the number of total (desired and actual) trips of one day.

Final outputs are:

- **Number of vehicles** ($N_{vehicles}$) that must make-up the fleet and be available at the start of the daily service at each station, in order to satisfy the percentage of requests defined by the parameter “probability to find a vehicle”;
- **Number of bays** (N_{bays}) that must be provided at each station to park the maximum peak of vehicles that is expected during the day at a station, and therefore guarantee the possibility to park all the vehicles that are temporarily not used at any time of the service;
- **Total number of daily km covered** (KM_{CS}) by all the vehicles of the service resulting from the sum of the km covered for each trip that is simulated by the model.

2.3 Operations

Some of the most important theoretical and operational aspects of the simulation of the vehicle sharing service are described below, thus making the operation of the developed model more comprehensible.

2.3.1 Calculation of the Matrix of the Distances Between Stations

Knowing the road distance between each couple of stations of the vehicle sharing service is fundamental for the simulation model, in order to correctly estimate the km covered by the vehicles and the time between the pickup of the vehicle at the origin and its return at the destination.

A graph of the road network of the city of Milan, which was provided by AMAT (Agenzia Mobilità Ambiente e Territorio—Mobility and Environment Agency of Milan), was used to define the distances, with the indication of the length of each road link. Dijkstra's algorithm[1] was used to calculate the minimum-length route l_{s1s2} between each couple of stations s1, s2 belonging to the set S that includes all the stations of the configuration under consideration.

The matrix of the distance ($M_{distances}$) is therefore obtained, where the distance between generic stations s1 and s2 results from $l_{s1s2.}$ This matrix is not symmetric, because the graph associated with AMAT's road network is antisymmetric as it takes into consideration road directions.

2.3.2 Calculation of Desired and Actual Trips

Starting from users' origin/destination matrices (M_{O,D_users}), which are generated from the model of creation of O/D matrices, the matrix of desired trips ($M_{O,D\_desired\_trips}$) is calculated by applying a coefficient. It is defined from the literature [enter a reference] and indicates the average daily number of trips generated per user ($coeff_{us/tr}$):

$$M_{O,D\_desired\_trips} = M_{O,D\_users} \cdot coeff_{us/tr}$$

It is now possible to calculate the actual trips matrix ($M_{O,D\_carried\_trips}$) by subtracting from the desired trips matrix the share of trips that are not satisfied due to the unavailability of a vehicle, and which must not be considered in the following phase of service simulation.

The matrix of actual trips is therefore defined as:

$$M_{O,D\_carried\_trips} = M_{O,D\_desired\_trips} \cdot \%VEH$$

where %VEH is the configuration parameter expressing the probability to find a vehicle available.

[1]Dijkstra, E. W. (1959). "A note on two problems in connexion with graphs". Numerische Mathematik 1: 269–271. doi:10.1007/BF01386390.

In the case, 2w the origin and destination of trips coincide (the user must return the vehicle to the pickup point). O/D matrices are therefore used by simply extracting the total trips that started from each station, without considering the information on the destination.

2.3.3 Method to Define the Vehicles of the Fleet

During the service simulation phase, each station is provided with a counter of the vehicles available, which is set to zero at the start. This setting allows to instruct the model to calculate the vehicles needed "inversely" with respect to the real situation: at the initial instant of the simulation, it is fictitiously supposed that there are no vehicles available. Only at the instant when a pickup is requested a vehicle is "generated", which immediately leaves the station to simulate the trip required and travels towards the target station. Even at the following instants, every time a pickup request cannot be satisfied with the vehicles that were previously entered in the simulation (e.g. if the pickup station at that time does not have any parked vehicle or has a lower number than the requests), a new vehicle is generated.

Each station is actually provided with two specific counters: the first monitors the present vehicles (which are therefore available for pickup) at the station at a general instant *t* of the simulation ($N_{virtual\_available\_vehicles,t}$); the second counts the vehicles generated from the beginning of the simulation (time 0) until the general instant *t* of the simulation ($N_{generated\_vehicles,t}$). The final value of this counter (at the end of the period of simulation of the daily service) exactly represents the number of vehicles needed to satisfy all the pickup requests made during the whole daily service ($N_{vehicles}$), which must therefore be at the station at the instant the service starts.

If the simulated configuration includes a prefixed percentage of electric vehicles in the fleet (expressed by a greater value than zero of the configuration parameter % FEV), the previously calculated value $N_{vehicles}$ will be increased by using a multiplicative coefficient in order to consider the downtime necessary to recharge the electric vehicles.

This coefficient considers that for each vehicle driving time unit, during which the battery runs down, a corresponding time unit is required to recharge the power that is used up. During this time, the vehicle must not be used.

The total running downtime depends on the number of km covered per time unit (and therefore on the journey average speed) and on the total range of the battery. The total recharging time depends, besides on the range of the battery, also on the recharging speed, which in turn depends on the technology used.

As already mentioned, a variation of the model was developed to analytically and dynamically simulate the charging and running down process of vehicles, see Sect. 3.

2.3.4 Simulation of Pickups at the Stations of Origin

For each station, the model provides a list of pickup requests, defining the exact time when the requests will occur. The following procedure is hereby applied:

- for each hour of service operation (24 h in the simulated configuration), the corresponding trips demand is considered. It is differentiated according to the pickup station and derived from the previously calculated matrices of actual trips ($M_{O,D\_carried\_trips}$);
- within each hour, the total pickup requests for each station are randomly spread along the 60 min of the time slot, thus defining the exact minute when the model must take into consideration each trip request. This random distribution is modified at each run that is carried out by the model for each simulated configuration (10 runs are expected for each configuration, as explained in deeper detail below);
- for each station and time step of the simulation (minute), the pickup request is compared with the fleet at the station and handled as follows:
- with vehicles available ($N_{virtual\_available\_vehicles,t > 0}$), the model reserves a vehicle that is already at the station;
- without vehicles available ($N_{virtual\_available\_vehicles,t = 0}$) the model "generates", as previously described, a new vehicle, thus increasing by a unit the counter of generated vehicles ($N_{generated\_vehicles,t}$), and moves it to its destination;
- at each pickup, the counter of vehicles ($N_{virtual\_available\_vehicles,t}$) available at the station is decreased by a unit. However, in case a new vehicle is generated, the same counter is previously increased by a unit, just as the counter of generated vehicles ($N_{generated\_vehicles,t}$). Basically, a vehicle is virtually generated, made immediately available for pickup and then immediately picked up.

2.3.5 Simulation of Trips

When a pickup is simulated at a certain station of origin and at a certain time instant, the model will define:

- the trip destination:
  - in the case 1w, it is defined by means of a random extraction based on the probability distribution provided by O/D matrices $M_{O,D\_carried\_trips}$ (once the origin of the trip is prefixed, this matrix allows to calculate the percentage distribution of trips with respect to the several possible destinations);
  - in the case 2w, the destination coincides with the origin.

- the length of the trip:
  - in the case 1w, once the origin and destination of the trip are known, the length is calculated by means of the matrix of distances ($M_{distances}$) that is previously calculated;
  - in the case 2w, it is randomly generated from an exponential probability distribution whose average is the input parameter “average length of the route in 2w mode”.
- the duration of the trip:
  - in the case 1w, it is calculated from the length of the trip, by considering a constant journey speed on all road links, however depending on the time slot (lower speed in rush hours with heavier traffic);
  - in the case 2w, the distance is calculated as in the case 1w, however summing an intermediate stopping time ($T_{parking}$) that is randomly generated from an exponential probability distribution whose average is the input parameter “average duration of intermediate stops in 2w mode”.

2.3.6 Simulation of Returns at the Stations of Destination

For each simulated trip, based on the journey simulation described above, the model handles the return to the selected station of destination as follows:

- the vehicle used is returned at a time instant that is calculated by adding the duration of the trip to the instant of the pickup from the station of origin;
- the counter of the vehicles available at the station of destination ($N_{virtual\_available\_vehicles,t}$) is increased by one unit.

2.3.7 Definition of the Necessary Number of Bays

The number of bays per station that is necessary to park the vehicles must be calibrated according to the maximum peak of parking requests occurring over the time span of the daily service.

In order to calculate the number of bays that are necessary for each station (N_{bays}), once the main simulation is concluded, the model repeats for the second time the simulation that was already carried out according to the following criteria:

- in this case, the number of real vehicles that are available at each station at the beginning of the service (time 0) is not set to zero, but it is equal to the need of vehicles that was previously calculated ($N_{real\_available\_vehicles,0} = N_{vehicles}$);

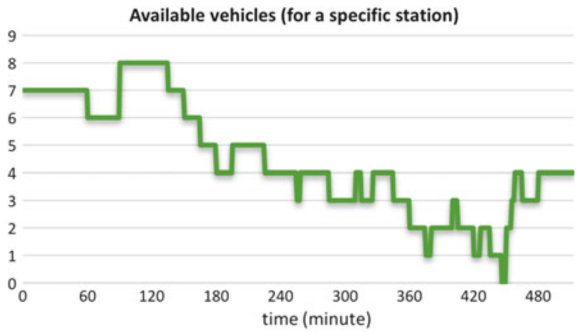

Fig. 1 Example of trend during the period of simulation of the number of real vehicles that are available at a pickup station

- the number of pickups and returns at each station for each time step t is already defined in the main simulation (the simulation is being repeated, no new one is generated);
- for each simulation time step t, the model calculates the real vehicles that are available at the station ($N_{real\_available\_vehicles,t}$) starting from the vehicles that were available in the previous time step ($N_{real\_available\_vehicles,t-1}$), then subtracting the vehicles picked up in the time step t and adding the vehicles returned in the same time step t. Figure 1 shows the trend of the number of real vehicles that are available at a specific station during the simulation period.

The number of necessary bays (N_{bays}) therefore results from the maximum number of real vehicles available at the station at each time instant t of the simulation period $[0..T]$:

$$N_{bays} = \max_{t \in [0..T]} N_{real\_available\_vehicles,t}$$

2.3.8 Use of Several Runs for Each Simulated Scenario

As already mentioned, each configuration under evaluation is simulated by means of several runs of the model (10 runs). In each run some data inputs, e.g. the minutes when the actual pickup requests occur and the destination of the several journeys, are different because they are randomly generated from a proper distribution of probability.

For each simulated configuration, the average values of the several model outputs are extrapolated with respect to the 10 runs.

This allows to take into account the variations in users' behaviour that may naturally occur during the real operation of the service, thus avoiding the risk of sizing fleet and bays based on peculiar cases that may prove extreme and do not represent an average working condition.

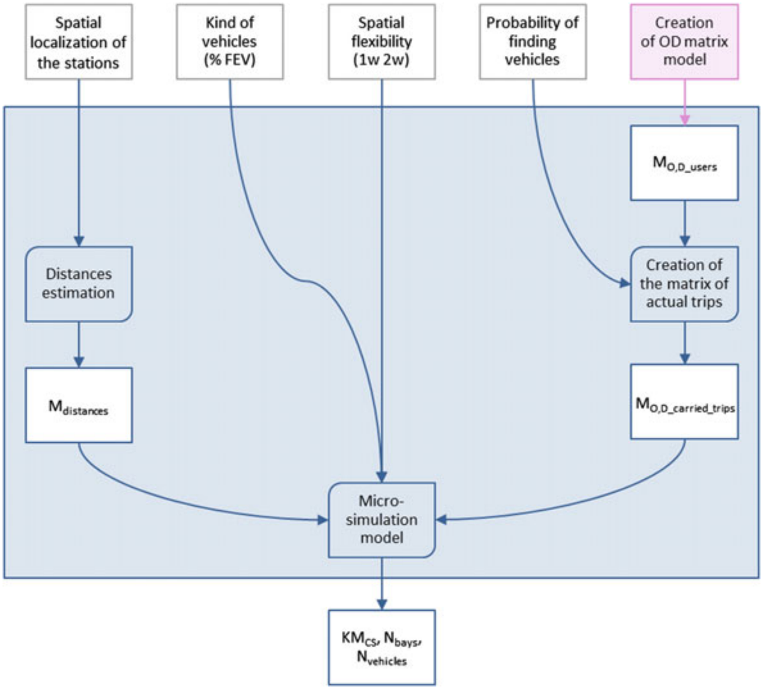

Fig. 2 Scheme of the sizing model (in sky blue)

However, the model also extrapolates the minimum and maximum values of the several outputs obtained in the 10 runs. The range of a possible variation in the sizing values can therefore be estimated, thus clarifying the level of uncertainty that characterizes the results (Fig. 2).

3 Dynamic Simulation of Electric Vehicles Fleet

In the developed model that was described above, the fleet sizing with electric vehicles was estimated by using a multiplicative coefficient that allows to consider the additional time necessary for the electric recharging, therefore the need for a greater fleet with other service configuration parameters being equal.

In order to simulate this aspect at its best, a variation of the main model was developed. It can be used with entirely electric fleet and allows to simulate real charging and running down processes during the service, and to obtain a more precise estimate of the number of necessary vehicles.

This variation of the model requires the input of some additional and/or more precise configuration parameters with respect to the base model:

- **total range**: maximum number of km that the vehicle can cover after a complete battery charging cycle; it depends on the type of vehicles used;
- **recharging time**: the time necessary for a complete recharging cycle; it depends on the type of vehicles and on the recharging station used;
- **minimum range threshold**: the residual range of a vehicle (in km). Below this threshold, the user must be prevented from using a vehicle to avoid the risk of running down during the trip.

With respect to the base model, further theoretical and operational aspects are introduced during the simulation phase:

- for each simulated vehicle a counter is added, which monitors in every instant the charge of the vehicle (residual range in km);
- in the return phase:
  - vehicles having a lower charge than the minimum threshold of range cannot be used; if no vehicles are charged enough, the model will generate a new vehicle by increasing the relating counter ($N_{generated\_vehicles,t}$);
  - if there are several vehicles available having a higher charge than the threshold, the model will reserve the vehicle with a higher level of charge;
- in the return phase, the counter of the vehicle residual range is updated by subtracting the total km covered during the just concluded trip;
- in the stopping phase, at each simulation time step the counter of the residual range of each vehicle in charge is progressively increased as a function of the recharging speed; the residual range cannot obviously exceed the total range of the vehicle.

4 Conclusions

The simulation model developed that is described in this chapter represents an effective instrument for the correct sizing of a vehicle sharing service having certain characteristics that are predetermined by the manager (configuration parameters). The dynamic and microscopic approach applied, as well as the capacity of the model to simulate the real dynamics of the handling of the fleet vehicles, allow an accurate estimate of the vehicles and bays necessary to properly provide the required characteristics of the service. The same outputs given by the simulation model are important for the extended evaluation model of the service, as they provide essential elements to evaluate the financial–economic sustainability as well as to estimate the impacts on traffic and on polluting and climate-altering emissions.

Conclusions and Future Trends: From Ownership to Sharing

Daniele Fabrizio Bignami, Alberto Colorni, Alessandro Luè, Roberto Nocerino, Matteo Rossi and Sergio Matteo Savaresi

Abstract In this chapter, we summarise the main "lessons learned" that originated from the study and the onsite experimentation within the Green Move project. These are presented under the form of brief "guidelines" that may represent launching pads for a complete engineering of an advanced system of vehicle sharing. In the (relatively short, a little more than two years) duration of the project, the technologies and experiences of vehicle sharing underwent a noteworthy evolution which in any case appears to be in line with many of the points analysed. The remarks presented in this chapter represent a contribution for identifying the conditions, related to both the service model and the technology, for shifting from car ownership to vehicle sharing: providing this option to citizens is an essential aim that each city has to pursue as a first step for becoming a smart city.

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1 The Future of Sharing Mobility

The future of sharing mobility will be influenced by several drivers; focusing particularly on recent (in the 2010s) trends, the following factors can be identified as particularly important contributors (Luè 2015).

- Venture capital markets have become increasingly focused on personal mobility, making available larger pools of capital with which to support development of the "back-end" of Mobility as a Service (MaaS) networks.
- The maturation of Information and Communications Technology has proven to be a major catalyst for the growth of MaaS.
- Peer-to-peer markets have emerged as part of the wider (i.e. aside from transport) sharing economy.
- There has been a clear generational shift (Lee-Gosselin 2017) in policy preferences across all levels of government in Europe (local authority through to pan-European), with attitudes (and consequent policies) evolving towards increasingly negative views of provision for growth in private motorised transport.
- There has also been a generational shift in access to economic resources, with younger adults (the age group that uses sharing mobility in different ways, time windows, etc.) in many European countries having consistently lost ground economically in the 2000s relative to older age groups.
- Finally, the attitudes and actions of specific entrepreneurs to directly challenge both incumbents and policymakers in the urban mobility space have been the key to service innovation.

The future development of car sharing will depend not only on the above factors, but also on the potential influence of disruptive elements. One example is the introduction of fully autonomous vehicles, which is likely also to boost vehicle-sharing deployment as it would enable the ability to re-position the vehicles to where and when demand is likely to be high, without the cost of human intervention (Le Vine et al. 2014).

2 The Green Move Solution

Green Move has been able to anticipate some of these drivers, creating a flexible solution, with the following characteristics:

- **Wide vehicles portfolio**. Green Move has been created as a multi-vehicle system, with the integration of different classes of vehicles. The system has not been developed for a small number of new vehicles, but with an inclusive logic that can permit any manufacturer easy adaptability and integration in the system of its own vehicles through the installation of a small electronic dashboard (the "Green e-Box").

- **Interoperability**. This is a fundamental characteristic of the project. In close analogy with the Internet, all vehicles of the system (like every Internet hub) may differ by size, cost and structure, but must respect a system “protocol”, shared and standardised, which allows the access to the network (the sharing system) and guarantee complete interoperability.
- **Ownership of the system. In accordance with a MaaS perspective**, Green Move was created and planned as a distributed system. The system may comprehend a series of subsystems (vehicles and recharging stations) belonging to different organisations and companies; vehicles and recharging stations are “standardised” in their interfaces (computer, electric, mechanic) and therefore completely interoperable (each vehicle may be hooked up to each docking station).
- **Business model**. Within the scope of the designed system, a number of various business models may coexist. For example, vehicles were made available by a public administration for its citizens (with the payment of a flat-rate annual tariff), by a company for its employees (for transfers between branches or from stations to the company), by an airport vehicle-rental company, by a hotel or a trade organisation for its clients, etc. Each actor is free to purchase the vehicles (upon which to impose their own limits and rates) and to contribute to the network by installing their own recharging stations; the only condition is the conformity of the system standards, in terms of access to the vehicles, protocols for data exchange, power points.

According to these principles, the next sections summarise the main remarks that emerged during the project.

2.1 Service Model

Adequate service model design is an essential aspect, in which different elements have to be taken into consideration in order to implement an electric vehicle-sharing service that is both efficient and able to address the user’s needs. The following are some of the main characteristics that an efficient electric vehicle-sharing service should have.

- **Capillarity**: the vehicles and the docking stations must be easily reached by the user by foot, for guaranteeing a level of capillarity comparable to that of privately owned cars. The recharging stations have to be placed near the main mobility generators and LPT stations, in order to guarantee an effective intermodality and efficient synergy with public transport: this permits a broadening of the area of use from residents to commuters and to city-users.
- **Interoperability**: the interoperability among different services regards tariff integrations with the LPT and among the various car-sharing operators; it should be stimulated and sustained by the local public administration, the stakeholder able to encourage this integration.

- **Annual rate**: this is one of the main obstacles to registration; the user does not know how often he will use the service and is reluctant to adhere thereto if the entrance fee is too high. A low (or zero) annual fee enhances the growth of a potential user base that may determine a rapid attainment of critical mass of users.
- **Pricing system**: this must be clearly defined and easily customised in function of the user's profile, for allowing the broadest range of uses possible. In an electric vehicle-sharing system, in particular, the pricing system based on time seems to be more consistent than one based on distance covered.
- **One-way trips**: in this type of service customers can return the vehicle to a different place than it was accessed. This offers users a fundamental chance to undertake "one-way" journeys, especially if aimed at business clients or occasional travellers. More flexibility is guaranteed by free-floating services, even though, for electric car sharing, the recharging stations must be present and reallocation for recharging can request remarkable effort in terms of management and costs.
- **Balancing of the fleet**: one-way services, in general, and free-floating ones, in particular, need to rebalance the fleet: this may occur through reallocation mechanisms, possibly performed both by the users (acting on reward) and by the operators (through dedicated staff).
- **Range of vehicles**: the availability of a wide range of vehicles (cars, but also electric quads, scooters and bikes) allows services to satisfy different user needs: this may be facilitated by guaranteeing the interoperability between different operators (e.g. interoperability among car-sharing operators with different types of vehicles, bike- and scooter-sharing services, etc.) and through the introduction of peer-to-peer services.
- **Technological and service standards**: the great dynamism of the vehicle-sharing market seems to suggest the adoption of standards, to foster the integration of different systems together.
- **Booking system**: this is one of the key mechanisms of an advanced vehicle-sharing system. The range of options is wide (one-way, two-way, immediate booking or short-/medium-/long-term booking, with/without limits of use, etc.). The more flexible the booking process, the higher the probability of being able to satisfy the user's needs.
- **Alternative models**: as well as a "generic" car-sharing service, there are also alternative systems, such as community car sharing, the peer-to-peer car sharing. These services can work in synergy with traditional services, helping to satisfy specific niche needs.

2.2 Technology of the System

Technology plays a fundamental role in allowing designed service models to have a real application in practice. One of the main points of the project is the hypothesis that the user may access the system exclusively using his personal device and the software applications installed on it, without further intermediaries. Today this appears realistic, as the availability of mobile devices (smartphones and tablets) is such that the potential users of the system have access to them on a daily basis. This scenario was perhaps—at the beginning of the project—optimistic, but it quickly became realistic due to the huge evolution of the technological context in which the Green Move project has operated. Given the high dynamism of said context, it appears to be crucial that an innovative system be designed so as to avoid anchoring it to specific technologies, instead favouring the possibility of constantly modifying and updating the technologies on which the system is based. This may be obtained in a variety of ways, listed below.

- **Interoperability**: this is the possibility to ease communication between the components of which the system is made up; this makes it easier to integrate within it new components and technologies (in the moment in which these became available) and enriches the system of new functionalities, (also) acquired by third parties.
- **Open platforms**: building the system on the most possibly open and standard platforms and technologies (meaning they are independent of specific suppliers) makes it easier to keep it up to date and takes advantage of the innovations, which is particularly important in the interaction between the system and the vehicles.
- **Involvement of the manufacturers**: standard procedures allowing users to interact with the vehicle independently from the manufacturer are not always available. Standards such as On-Board Diagnostics (OBD) are a first step in this direction, but they are not yet rich enough to be the basis for a vehicle-sharing system. Without such standards, it is crucial to be able to involve vehicle manufacturers in the development of sharing system, in order to obtain suitable interfacing mechanisms.
- **Charging points**: similarly, to the interaction between system and vehicles, that with the docking systems should also occur as soon as possible through open standard mechanisms, which at the moment is not possible. In the near future, we can predict a quick increase in the distribution of charging points, which should give a significant push towards their standardisation.
- **Ease of (re)configuration**: The Green Move solution is in continuous evolution, not only technologically, but also for what concerns the needs and preferences of involved actors (users, institutions, vehicle suppliers) or the related regulations. Hence, the ease of reconfiguration (in terms of constraints on the use of vehicles, mechanisms for the monitoring and management of the fleet, services offered to the users, etc.) must be one of the main aims pursued by the system.
- **Software development practices**: for a complex system, such as Green Move, it is important to adopt software development standards that are solid and strict, taking care to suitably document the choices made. The system is by its nature heterogeneous and must be developed by a team with a broad range of skills,

including server-side programming, code development for mobile devices, embedded control unit programming, but also development of electronic devices to manage the interfacing with the low-level components of the vehicles.

- **Security (of data and networks)**: a system like Green Move is greatly distributed and involves continuous and important interactions between components that are connected through telematics networks: it must therefore be planned while constantly keeping in mind security matters. In this regard, the exposure of the system to computer attacks should be minimised, for example by avoiding to keep unnecessary functionalities and services active.
- **Solidity**: the need for solidity of planning/realisation is not confined to software components. When physical devices lie at the heart of the system (e.g. the Green e-Box), it is of the utmost importance that they are also solid from the physical point of view, considering the fact that they may operate in insufficient environmental conditions (very high or very low temperatures, adverse atmospheric conditions, damp, etc.).

References

Lee-Gosselin M (2017) Beyond “Peak Car”: A reflection on the evolution of public sentiment about the role of cars in cities. IATSS Res press. doi:10.1016/j.iatssr.2016.05.004

Le Vine S, Zolfaghari A, Polak JW (2014) Carsharing: evolution, challenges and opportunities, report to the European automobile manufacturers association (ACEA) Scientific Advisory Group

Luè A (2015) Design and decision aiding for mobility services and systems (Doctoral thesis, Politecnico di Milano, Milano, Italy). Retrieved from http://hdl.handle.net/10589/113583