Sustainable Logistics in Urban Areas: Innovative Approaches for Externalities Reduction in Smart Cities

Department of Mechanics, Mathematics and Management
MECHANICAL AND MANAGEMENT ENGINEERING
Ph.D. Program
SSD: ING-IND/17–MECHANICAL INDUSTRIAL PLANTS

Final Dissertation

Sustainable Logistics in Urban Areas: Innovative Approaches for Externalities Reduction in Smart Cities

---

by

SILVESTRI BARTOLOMEO

Supervisors:

Prof. Salvatore Digiesi

Prof. Maria Pia Fanti

Coordinator of Ph.D. Program:

Prof. Giuseppe P. Demelio

Course n°32, 01/11/2016-31/10/2019

To my wife

“Stay hungry, stay foolish”

Steve Jobs

Abstract

Globalization and e-commerce lead the actual growing trends of home delivered goods. The increase of inhabitants in the cities requires more services for the mobility of people. In the coming years, the increasing demand of freight and people transport in urban areas will further stress their negative impacts or externalities. An externality is defined as a cost arising "*when the social or economic activities of one group of persons have an impact on another group and when that impact is not fully accounted, or compensated for, by the first group*".

The Smart City concept promotes a new vision based on the radical reduction of negative impacts in cities through the use of technological, methodological and organizational innovations. Smart mobility is one of the pillars of this new idea.

Several technological and organizational improvements are available in scientific literature such as Electric Vehicles (EVs), ICT tools and systems, Autonomous Vehicles (AVs), different usage schemes in urban mobility, policies and rules, and efficient urban mobility management. A new arising concept that could integrate these innovations and strongly reduce externalities in the urban areas is the Mobility as a Service (MaaS) paradigm. People are interested in moving from one point to another in the city and through these new technologies different mobility alternatives are available. The same concept can be considered for goods delivery in urban areas. A high level of service is an important factor in engaging users towards sustainable mobility.

The analysis of the last mile logistics innovations shows that it is possible to increase sustainability, reduce the transport externalities in the urban area and, at the same time, improve the companies' economic results.

In urban people mobility, sharing, pooling, and rental systems are also growing thanks to the new types of EVs available on the market such as Electric Light Vehicles, electric kick scooter and Segway. Sharing mobility systems have great potential in cities because they perfectly integrate with public transport to perform short trips or the last leg of the trip in the case of public transport lack or low frequency.

In this context, identifying new strategies and ICT innovations to promote the electro-mobility, to improve the efficiency of organizational methods both in freight transport for the last mile logistics and for the people mobility is the aim of this PhD thesis. The crowd-sourcing paradigm and user centric approaches are at the basis of the proposed method solutions in order to reduce the urban externalities. Scientific literature proposes different approaches in the field of policies and rules mainly based on prohibitions and charges; users, on the other hand, can be involved through games and incentive schemes. Economic behaviour, a branch of cognitive science, proposes the positive incentive to define the "nudge" paradigm, in order to help people, make better decisions if they act rationally or if well-informed. In a station based EVs sharing system the relocation process is a fundamental activity to ensure a high service level to users. Relocation is expensive and does not contribute to improve environmental sustainability since additional transport means are adopted to fulfil it. Thus, the idea of involving users in the relocation process through an innovative incentive mechanism can lead to jointly reduce externalities in the urban area and to guarantee high service level to users. Similarity, customers can be involved in the relocation of goods between stores in the city. In addition, the optimization of the incentive-based approach can be applied in the goods cross-distribution between shops and a warehouse in an urban area. The proposed method allows to have both environmental and economic advantages and further engages users in a more sustainable vision with credits to spend on the mobility service or company products.

The PhD thesis structure is as follows:

1. State of the art analysis of the transport externalities in urban areas with a focus on the approaches to reduce negative impacts in people mobility and last mile logistics; an evaluation of gaps and achievable targets is proposed.

2. Definition of a new user-centric approaches to develop ICT tools and platform for promoting electro-mobility in urban areas; a Serious Game App developed with the aim of increasing citizens awareness in the use of EVs is detailed.
3. Analysis of the relocation problem in EVs / ELVs sharing systems and innovative strategies for involving users through optimized incentive-based approaches; both a centralized and a distributed optimization approaches developed to reduce the total relocation costs, including external costs are described. In addition, numerical experiments with EVs and ELVs demonstrate the potential benefits of the approaches.
4. Analysis of last mile logistics innovations and definition of a new optimization incentive based approach for the goods relocation and cross-distribution in urban areas; numerical experiments show the internal and external costs reduction achievable by adopting the proposed approach.
5. Conclusions of this work and future research developments.

Sommario

Il settore dei trasporti delle merci e delle persone sta causando problematiche ed impatti negativi nelle aree urbane. La vendita online e la globalizzazione guidano l'attuale crescita di beni consegnati a domicilio. L'incremento di abitanti nelle città richiede maggiori servizi per la mobilità di persone. Nei prossimi anni, tali fattori aumenteranno ulteriormente gli impatti negativi o esternalità. L'esternalità è definita come un costo derivante "quando le attività sociali o economiche di un gruppo di persone hanno un impatto su un altro gruppo e quando tale impatto non è interamente contabilizzato o compensato dal primo gruppo".

Il concetto di Smart City promuove una nuova visione basata sulla riduzione radicale degli impatti negativi nelle città mediante l'uso di innovazioni tecnologiche, metodologiche ed organizzative. La Smart Mobility è uno dei pilastri di questa nuova idea.

Diversi miglioramenti tecnologici e organizzativi sono presenti in letteratura come ad esempio veicoli elettrici, strumenti e sistemi ICT, veicoli autonomi, diversi schemi di utilizzo nella mobilità urbana, politiche e regolamenti, e una gestione efficiente della mobilità urbana. Il nuovo importante concetto cha può integrare queste innovazioni e ridurre fortemente le esternalità in area urbana è il paradigma della mobilità intesa come un servizio. Le persone sono interessate a muoversi da un punto ad un altro della città e mediante queste nuove tecnologie si rendono disponibili diverse alternative di mobilità. Lo stesso concetto può essere considerato per la consegna di beni in area urbana. Un

elevato livello di servizio è un fattore importante per coinvolgere gli utenti verso una mobilità sostenibile.

L'analisi delle innovazioni nella logistica dell'ultimo miglio mostra che sia possibile incrementare la sostenibilità, ridurre le esternalità da trasporto in area urbana e, allo stesso tempo, migliorare i risultati economici aziendali.

Nella mobilità delle persone, la mobilità condivisa, sistemi di raggruppamento e noleggio stanno crescendo anche grazie a nuove tipologie di veicoli elettrici adatti per le città e disponibili sul mercato come ad esempio veicoli elettrici leggeri, monopattini elettrici, segway. I sistemi di mobilità condivisa hanno un grande potenziale nelle città perché si integrano perfettamente con il trasporto pubblico per eseguire viaggi brevi o l'ultimo tratto del tragitto in caso di mancanza del trasporto pubblico o bassa frequenza.

Nel contesto descritto, l'obiettivo di questa tesi di dottorato è proporre nuove strategie basate su ITC per l'elettro-mobilità urbana, migliorare l'efficienza dei metodi organizzativi sia nel trasporto merci per la logistica dell'ultimo miglio che per il trasporto persone con strategie innovative. Il paradigma del crowdsourcing e gli approcci incentrati sull'utente sono alla base dei metodi proposti in questo lavoro per ridurre le esternalità urbane. La modifica del comportamento degli utenti è un processo fondamentale per raggiungere questi obiettivi. La letteratura propone diversi approcci in ambito di politiche e regole basati principalmente su divieti e tasse; gli utenti, invece, possono essere coinvolti attraverso giochi e schemi di incentivi. Il comportamento economico, una branchia della scienza cognitiva, propone l'incentivo positivo per definire il paradigma della "spintarella" allo scopo di aiutare le persone a prendere decisioni migliori se agiscono in modo razionale o se sono ben informate. Il processo di riallocazione dei veicoli elettrici in un sistema di condivisione basato su stazioni è un'attività fondamentale per assicurare un elevato livello di servizio agli utenti. Inoltre, questa attività è costosa e non molto efficiente dal punto di vista della sostenibilità ambientale in quanto vengono utilizzati mezzi aggiuntivi. Pertanto, l'idea di coinvolgere gli utenti nel processo di riallocazione attraverso un meccanismo di incentivazione innovativo può portare ad una riduzione delle esternalità in area urbana. Allo stesso modo, i clienti possono essere coinvolti nella riallocazione di merci tra un negozio ed un altro all'interno della città. In aggiunta, l'approccio per l'ottimizzazione basato su incentivo è applicato nella distribuzione di beni tra negozi ed un magazzino nella stessa città. Il metodo proposto consente di avere vantaggi sia ambientali che economici e coinvolge ulteriormente gli utenti in una visione più sostenibile con crediti da spendere per il servizio di mobilità condivisa o per prodotti dell'azienda.

La struttura della tesi di dottorato è la seguente:

1. Analisi dello stato dell'arte delle esternalità da trasporto in area urbana concentrandosi su approcci in grado di ridurre gli impatti negativi nella mobilità di persone e nella logistica dell'ultimo miglio. E' proposta anche una valutazione delle lacune e degli obiettivi raggiungibili.
2. Una revisione della letteratura dei sistemi ITC per l'elettro-mobilità e nuovi approcci incentrati sull'utente per sviluppare strumenti e piattaforme ITC per promuovere l'accettazione dell'utente e l'uso di veicoli elettrici, attraverso una specifica applicazione sui giochi seri.
3. Analisi del problema della riallocazione in un sistema condiviso con veicoli elettrici o veicoli elettrici leggeri e strategie innovative attraverso un approccio di ottimizzazione basata su incentivi per coinvolgere gli utenti. Approcci di ottimizzazione centralizzata e distribuita sono stati sviluppati per ridurre il costo complessivo della riallocazione, includendo i costi esterni. Inoltre esperimenti numerici con veicoli elettrici e veicoli elettrici leggeri sono proposti per dimostrate i benefici del metodo proposto.
4. Una revisione della letteratura delle innovazioni della logistica dell'ultimo miglio degli ultimi 5 anni e un nuovo approccio per l'ottimizzazione basato su incentivi per la riallocazione e la distribuzione di beni. Due esperimenti numerici sono modellati al fine di ridurre il costo per la compagnia e i costi esterni.
5. Le conclusioni con i risultati della ricerca e gli sviluppi futuri

Acknowledgements

Content

Glossary 4

List of tables 5

List of figures 6

1. Transport Externalities in Urban Areas 7
   - 1.1. Urban externalities of freight and people transport 8
     - 1.1.1. Classification 10
     - 1.1.2. Impacts 14
   - 1.2. Approaches to reduce peoples' mobility externalities 17
   - 1.3. Approaches to reduce last mile logistics externalities 19
   - 1.4. Gaps and achievable targets 20
   - 1.5. Chapter references 21

2. Innovative ICT tools to promote electro-mobility 26
   - 2.1. ICTs in sustainable urban people mobility 27
   - 2.2. ICT systems for electro-mobility 28
   - 2.3. User-centric ICT tools for electro-mobility 28
     - 2.3.1. Use case of the ICT the tools 32
     - 2.3.2. Software requirements 33
     - 2.3.3. Developing system for ELVs 36
   - 2.4. Innovative approach to the baseline analysis of KPIs in electro-mobility sector 37
   - 2.5. Original serious game approach for the electro-mobility 40
     - 2.5.1. User requirements, UML diagrams of use case and UML diagram of classes 41

2.5.2. Architecture of the Serious Game App 43

2.5.3. Serious Game rules and functionalities 45

2.6. Conclusions on the results obtained 47

2.7. Chapter references 48

3. Optimization of EVs and ELVs relocation in the sharing system 53

3.1. Relocation problem in the EVs and ELVs sharing system 54

3.2. Literature review on vehicles relocation problem in the sharing system 57

3.3. Innovative strategies for the EVRP in a sharing system with optimization approaches 58

3.3.1. Incentive schemes 60

3.3.2. Centralized optimization approach 62

3.3.3. Distributed optimization approach 66

3.3.4. Numerical experiments with EVs 69

3.3.5. Numerical experiments with ELVs 73

3.3.6. Benefits of the users involvement approach 74

3.4. Computational complexity analysis 75

3.5. Conclusions on the results obtained 76

3.6. Chapter references 77

4. Optimization of last mile logistics 81

4.1. Last mile logistics 82

4.2. Literature review on last mile logistics innovations 82

4.2.1. Recent vehicles in the last mile logistics 82

4.2.2. Proximity stations and points 84

4.2.3. Collaborative and cooperative urban logistics 85

4.2.4. Public policies and infrastructures 86

4.2.5. Optimization of transport management and routing 87

4.3. Goods relocation and cross-distribution in last mile logistics 90

4.4. Innovative goods relocation models with optimization approaches 92
4.4.1. Goods relocation incentive schemes 93
4.4.2. Goods relocation centralized optimization approaches 94
4.4.3. Numerical experiments with fashion retailers 97
4.5. New cross-distribution models with optimization approaches 101
4.5.1. Cross-distribution incentive schemes 102
4.5.2. Cross-distribution centralized optimization approach 103
4.5.3. Numerical experiments with pharmacies 106
4.6. Conclusions on the results obtained 109
4.7. Chapter references 111

5. Conclusions 117
5.1. Results of the research 118
5.2. Final considerations on the future developments 119

Annex 121

Glossary

Term	Explanation
AEV	Autonomous Electric Vehicles
App	Application
AVs	Autonomous Vehicles
AVoDs	Autonomous Vehicles on Demand
CO_2	Carbon-dioxide
DSS	Decision Support System
ELVs	Electric Light Vehicles
EVs	Electric Vehicles
EVRP	Electric Vehicle Relocation Problem
FCEVs	Fuel Cell Electric Vehicles
GDP	Gross Domestic Production
GHG	Green House Gasses
GPS	Global Positioning System
HEVs	Hybrid Electric Vehicles
ICE	Internal Combustion Engine
ICT	Information and Communication Technology
ILP	Integer Linear Programming
IoT	Internet of Things
IT	Information Technology
ITS	Intelligent Transportation System
KPIs	Key Performance Indicators
LCV	Light Commercial Vehicle
MaaS	Mobility as a Service
SoC	State of Charge
SVM	Support Vector Machines
UCC	Urban Consolidation Centre
UML	Unified Modeling Language
WTP	Willing to Pay
XML	eXtensible Markup Language

List of tables

Table 2.1 –	Main flow of actions of "Bool ELVs" Case	34
Table 2.2 –	ICT Requirement in ELVITEN project	36
Table 3.1 –	Classification of papers on the vehicles relocation in the sharing systems	56
Table 3.2 –	Initial number of EVs/ELVs per station	71
Table 3.3 –	Distance between station in km	71
Table 3.4 –	EVs/ELVs battery autonomy	71
Table 3.5 –	User acceptance rate and relocatable EVs/ELVs	71
Table 3.6 –	External costs for the relocation task of EVs and ELVs	72
Table 3.7 –	Results of EVs relocation simulation (Scenario 1) with ILP1 and ILP2	75
Table 3.8 –	Results of ELVs relocation simulation (Scenario 2) with ILP1 and ILP2	75
Table 3.9 –	Computational time of centralized optimization problem with different number of stations and EVs	76
Table 4.1 –	Last Mile Logistics innovations to reduce externalities in urban areas	89
Table 4.2 –	Initial number of goods per retailer	98
Table 4.3 –	Distance between retailers in km	98
Table 4.4 –	Acceptance rate of loyal customers and relocatable fashion goods	98
Table 4.5 –	External costs for the goods relocation task	98
Table 4.6 –	Results of goods relocation simulation with ILP1 and ILP2	100
Table 4.7 –	Distance between pharmacy shops and warehouse in km	106
Table 4.8 –	Limit distance imposed by each pharmacist in km	107
Table 4.9 –	Drugs demand from each pharmacy shop in number of packages	107
Table 4.10 –	Load factor for each vehicle of pharmacy shop in number of packages	107
Table 4.11 –	External costs for the cross-distribution activity	107
Table 4.12 –	Social constraints: willing to deliver package in the cross-distribution	108
Table 4.13 –	Results of drugs cross-distribution simulation	109

List of figures

Figure 2.1 –	UML process with Use Case approach	30
Figure 2.2 –	ELVITEN ICT Platform and services	31
Figure 2.3 –	Use Case Diagram of ICT functionalities	33
Figure 2.4 –	Activity diagram related to “Book ELVs” Use Case	35
Figure 2.5 –	KPIs Baseline values estimation methodology flow chart representation	40
Figure 2.6 –	UML diagram of use cases	42
Figure 2.7 –	UML diagram of classes	43
Figure 2.8 –	Authentication page	45
Figure 2.9 –	Database layout	45
Figure 2.10 –	Activated questionnaire	46
Figure 2.11 –	Screenshots of the Serious Game	47
Figure 3.1 –	Classification of rebalancing strategies	55
Figure 3.2 –	The incentive base relocation process	59
Figure 3.3 –	Algorithm 1 in the distributed optimization approach	68
Figure 3.4 –	Algorithm 2 in the distributed optimization approach	69
Figure 3.5 –	Electric car relocation process with company staff (Scenario 1)	72
Figure 3.6 –	Electric car relocation process with user involvement (Scenario 1)	73
Figure 3.7 –	Electric bike relocation process with company staff (Scenario 2)	73
Figure 3.8 –	Electric bike relocation process with user involvement (Scenario 2)	74
Figure 4.1 –	Algorithm of incentive system process	93
Figure 4.2 –	Goods relocation in city fashion retailers by company trucks	99
Figure 4.3 –	Goods relocation in city fashion retailers involving loyal customers	100
Figure 4.4 –	Algorithm of incentive scheme in drugs distribution	102
Figure 4.5 –	Cross-distribution with warehouse in urban areas	103
Figure 4.6 –	Drugs cross-distribution with warehouse in urban area	108
Figure A.1 –	Activity diagram related to “Select Reachable Destination” Use Case	121
Figure A.2 –	Activity diagram related to “Book Charging Points” Use Case	122
Figure A.2 –	Activity diagram related to “Book ELV parking slot” Use Case	123
Figure A.4 –	Activity diagram related to “Require Assistance” Use Case	123
Figure A.5 –	Activity diagram related to “ELVs and public transport combination” Use Case	124

1. Transport Externalities in Urban Areas

In modern economies transport of goods and people plays a key role. Traditional transport modalities are the main responsible of negative impacts, especially in urban areas.
In order to improve citizens' quality of life, there is the need to reduce such impacts, by adopting a new concept of mobility and shifting towards more sustainable transport modalities.

1.1. Urban externalities of freight and people transport

The transport of goods and people is a very important activity in the modern world. Transport sector produces positive and negative impacts, according to Korzhenevych et al. (2014). This sector is one of the main responsible of air pollution and Green House Gasses (GHG) emissions in the world with about 20-25% of the total emission and this percentage will grow in the next years (Olivier et al., 2016). De Langhe (2017) indicates the transport sector as one of the main responsible of several negative impacts in urban areas.

A large number of people live in the cities and use many vehicles, therefore these issues are stressed, according to van Essen et al. (2019), Maibach et al. (2007), and Verhoef (1994). At the same time, transport activities prove to be very important for the economic and social development. EC Staff Working Document (2016) shows that in the last 20 years, the transport volumes trends follow the Gross Domestic Product (GDP) evolution in EU countries.

In the coming years, the increasing demand of freight and people transport in urban areas will further grow their negative impacts or externalities. EU (2003) definition of an external cost is a cost arising "when the social or economic activities of one group of persons have an impact on another group and when that impact is not fully accounted, or compensated for, by the first group". This means that the external costs of transport are not borne by the transport user and therefore the user makes decisions without these costs being considered, with sub-optimal outcomes. Externalities should be internalized to be part of the decision making process through regulation or market based instruments (i.e. taxes, charges, etc.). European Commission stressed the need to charge logistic players for the external costs they generate (internalization of external costs) since 1999 with the Directive 1999/62/CE, and different internalization strategies can be adopted (Digiesi et al., 2016). At current, however, strategies to internalize external costs are often limited to extra-urban transports and in few cases they are adopted in urban areas (i.e. urban road pricing schemes). According to van Essen et al. (2019), the main externalities of transport are: accidents, air pollution, climate change, noise pollution, congestion, well-to-tank emissions, and habitat damage. In addition, further transport externalities are soil and water pollution, up and down stream emissions of vehicles and infrastructure, external costs in sensitive areas, separation costs in urban areas, land use and ecosystem damage for upstream processes, and cost of nuclear risks.

Externalities cause people and environmental damages such as loss of life, injuries, health effects, crop losses, biodiversity loss and global warming. The assessment of external costs is not based on market because there are not prices for them. Then different methodologies are proposed in literature to calculate external costs. The main approaches are based on the damage cost, the avoidance cost and the replacement cost.

The damage cost approach considers all damage suffered by people due to the existence of an externality. The market prices are often not available for the damage suffered, therefore the willingness to pay (WTP) to avoid the damage or the willingness to accept the damage is used.

The avoidance cost approach considers evaluation factors to set the cost to achieve a specific policy target. Using an avoidance cost function, the minimum cost required to reach the target is estimated. The assumption is that the policy target brings collective preference; therefore the minimum cost is a good indicator of the WTP.

The replacement cost approach considers the value of an externality based on the costs of replacing/repairing the negative impacts caused by the externality. It is often used to assess an external cost for which reliable damage or avoidance costs are not available.

In the urban area the transport externalities are more significant due to the high number of vehicles and people in a limited space (Friedrich and Bickel, 2001).

A large number of goods delivered in the city produce the presence of many trucks and vans with consequences on emissions and congestion. The last mile logistics, considered as delivery of goods within the city, causes several urban transport externalities.

Passenger transport with private transport means generates considerable issues: large number of vehicles produces mainly GHG emissions, congestion and noise pollution.

All these factors negatively affect the quality of life and health of urban citizens. In addition, increased public knowledge of environmental issues and problems generated by the transport sector is leading policy makers to develop long time strategy to reduce transport externalities.

European Commission stressed the need to charge logistic players for the external costs they generate (internalization of external costs) since 1999 with the Directive 1999/62/CE, and different internalization strategies can be adopted (Digiesi et al., 2016). However, strategies to internalize external costs are often limited to extra-urban transports and in few cases they are adopted in urban areas (i.e. urban road pricing schemes).

In the last years, European Union introduced limits and target strictness in the transport sector to improve the citizens’ life quality. Regulation n. 433/2009 taken by European Union concerns with an agreement signed with the car industry to achieve the average CO_2 limit of 95 g/km since 2020. Even using the best technology with combustion engine, the technical target is 103–104 g/km. So it is necessary to sell and use electric or hybrid vehicles that move towards zero emissions (at least on urban area). To achieve the EU average limit target, it is estimated that a percentage of about 10–12 % of electric and hybrid vehicles in the market is need.

In addition, the European Commission has set the objective of decarbonization by 2050 with an 80% reduction in CO_2 emissions compared to 1990 level through short and medium terms goals, respectively 2020 and 2030. The targets of EC 2050 long-term strategy (2018) are referred to set levels of energy saving, reduce CO_2 emissions and increase energy production from renewable sources. The European Union addresses must be transposed by the member states with planning and programming operational actions. These are able to identify specific actions to achieve the targets, which include reduction externalities in urban mobility.

1.1.1. Classification

The transport externalities in the urban area are related to the damage caused to citizens, directly and indirectly. The main urban transport externalities identified in the scientific literature are: air pollution, congestion, accidents, noise pollution and climate change. Externalities as well-to-tank emissions and habitat damage are important but very often they are not tangible in urban areas; urban transport causes such externalities in other areas of the planet. Further externalities, such as separation costs in urban areas, play a significant role depending on the urban context considered.

Air pollution

The emission of air pollutants causes human health, environment, and material damage. Several studies such as NEEDS (2008), Umweltbundesamt (2018), Rabl et al. (2014), OECD (2014), analysed this external cost, but in the last few years, no large international studies on these impacts have been published. Epidemiological researches demonstrated the dose response relationship between the exposure of air pollutants and the associated health risks.

The air pollution costs are calculated by a bottom-up approach. The two main input values are the emissions and the cost factors per tonne of pollutants. The emission factors are calculated by using average emission factors per vehicle type and country. The cost factors are calculated per pollutants, with Economic damage cost estimates, as performed in NEEDS approach (2008) or with Lifecycle Assessment, as performed by Goedkoop et al. (2013). The output values of the air pollution cost are expressed in vehicle per kilometre (vkm), person per kilometre (pkm) or tonne per kilometre (tkm).

Congestion

A congestion cost indicates the increase in travel time caused by an additional vehicle that reduces the speed of the other vehicles of the flow. In the urban area the congestion cost is based on the speed-flow relationship. Goodwin (2004) defines the road congestion as the impedance that vehicles impose on each other, as the traffic flow approaches the maximum capacity of the network. The two approaches to estimate road congestion costs are delay cost and the deadweight loss. The delay cost approach defines the value of travel time lost compared to a free flow condition. The deadweight loss approach determines the economically optimal solution. In this approach the congestion cost is related to the mobility demand exceeding the infrastructure capacity in a given time range.

The estimation of the urban congestion cost is based on aggregate congestion indexes by city that considers the level of congestion, the road network length by road type, the average delay per day and the overall delay per year. The congestion costs for freight vehicles in the urban area is calculated with a simplified approach based on estimation for cars, value of time by road vehicle category and data on vkm.

Accidents

Accidents involve two types of costs: material and immaterial costs. Material costs can be calculated through market prices while immaterial costs do not have a similar reference. A part of the accident costs are already internalised with insurance premium or by accounting for well-anticipated risks.

The external accident costs are the social costs of road accidents that are not covered by risk-oriented insurance premium, according to van Essen et al. (2019).

Accident costs can be classified in five main components: human costs, medical costs, administrative costs, production losses and material damages.

The method for calculating accident costs is based on a top-down approach that assigns total accidents to different types of vehicle. The main input values are the number of casualties per vehicle category and the costs per category. Statistic database are used for the number of casualties per vehicle category. The cost per casualty considers the components aforementioned.

Noise pollution

Traffic noise is a growing environmental problem due to the combined increasing trends in urbanisation and in traffic volumes. The increase in traffic volume results in higher noise levels. Increased urbanisation causes more people to be subjected to disutility due to noise.

Noise is defined as unwanted sounds of varying duration, intensity or other quality that causes physical or psychological harm to human, according to van Essen et al. (2011). Noise is considered a nuisance when it exceeds certain thresholds. Previous literature has employed thresholds of 50, 55 and 60 dB(A). It is emphasized that the choice of a threshold has a significant impact on marginal noise costs. A lower threshold is preferable to avoid underestimating noise costs, but several noise maps available (i.e. EEA Noise Maps) start from 55 dB(A).

Climate change

The effects of climate change are global, but the negative consequences that they produce even at the urban level are now indisputable. Climate change costs are defined as the costs associated with all of the effects of global warming, such as sea level rise, biodiversity loss, water management issues, more and more frequent weather extremes and crop failures, according to van Essen et al. (2019). Climate change costs are calculated with a bottom-up approach. The input values are: GHG emission factors per vehicle type, vehicle performance data (fuel consumption) and the climate change costs per tonne of CO_2 equivalent. The GHG emission factors per vehicle type are calculated considering the vehicle kilometres per vehicle type in each county and the vehicle emission factors for each GHG. The conversion factors allow to calculate the total CO_2 equivalent GHG emission. The climate change costs per tonne of CO_2 equivalent are monetised with two main methods: a damage cost approach or an avoidance cost approach.

Costs of well-to-tank emissions

The cost of well-to-tank emissions or costs of energy production, are externalities not completely present directly in the urban area, but are also caused by transport in the cities. The well-to-tank emissions are generated for the extraction of energy sources, the processing, the transport and transmission, the building of energy plants and other infrastructures. Energy production processes generate significant emissions in terms of total external costs. The cost of well-to-tank emissions is calculated with a bottom-up approach. The input values are the emissions factors for the emissions of energy related upstream emissions and the damage cost factors for monetizing the emissions. The emissions factors consider the emission of GHG and air pollutants generated during the energy production process. A database is used for the emission factors. The cost factors for monetizing the emissions is the sum of two costs: air pollution costs and the climate change for the activity of the energy production.

Habitat damage

The cost of habitat damage is not directly observable in the cities but is also caused by the emissions generated by the urban transport. The habitat degradation is also due to emission of air pollutants and other toxic substances, such as heavy metals. The habitat damage is calculated with a bottom-up approach based on the infrastructure network length or area, and average cost factors for habitat loss and habitat fragmentation.

Other external costs

The other external costs concern soil and water pollution, up and downstream emission of vehicles and infrastructure, external cost in sensitive areas, separation costs in urban areas, land use and ecosystem damage for upstream processes, and cost of nuclear risks.
In urban area, separation costs are related to large transport infrastructures, such as motorways and large rail fields.

1.1.2. Impacts

The externalities cause damage and issues, both tangible and intangible. Many externalities are very dangerous for human health and cause a lot of problems and for the future generation according to Di Ciaula and Bilancia (2015), especially in the cities where the people and transport means density, is higher. A description of the impacts in the urban area is presented for each externality.

Air pollution

The impacts caused by the emission of air pollutants generated by urban transport are: health effects produced by the inhalation of particles (PM_{10}, $PM_{2,5}$) and nitrogen oxides with a higher risk of respiratory and cardiovascular diseases; crop losses caused by ozone and other acidic air pollutants; material and building damage due to pollution of building surfaces with particles and dust, corrosion processes of building facades and materials caused by acidic substances; biodiversity loss through acidification of soil, reduction of rainfall and water, and the eutrophication of ecosystems.

Congestion

The main effects of congestion are the loss of time and the delay caused by traffic. These two effects are related to the value of time that is based on GDP pro capita. In the freight transport the value of time is based on tonne per hour, assuming the average load factor per type vehicle.

Accidents

The impacts caused by accidents are related to material and immaterial damage. The main damages are: loss of life, injuries, pain and suffering, loss of utility, production losses, medical treatment, costs of appliances and medicines, deployed police force, fire service and other emergency services, administration of justice, damages to vehicles, infrastructures, freight and personal property.

Noise pollution

Noise prolonged and frequent exposure causes health issues. The health issues with significant evidence available, according to World Health Organization (2011), World Health Organization (2017-2018), DEFRA (2014), are: ischaemic heart disease, stroke, dementia, hypertension, and annoyance.

Climate change

Climate change is a consequence of emission of GHG that leads to global warming with impacts on ecosystems, human health and societies. The rise of GHG has reached very high levels: NOAA data (2019) indicates that the rate of CO_2 in atmosphere has exceeded 400 parts per million – ppm, a value never reached by millions years. This process is related to the global temperature growth: data show a very similar trend over the years. Climate change is the main effect of this climb, as well as pollution, fast melting glaciers, rising sea levels, water management issues, desertification, biodiversity loss, frequent weather extremes and crop failures.

Costs of well-to-tank emissions

The energy production caused a broad range of negative environmental impacts: emission on air pollutants, GHG and toxic substances emissions, land use and environmental risks.

Habitat damage

The negative effects of transport on nature and landscape are: habitat loss, which are natural habitats of plants and animals no more available due to transport infrastructure; habitat fragmentation and separation effects for animals; habitat degradation due to emissions; visual intrusion in the landscape scenery; invasive plants and light emissions.

Other external costs

The impacts caused by pollution of soil and water are related to: heavy metals of abrasion of brakes, abrasion of tyres as well as the fuel combustion; organic toxic substances, according to Bieler et al. (2019); oil spills and oil risks, according to Navrud et al. (2017), Farrow and Larson (2012) and Bigano et al. (2009). The up and downstream emissions of vehicles and infrastructure are related to production, maintenance and disposal of them, based on life-cycle emissions of air pollutants and GHG, according to Umweltbundesamt (2018), van Essen et al. (2011). The impacts in sensitive areas such as mountains regions are related to a greater concentration of air pollutants due to gradients and altitude, to a greater concentration of air pollutants due to topographical and meteorological conditions, to a different impact related to the dose-response evidence due to the population density or other risk factors, and various factors for damage costs due to country specific monetization values.

Other negative externalities of transport are linked to time losses for pedestrians in the case of large transport infrastructures in urban areas, which generate physical separation effects; land use and ecosystem damage for upstream processes due to electricity generation or exploitation of mineral oil products; and nuclear risks for power plants.

1.2. Approaches to reduce peoples' mobility externalities

A recent study (Fiorello and Zani, 2015) shows that, in European countries, the most frequent trip is made by car: private car represents about 60% of total transport modes used. The extensive use of cars makes the existing transport systems not efficient, resulting in negative effects such as urban traffic congestion, parking shortages, air and noise pollution, GHG emissions. Almost all transport vehicles in the cities have an internal combustion engine (ICE) that cause polluting emissions.

Smart mobility proposes solutions, methods, approaches and innovations able to reduce externalities considering also social costs. The strategies to reduce the externalities in the urban area are related to new technologies and a new concept of transport, such as Mobility as a Service (MaaS). These approaches allow improving the sustainable performance of vehicles, and reducing the number of ICE and private vehicles that generate several externalities, towards efficient public transport service. Zero emission vehicles such as EVs and suitable EVs for urban area as Electric Light Vehicles (ELVs) are important to reduce externalities. The EVs allow to cut air pollution and GHG emissions in urban areas and also for public transport means can be used this technology.

In the urban mobility and transportation systems, disruptive technologies are proposed to increase safety such as Autonomous Vehicles (AVs) or Autonomous Vehicles on Demand (AVoDs). Tests on the roads of AVs are in progress: Google Waymo began as the Google Self-Driving Car Project (2009) and Tesla autopilot project (2013). A lot of companies as GM, Ford, Renault, Nissan, Volkswagen group, Volvo, BMW and others are investing and developing innovative technologies with sensors (i.e. LiDAR, camera, etc.) and software managed with Artificial Intelligence (AI) able to have full autonomous vehicles.

In addition, the development of ICT systems and the reduction of sensor costs allow obtaining considerable advantages in the urban mobility.

A new vision of mobility is developing: today MaaS is a new paradigm in the smart mobility. The new concept changes from item/good (vehicles) to an intangible service (travelling from one point to another with a desired service level). The service-mobility is mainly based on ICT and Mobile technology, integrated with new multimodal approach: people need to move from different point of the city and for several reasons (study, work, shopping, meetings and so on), and with different requirements (maximum waiting time, travel time, acceptable costs, type of vehicles, etc.); all these information are needed to provide them the best travel solution. The millennium generation is accelerating this change with its predisposition to ICT technologies.

In the smart mobility, Wensveen (2015) considers the movement of people and goods from one place to another no longer related to the transport means used but only to the service and its level (availability, time).

Furthermore, to foster this concept the public administration and transport authorities have to lead the challenge of reducing urban externalities, with sustainable environmental policies and rules in order to improve the urban mobility system. The action are based on: a well-organized public transport (i.e. high frequency in rush hours, dedicated lane road or rail in urban area), reconfiguration of urban roads (i.e. with roundabout, 30 km/h zones, cycle paths), incentivize users to alternative mobility (i.e. incentive systems, gamification), urban pricing systems (i.e. cordon pricing charging for every cross the limit of the area, distance based pricing is related to the number of km travelled by the vehicles, with different prices depending on the type of vehicles, daily time and roads used), integration of intelligent traffic light that privileges public vehicles in the crossroads to reduce time travel and increase transport efficiency system, use of ICT, IoT and big data with large number of sensors installed in the city (to collect data that can be used to improve and manage the mobility inside the city with analysis and processing data, simulations, forecasts and decision support based on real-time information).

In addition, the city transport efficiency can be improved by applying: dynamic route planning algorithm; smart parking; smart transport and services payment; intermodal transport ways; increase energy performance of transport sector; integration of the transport and grid infrastructure to use renewable energy, load balance and storage energy.

The objective of mobility management is to reduce congestion and travel time in urban area, increase safety level for passengers and pedestrians, and reduce pollution and save energy.

1.3. Approaches to reduce last mile logistics externalities

The last mile logistics or delivery generates urban transport externalities due to the large number of vans and trucks travelling in the city. The load factor is the predominant aspect to be optimized to increase the freight transport system efficiency. New transport means concept is developing: in the urban area flexible and suitable vehicles able to serve transport demand with high efficiency are required. Menga et al. (2013), Lebeau et al. (2013), Davis and Figliozzi (2013) consider the use of more ecological vehicles, such as EVs, Hybrid Electric Vehicles (HEVs) and Fuel Cell Electric Vehicles (FCEVs), the solution to reduce emissions in the urban delivery activities. In addition, in order to seek solutions that lessen impacts on existing vehicles, Rezgui et al. (2015), and Sachs et al. (2016) explored solutions with modular or light vehicles. Moreover, other factors can be considered to reduce externalities in the city. Several projects with AVs and AVoDs in the last mile delivery are developed such as YAPE (2017) and STARSHIP (2014).

Ranieri et al. (2018) suggest a literature review on innovative methods and strategies in last mile delivery, able to reduce externalities. They classify these innovations into five main categories: innovative vehicles, proximity station, collaborative and cooperative logistics, optimization of transport management and routing, and innovations in public policies and infrastructures.

1.4. Gaps and achievable targets

The city plays a central role in this new process of innovation; therefore, a new concept of city, the smart city, has been defined by Giffender et al. (2007), Caragliu et al. (2011), Lombardi et al. (2012), Kourtit et al. (2012), and Albino et al. (2015).

The Smart City concept promotes a new vision based on the radical reduction of negative impacts in cities through the use of technological, methodological and organizational innovations. Smart mobility is one of the pillars of this new idea.

In recent years, various innovations have been introduced such as EVs, ELVs, AVs and AVoDs, ICT tools and systems, the new MaaS concept with original vehicles usage schemes in urban mobility, different policies and rules, and efficient urban mobility management, useful for reducing externalities in urban areas. Similar concepts can be considered for goods delivery in urban areas, adding collaborative and cooperative urban logistics, and proximity stations.

The widespread in the use of EVs is limited due to users' low awareness about the performance and functionalities, a limited direct experience and the feeling of uncertainty as regards the possible need to re-charge the vehicle during the trip (autonomy anxiety). Therefore, innovative methods also based on ICT tools can be applied to increase the electro-mobility use in the cities, in order to reduce urban externalities.

In addition, the spread of new usage scheme in urban area such as EVs or ELVs sharing system is based on high service level. Thus, the vehicles relocation process is a fundamental activity to achieve this objective, but it is an expensive cost for the sharing companies. The same issue is present in the relocation of goods in urban area between different stores.

The crowd-sourcing paradigm, user centric approaches and incentive system can be used to reduce the relocation cost for companies and at the same time the external costs related to this activity. Furthermore, it is possible to apply an original incentive system with rewards in form of credits, to engage users in the greater use of the sharing service and customers in the purchase of company goods.

1.5. Chapter references

Albino, V., Berardi, U., Dangelico R. M. (2015). Smart cities: Definitions, dimensions, performance, and initiatives. Journal of Urban Technologies, vol. 22, n. 1, pp. 3-21.

Bigano, A., Cassinelli, G. L., Navrud, S. (2009). The External Cost of European Crude Oil Imports. Fondazione Eni E. Mattei (FEEM) Working Papers n. 13.

Bieler, C., Sutter, D., Lieb, C., Sommer, H., Amacher, M. (2019). External Effects of Transport 2015 in Switzerland ("Externe Effekte des Verjehrs 2015"). Update study on the calculations of environmental, accident and health costs of road, rail, air and water transport 2010-2015. INFRAS - ECOPLAN.

Caragliu, A.; Del Bo, C.; Nijkamp, P., (2011). Smart Cities in Europe, Journal of Urban Technology, Vol. 18, 2011, No. 2, pp. 65-82.

Davis, B.A., Figliozzi, M.A. (2013). A methodology to evaluate the competitiveness of electric delivery trucks. Transport Research Part E: Logistics and Transportation Review. Vol. 49, issue 1, pp. 8-23.

De Langhe K. (2017). The importance of external costs for assessing the potential of trams and trains for urban freight distribution. Research in Transportation Business & Management. Volume 24, pp. 114-122.

DEFRA (2014). Environmental noise: Valuing impacts on: sleep disturbance, annoyance, hypertension, productivity and quiet. London: Defra.

Di Ciaula, A., Bilancia, M. (2015). Relationships between mild PM10 and ozone urban air levels and spontaneous abortion: clues for primary prevention. International Journal of Environmental Health Research, Vol. 25, Iss. 6.

Digiesi, S., Mascolo, G., Mossa, G., Mummolo, G. (2016). Internalisation strategies of external costs of transport for a sustainable logistics. International Journal of Productivity and Quality Management, vol. 18 (2-3), pp. 238-257.

EC Staff Working Document (2016). The implementation of the 2011 White Paper on Transport "Roadmap to a Single European Transport Area – towards a competitive and resource-efficient transport system" five years after its publication: achievements and challenges. Brussels, 1 July.

EC Regulation n. 443/2009 of 23 April 2009 of the European Parliament and of the Council on setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles.

EC 2050 long-term strategy (2018). Communication from the Commission to the European Parliament, the European Council, The Council, The European Economic and Social Committee, the Committee of the Regions and the European Investment Bank. A Clean Planet for all, A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy. Brussels, 28 November.

European Commission (EU), 2003. External Costs: Research Results on Socio-environmental Damages due to Electricity and Transport. Brussels: European Commission, Directorate-General for Transport and Energy.

EU Directive 1999/62/EC of 17 June 1999 of the European Parliament and of the Council on the charging of heavy goods vehicles for the use of certain infrastructures.

Farrow, S., Larson, D. (2012) News and Social Cost: The Case of Oil Spills and Distant Viewers. Journal of Benefit-Cost Analysis, De Gruyter, 3(4), pp. 1-24.

Fiorello, D., Zani, L. (2015). EU Survey on issues related to transport and mobility. JRC Science and Policy Report.

Friedrich, R., Bickel, P. (2001). Environmental external costs of transport. Ed. R. Friedrich and P. Bickel, Springer-Verlag Berlin Heidelberg GmbH.

Giffender, R.; Fertner, C.; Kramar, H.; Kalasek, R.; Pichler-Milanovic, N.; Meijers, E. (2007) Smart cities: ranking of European medium-sized cities. Vienna, Austria: Centre of Regional Science (SRF), Vienna University of Technology. Final Report.

Goedkoop M. J., Heijungs, R., Huijbregts M. A. J., De Schryver, A., Struijs, J., Van Zelm, R. (2013). ReCiPE 2008: A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. First edition Report I: Characterization. Update may 2013, Bilthoven: RIVM.

Goodwin, P. (2004). The economic costs of road traffic congestion. London: University Collage London (UCL). The Rail Freight Group.

Google Self-Driving Car Project (2009). url: https://waymo.com.

Korzhenevych A., Dehnen N., Brocker J., Holtkamp M., Meier H., Gibson G., Varma A., Cox V., 2014. Update of the Handbook on External Costs of Transport, Final Report for the European Commission: DG MOVE. MOVE. DIW econ, CAU, Ricardo-AEA.

Kourtit, K., Nijkamp, P. & Arribas, D. (2012) Smart cities in perspective – a comparative European study by means of self-organizing maps. Innovation: The European Journal of Social Sciences, 25, No. 2, pp. 229-46.

Lebeau, P., Macharis, C., Van Mierlo, J., Maes, G. (2013). Implementing electric vehicles in urban distribution: a discrete event simulation. Proceedings of the Electric Vehicle Symposium and Exhibition (EVS27), 17-20 November 2013, Barcellona, Spain.

Lombardi, P., Giordano, S., Farouh, H., Yousef, W. (2012). Modelling the smart city performance, Innovation: The European Journal of Social Science Research, Vol. 25, No. 2, pp. 137-149.

Maibach, M., Schreyer, C., Sutter, D., van Essen, H.P., Boon, B.H., Smokers, R., Schroten, A., Doll, C., Pawlowska, B., Bak, M. (2007). Handbook on estimation of the external cost in the transport sector. Internalization Measures and Policies for All external Cost of Transport (IMPACT)". CE Delft.

Menga, P., Buccianti, R., Bedogni, M., Moroni, S. (2013). Promotion of freight mobility in Milan: Environmental, energy and economical aspects. Proceedings of the Electric Vehicle Symposium and Exhibition (EVS27), 17-20 November, Barcellona, Spain.

Navrud, S., Lindhjem, H., Magnussen, K. (2017). Valuing Marine Ecosystem Services Loss from Oil Spills for Use in Cost-Benefit Analysis of Preventive Measures. Chapter 5. In L. E. Svensson & A. Markandya (Eds.). Handbook on the economics and management of sustainable oceans, pp. 124-137. Cheltenham: Edward Elgar Publishing.

NEEDS (2008). Deliverable n. 1.1 RS 3a Report on the procedure and data to generate averaged/aggregated data. Brussels: European Commission.

NOAA data (2019). National Centers for Environmental Information NOAA web site: https://www.ncdc.noaa.gov.

OECD (2014). The costs of air pollution: Health impact of road transport. Paris: OECD.

Olivier, J.G.J., Janssens-Maenhout, G., Muntean, M., Peters, J.A.H.W. (2016). Trends in global CO_2 emissions: 2016 Report. PBL Netherlands Environmental Assessment Agency, EC Joint Research Centre.

Rabl, A., Spadaro, J., Holland, M. (2014). How Muchi is Clean Air Worth? Calculating the Benefits of Pollution Control. Cambridge: Cambridge University Press.

Ranieri, L., Digiesi, S., Silvestri, B., Roccotelli, M. (2018). A review of Last Mile Logistics Innovations in an Externalities Cost Reduction Vision. Sustainability 10 (3) : 782, March.

Rezgui, D., Aggoune-Mtalaa, W., Bouziri, H. (2015). Towards the electrification of urban freight delivery using modular vehicles. Proceedings of the IEEE International Conference on Service Operations And Logistics (SOLI), November 15-17, Hammamet, Tunisia.

Sachs, C., Burandt, S., Mandelj, S., Mutter, R. (2016). Assessing the market of light electric vehicles as a potential application for electric in-wheel drives. Proceedings of the International Electric Drives Production Conference (EDPC), November 30- December 1, Nuremberg, Germany.

STARSHIP project (2014). Web site: https://www.starship.xyz.

Tesla autopilot project (2013). url: https://www.tesla.com/autopilot.

Umweltbundesamt (2018). Methodenkonvention 3.0 zur Schatzung von Umweltkosten. Berlin. Umweltbundesamt Deutschland (UBA) – German Environmental Agency.

van Essen, H., Schroten, A., Otten, M., Sutter, D., Schreyer, C., Zandonella, R., Maibach, M. , Doll, C. (2011) External Costs of Transport in Europe. Report, Delft, November.

van Essen, H.P., van Wijngaarden, L., Schroten A., Sutter, D., Bieler, C., Maffii, S., Brambilla M., Fiorello, D., Fermi, F., Parolin, R., El Beyrouty, K. (2019). Handbook on the external costs of transport. Version 2019. CE Delft. European Commission, Directorate-General for Mobility and Transport.

Verhoef, E. (1994). External Effect and Social Costs of Road Transport. Transportation Research A, 28A (4), pp. 273-287.

YAPE project (2017). Spin-off of Polytechnic of Milan, Italy. Web site: https://e-novia.it/startup/yape/.

Wensveen, J. G. (2015). Air transportation: A management perspective. Ashgate Publishing, Ltd.

World Health Organization (2011). Burden of disease from environmental noise. Quantification of healthy life years lost in Europe. World Health Organization, Regional office for Europe – JRC European Commission.

World Health Organization (2017-2018). World Health Organization in Systematic Reviews 2017-2018. BioMed Central.

2. Innovative ICT tools to promote electro-mobility

The growth of the electro-mobility sector is fundamental to achieve the target of reducing GHG emissions from vehicles and other externalities.

Innovative ICT systems are able to support the use of EVs and ELVs in urban areas. In this chapter, a user-centric approach for the development of ICT tools to increase electro-mobility in urban areas is formalized. An innovative ICT tool developed on this architecture under the framework of the EU Project ELVITEN is detailed.

2.1. ICTs in sustainable urban people mobility

The ICT systems and tools are very powerful means to support the use of sustainable vehicles in urban mobility. They provide several innovations in mobility sector. Sciuto (2012) identifies the usefulness of ICTs for the spread of smart mobility in a smart city in: i) capillary tracking of displacements with localization technologies (GPS and mobile network); ii) information exchanging from and to the user with satellite or other technologies; iii) developing of mobile application with user-friendly interface technologies; iv) real time data retrieving (sensors, internet of things, big data analytics). Today most of these technologies are available in one only device, the smartphone, which became an essential item in different fields. Smart mobility and smart cities are deeply related through the use of this device and of APPs that can be developed for it. The potential of smartphone to open communication channel for smart mobility is analysed by Petrovic et al. (2013). Mobility as well as other sectors are undergoing a period of major changes due to introduction of new ICT technologies, sensors and big data generated.

In the recent years, the urban mobility innovations are successful thanks to the integration and interconnection of available technologies. The AVs and AVoDs require numerous sensors and advanced ICT systems. Services for sustainable urban mobility developed on ICT platforms or systems are many, such as the Global Positioning System (GPS) commonly used in many vehicles, the smart payment system that allows to book and pay electronically for the use of public transport, of shared vehicles, of parking lots, of charging points, and for access in limited traffic areas (congestion charge or eco-tax). The smart payment permits purchases in real time and at any time and does not require a physical store, thus reducing costs; Soe and Mikheeva (2017), and Kuganathan and Wikramanayake (2014) analyse the opportunities and the issues related to the applications of this new service.

Another application of ICT systems is the real-time optimization algorithm for intelligent traffic light, parking, and recharging vehicles time management based on Decision Support Systems (DSSs). DSSs adoption in the electro-mobility sector allows achieving efficient results in a sustainable vision, especially in the case of people mobility.

2.2. ICT systems for electro-mobility

Different platform and ICT tools have been developed to provide service able to facilitate the spread of electro-mobility. In this Section an overview on ICT services able to improve acceptance and user experience is provided. ICT technologies facilitate the use in a sustainable smart mobility: nowadays the mobile apps can monitor the routing and the transport mode used in real time; Petri et al. (2016) analyse virtuous behaviour – changing of the transport mode from ICE private car to public transport or sustainable vehicles such as bikes, EVs, sharing vehicles, etc. – in presence of rewards/incentive; the modal shift can be encouraged thanks to the real usage of sustainable transport means.

Sierpinski and Staniek (2018) propose the concept of an innovative tool for supporting electro-mobility development consisting of integrated modules related to travel planning, charging point location and simulation. Werther and Hoch (2012) present a formal ICT based modelling approach, which is developed within the EU project ASCENS and an ICT based value-added-service, namely the EV Daily Travel Planning Service, which has been designed for user-centric resource coordination in the EV domain. Bianchessi et al. (2014) present a platform for vehicle sharing developed in the Green Move project, which allows services to be dynamically loaded and unloaded on vehicles, and describe prototype applications to illustrate its benefits. EU project NEMO (2016) implements a system of tools, models and services, which provide seamless interoperability of electro-mobility, creating an open, distributed, and widely accepted ecosystem for electro-mobility. The objective is to provide accessibility to charging infrastructure, ICT services, and wider B2B interconnectivity.

In the analysis of scientific literature carried out, few contributions have been found on a user centric approach in the electro-mobility ICT systems and on ICT tools for sharing systems.

2.3. User-centric ICT tools for electro-mobility

The design of appropriate ICT tools able to engage users in the use of EVs is essential to lead a cultural revolution in the field of sustainable mobility. A user-centric approach for the development of ICT tools to improve electro-mobility user's acceptance has been developed and detailed in this Section.

In according to this, the Unified Modeling Language (UML) is the selected technique. UML enables system developers to specify, visualize, and document models in a manner that supports scalability, security, and robust execution (Pender, 2003). According to Pender (2003), in the UML, the Use Case Approach is a written description of how users will perform tasks on system. This approach is used to collect requirements in order to develop quality ICT system. The Use Case Approach identifies the functionalities need to include and exclude, how to connect the ICT system to develop with others, users, dependencies, products and/or results of the ICT system, the motivations of the use of ICT system functionalities by users.

The Use Case Diagram provides the means to model the system in precisely manner. The use case diagram can represent the decomposition of a single use case, yielding a hierarchical model. The Use Case Diagram consists of six elements: *actors*, *use case*, *association*, *include relationship*, *extend relationship*, and *generalization* (Pender, 2003). The "actor" is the user (people who use the ICT system or other systems, devices, and so on, that trade information). Normally, people are represented using stick figures and other types of actors with a rectangle stereotyped named for the type of actor. The "actors" are modelled as communicating with the use cases. The "use case" identifies a key behavioural characteristic of an ICT system (or sub-system): a goal that the ICT system must achieve and /or result that it must produce. The "association" is the interaction between an actor and a use case and is represented by a line. It describes the event of the "actor" that communicates with the "use case"; different "actors" who communicate with the same "use case" means that they interact differently. "Relationships" are of two types: include and extend. They define discrete behaviours: the ICT system can use the same behaviour in different circumstances (include), and as a part of many wider and more complete behaviours (extend). "Generalization" identifies an inherited relationship between actors or use cases.

The use case diagram is based on the following steps: the first activity is the definition of the system context: i) identify the actors and their responsibilities, ii) identify the use cases, the features of the system (goals and/or results to produce). In the second step, the actors and use cases for refinements (split or merge) are evaluated. In the next steps, use cases to find include and extend type relationships are assessed. Finally, the actors and use cases for generalization opportunities (shared characteristic) are evaluated.

The Activity diagram is the UML version of the flowchart. It can be applied to any process The Activity diagram is applied in a common way to explain: a workflow (in the case of a series of use cases), a single Use case, and a method. The representation of the Activity diagram is carried out by means of rounded rectangle (ActionState), arrows (transition from one activity to another), dot (start point), bull's eye (end point), diamond (decision), fork bar (a transition that triggers multiple transitions), and synchronization bar (multiple transitions that end and a new transition takes over). Often text can be too ambiguous to define a complex process. The Activity diagram offers a visual alternative that also supports common programming constructs. As such, it bridges the gap between user requirements and programming requirements.

At the end the ICT requirements are identified based on use cases and Activity diagram: ICT requirements that belong to the use case diagram are selected and developed in ICT service.

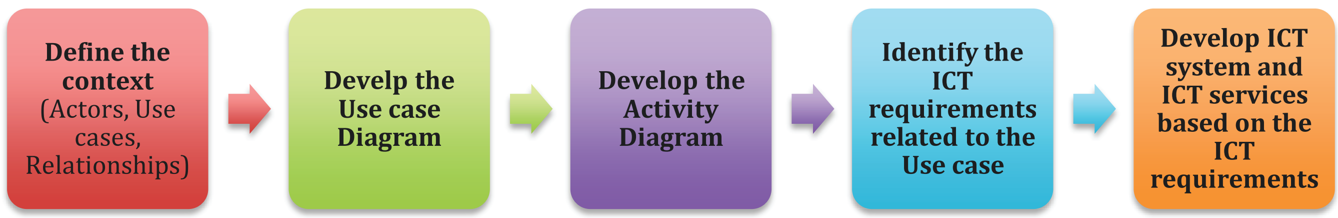

Figure 2.1: *UML process with Use case approach.*

The approach has been formalized and applied to the development of the ICT systems of the European H2020, project ELVITEN (2017). The project aims to demonstrate the usefulness of light electrified vehicles for urban transportation. The goal is to develop

replicable usage schemes of ELVs for owners, sharers and light goods deliverers based on the deployment of ELVs innovative parking and charging services, ELVs sharing and rental services, support ICT tools to facilitate the usage of ELVs and appropriate policies and incentives. ELVITEN project is based on long term demonstrations of the usage schemes and ICT tools in six European pilot cities. The ELVITEN ICT system is developed to provide ICT tools and services in order to sustain a good and motivating experience for ELVs users in the demonstration and beyond. The strategy project is to create a big data bank of real driving, usage data, users experiences and opinions in order to create guidelines towards ELV manufacturers and planning authorities. The ICT tools and services are based on user-centric approach and developed with an ICT platform that receives data from users (via smartphone device) and from ELVs (via black box device). The devices collect data and send it via internet connection in order to allow online monitoring of several features (positioning of users and ELVs, association of user to the ELV in the use, speed, speed, travel times, and more).
In figure 2.2, the ELVITEN ICT platform and services is shown.

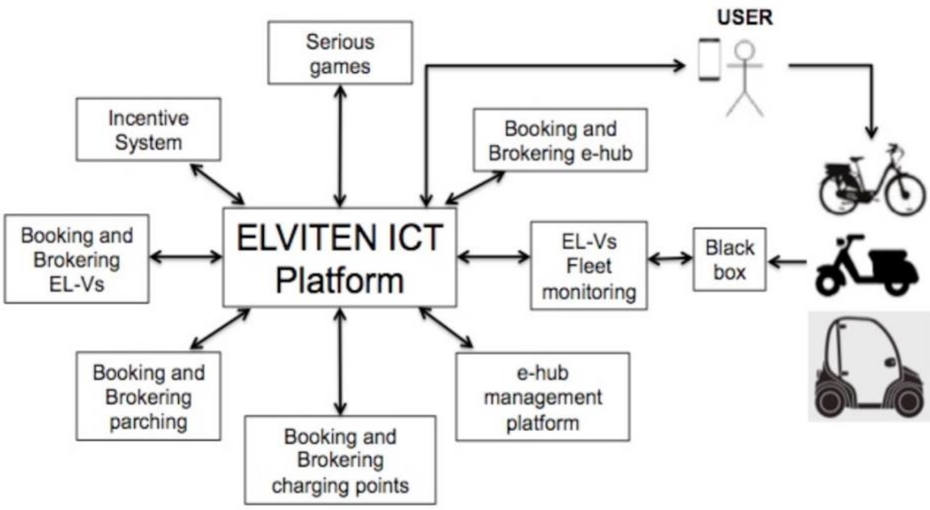

Figure 2.2: *ELVITEN ICT Platform and services.*

Each tool of the ELVITEN ICT System has been developed in accordance with a user-centric approach. In the following, each step aforementioned is detailed.

2.3.1. Use case of the ICT tools

The approach proposed (Fanti et al., 2018) is based on usage schemes in urban mobility sector with EVs and ELVs, in order to identify the main "actors" involved. Use cases identification is strictly related to the city context and the ELVs usages foreseen in that city. More specifically, several aspects are examined to determine the ELVs use cases, such as a) functionalities to be included and excluded; b) relations between the involved systems; c) identification of the users of each system; d) identification of the dependencies between the involved systems; e) expected

outputs from each system. In order to properly design the required ICT system, the software architecture must feature the following elements:

- a cloud platform for the ICT services and apps;
- a cloud database where to store the EVs' or ELVs' and trips' information;
- black boxes (one on each EV or ELV);
- interaction with the users' smart devices

Based on the described features, the CIT and software requirements are defined to implement ELVs usages schemes. Six use cases are described, the main actors:

- the final user (i.e., the EV or ELV driver);
- the booking service to manage EVs and ELVs, charging points and parking spaces to enable booking of any combination of resources available (e.g. e-car, e-bikes and parking spots in a e-hub or available charging point near to current location);
- the brokering service that manages the availability of resources per time frame. The brokering service can also provide forecasting of energy requirements of charging-points if needed;
- the ELV sharing service, namely the service for the management of the ELVs fleet;
- the repository platform, where all trips' data (e.g. duration, length, average speed) are stored;
- the incentive platform, which monitors and keeps track of all the virtuous behaviours of ELVs users and assigns rewards to them accordingly.

In Figure 2.3 the use case diagram of ICT functionalities is shown.

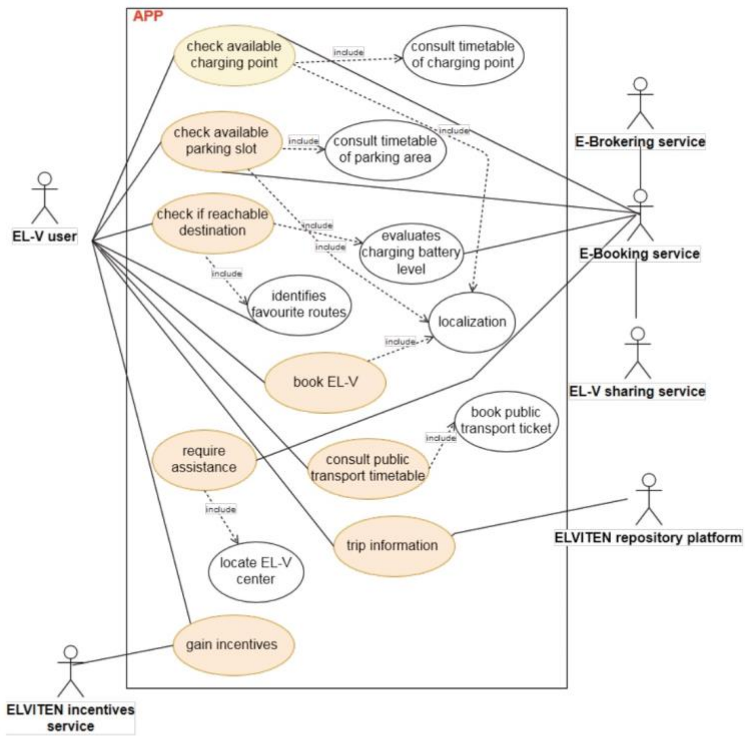

Figure 2.3: *Use Case Diagram of ICT tool functionalities.*

The proposed ICT tools and platform useful to integrate all electro-mobility services in order to improve the user acceptance can be identified through the use cases method. They focus on the following actions and needs of EVs or ELVs users:

1. select the destination which EVs or ELVs can reach;
2. book EV or ELV charging points;
3. book EVs or ELVs parking slots;
4. require assistance;
5. book EVs or ELVs;

combine EVs or ELVs usage with the public transport system.

2.3.2. Software requirements

The description of the selected use cases and the main flow of actions performed by the different actors involved in the processes managed by the ICT system are formalized in activity diagrams. For each use case the corresponding activity diagram is defined, and the corresponding ICT requirements are identified. In this way, the behaviours that depend from the results of other processes, together with the associated interactions, are described as follows:

• Select Reachable Destination;

• Book charging point;

• Book ELV parking slot;

• Require Assistance;

• Book ELV;

• ELV and public transport combination.

The Activity diagram is developed based on the main flow of actions present in a use case. Table 2.1 and figure 2.4 show respectively, the main flow of actions and the Activity diagram related to the "book ELVs" use case. The annex contains the other Activity diagrams relating to the use cases mentioned.

Use Case	*Main flow of actions*
Book EL-V	1. The user requests the APP to show all the closest EL-Vs available. 2. The APP requests the sharing service the location of all the closest EL-Vs available and the battery charge status. 3. The APP shows all the closest EL-Vs available on a map and the timetable for EL-V sharing service., 4. The user chooses an EL-V and requests the APP to book it. 5. The APP requests the e-booking system to reserve the selected EL-V for a limited time. 6. The user reaches the EL-V and unlocks it. 7. The user gains rewards according to his use of the EL-V booking service through the Incentive and facilitation service 8. Incentive and facilitation service sends data on the incentives to the APP. 9. The APP shows the possible incentives to the citizen. 10. The APP sends interaction information to the platform.

Table 2.1: *Main flow of actions of "Book ELVs" Case.*

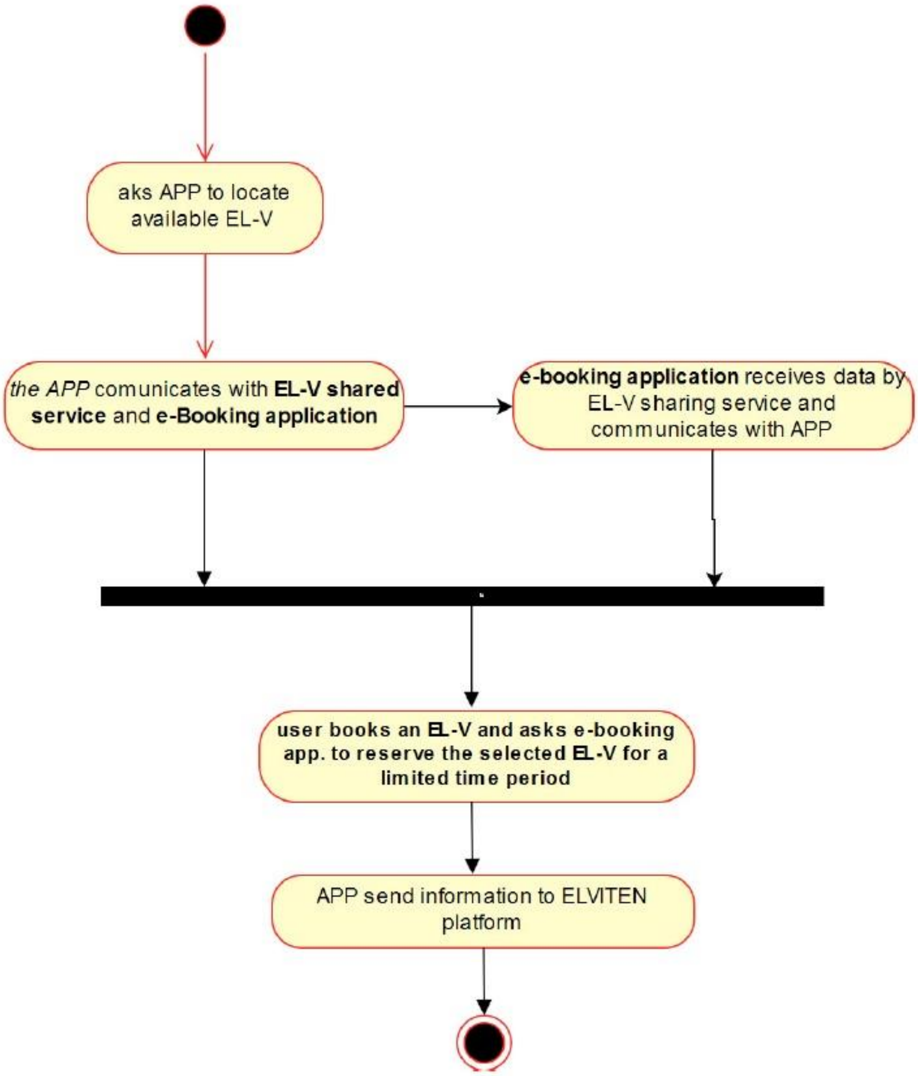

Figure 2.4: *Activity diagram related to "Book ELVs" Use Case.*

2.3.3. Developing system for ELVs

The proposed approach allows to identify the ICT requirements for each ICT tool (or ICT asset) of the system. In the EU project ELVITEN a case study is included involving 6 demonstration sites located in EU cities (Bari, Berlin, Genoa, Malaga, Rome and Trikala) each employing different ELVs and usage scheme (owner, sharing, rental). Therefore, the required ICT assets and consistently ICT requirements are different in each city. In Table 2.1, ICT tools (services in tab. 2.2) and their requirements identified for the 6 cities are listed.

ICT applications/service	ICT requirements	Integration in ELVITEN	To be deployed in city
Booking and brokering EL-Vs	• Access to an inventory of resources (from EL-Vs black box, parking spaces, charging points)	API	Bari, Rome, Malaga, Trikala
Booking and brokering parking spaces	• Localization in real time of EL-Vs, charging points		Bari, Rome, Malaga, Trikala, Berlin
Booking and brokering charging points	• The synchronization service with external service providers (e.g. charging point providers) • The application will be connected with local sharing and charging service providers' systems		
Booking and brokering e-hubs	• Access to an inventory of resources (from EL-Vs black box and e-hubs) • Localization in real time of EL-Vs, e-hubs	Open REST API	Bari, Genoa
e-hub management platform	• Back end platform to manage charging infrastructure • **IoT development** to govern different site's infrastructure		Bari ,Genoa, Rome.
Fleet monitoring tool data and Digital Coach app	• Access to an inventory of resources (from EL-Vs black box). • Localization in real time of EL-Vs	RESTful Webservice: Interface for an easy access of data, analysis and services gRPC: designed for distributed computer systems. Web sockets: for data streaming. Allows an external application to receive data continuously with only one initial request.	Bari, Rome, Malaga, Trikala, Genoa, Berlin
Serious Game	• Localization in real time of EL-Vs.	API	Bari, Rome, Malaga, Trikala, Genoa, Berlin
Incentive Management Smart App for EL-Vs users	• ELVITEN authentication and authorization system. • EPPI platform. • ELVITEN data warehouse	API	Bari, Rome, Malaga, Trikala, Genoa, Berlin

Table 2.2: *ICT Requirement in ELVITEN project.*

The most needed ICT requirement for the ELV management services and applications is the capability to get the GPS coordinates of the ELVs in real time. The definition of use cases for the study of the ICT requirements in the six demonstration sites of the ELVITEN project has proved to be a good test sample, which ultimately led to significant results.

2.4. Innovative approach to the baseline analysis of KPIs in electro-mobility sector

The use of Key Performance Indicators (KPIs) allows monitoring significant aspects and activities of companies and projects. Shen (2013) investigate on the implementation of successful KPIs for organizations and Piela (2017) analyses the KPIs and dashboard visualization in a logistic company. In the new sector as electro-mobility, is essential measuring the KPIs at an early stage to improve the performances during the time. This is an issue at the beginning of projects or activities, for the absence of available KPIs historical data. Moreover, the introducing of new KPIs (as in the electro-mobility sector) not allows a comparison with the performance measured in other similar organizations or projects. Therefore, the baseline analysis to calculate baseline values of KPIs, in absence of suitable input data with new KPIs is an open problem. The few existing approaches in the related literature can be divided in two categories: the first category analyses different methods to estimate valid KPIs baseline based on real training data; the second category aims at estimating a KPIs baseline by simulations data according to the expected performance. In the first category, Barr (2018) believes that sensitive and useful baseline values can be obtained through consistent performance measurements: a minimum number of performance measures needed is five. This approach depends from the maturity of the KPIs: in some cases, it is possible to use historical raw input data, in other cases it is needed to collect some input data in advance. Studies classified in the second category point out that it is possible to estimate the baseline values using different techniques. West and Prahlad (2015), and in Proforecast (2018), the KPIs values are calculated, monitoring over a specific time period and establishing a low baseline value (10^{th} percentile of all the values for a given time period) and a high baseline value (90^{th} percentile of all the values for a given time period), taking a weighted average of these values. Moreover, Solow (2017) proposes an improved time series prediction approach. Yu et al. (2008) propose support vector machines (SVM), to acquire the baselines of KPIs for real-time performance monitoring. It is used a wavelet multi-resolution before modelling by SVM, and the result is the sum of prediction values of each branch. However, to create the baseline values prediction of KPIs, historical values as training data are necessary.

The ELVITEN project uses KPIs to analyse the collected data in the demonstration pilot test, as regards the driving patterns of ELVs per city and per user category, the recharging behaviour of the users, the users' experiences with ELVs and the users' and stakeholders' acceptance of ELVs and of the deployed services, ICT tools and incentives per city and per user cluster.

In this Section a novel methodology to estimate the KPIs baseline values with no available historical input data is presented. The research is based on the estimation of a limited number of KPIs that are relevant for all the involved actors, so called agreed KPIs, to propose efficient performance indicators, using different sources such as data retrieved by questionnaires, reports and input data from similar contexts. The innovative approach allows elaborating and comparing the raw input data to estimate the baseline values of KPIs (Silvestri et al., 2019a). In addition, a case study is proposed in the electro-mobility sector in the framework of EU project ELVITEN, which focuses on the strategies to improve the light electro-mobility experience of users by means of six demonstration pilot tests in Europe. In particular, in this paper we apply the proposed methodology to estimate KPIs related to the use of ELVs.

The proposed methodology to estimate the baseline values of a KPI set is presented. The proposed methodology is based on the following steps as it is shown in Fig. 2.5:

1. define the study areas and the study questions;
2. define and identify the initial set of KPIs;
3. define the criteria and select the agreed KPIs;
4. evaluate input data availability / retrieve input data from suitable sources;
5. elaborate input data;
6. estimate the baseline values.

The first step of the methodology consists in defining the areas of study in order to group specific topics in the considered framework. Moreover, for each study area, study questions can be defined to identify an initial list of related KPIs (Step 2).

In most cases, a large number of KPIs is defined even though some of them are not relevant according to some specific need or objective, especially in situation where multiple and variegate actors and contexts are considered.

Therefore, Step 3 aims at selecting a subset of agreed KPIs, based on the strategic goals and needs as proposed by Guide to KPI (2007), and by Antolic (2008). In particular, we define the agreed KPIs as the relevant KPIs for all the involved actors. The KPIs selection process is usually in charge of company or project managers to ensure the use of KPIs strictly related to the strategic goals.

The baseline analysis starts from Step 4 that aims at evaluating input data availability for the baseline values estimation or retrieving them from different sources, in case of data unavailability. Approaches to retrieve necessary data are based on surveys, questionnaires, interviews, or scorecards. In absence of suitable input data, it is also possible to search for them in similar contexts or situations.

The output information of these approaches can be used and elaborated in Step 5 to prepare the KPIs baseline estimation. The last step of the adopted methodology is the estimation of baseline values for the agreed KPIs (Step 6).

Hence, a computation model is necessary to estimate the KPIs baseline values. The baseline values can be considered as benchmarks or starting values for the KPIs and can be used to analyse changes over time, by measuring and/or comparing values during and after the project activities.

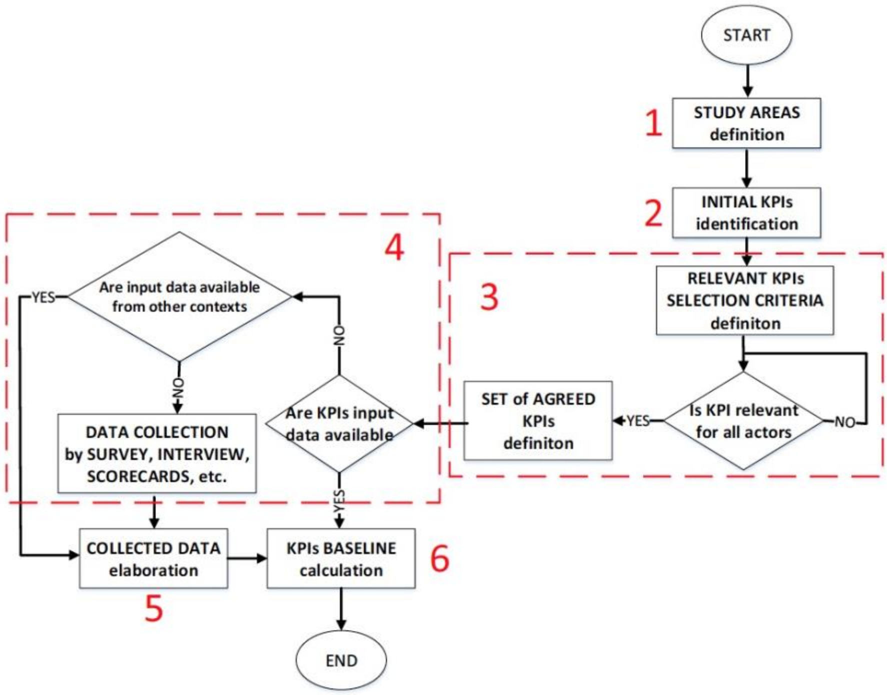

Figure 2.5: *KPIs Baseline values estimation methodology flow chart representation.*

2.5. Original serious game approach for the electro-mobility

Gamification or serious games is a new technique to incentivize sustainable behaviours, and it can be used in transport sector. Lorenzini et al. (2014) show how it is possible to modify the personal mobility behaviour using gaming strategies. These are new approaches to engage users with games designed for a primary purpose other than pure entertainment. Kazhamiakin et al. (2015) use gamification to incentivize sustainable urban mobility increasing the awareness of the citizens and promoting their behavioural change. Damm et al. (2014) proposed gamification to rethink the user's mobility behaviour in terms of economy, ecology and safety with multimodal mobility planning based on pedalec using data. Serious games are the synthesis of educational contents, game technics, storytelling and fun. Dange et al. (2017) described a serious gaming approach for motivating people to drive in a safe and environmental friendly way, while Shreenath et al. (2015) to improve transport maintenance and operations. Wang and Hu (2017) indicate the ICT tools and smartphones as effective way to develop serious games.

In this Section an original serious game approach to promote electro-mobility developed under EU project ELVITEN is presented. An incentive mechanism is used to increase users' awareness of the environmental benefits of electro-mobility, to enhance voluntary behavioural changes and sensitize towards historical-artistic places in the cities. The curiosity of users is stimulated with information about monuments and historical places that very often remains unknown to the citizens or visiting tourists.

The proposed serious game approach aims at engaging users, by providing information and curiosities about the city and the use of green transport means, and at the same time encouraging to travel with EVs or ELVs in a more familiar way. In addition, the approach raises user awareness regarding the environmental issues, such as CO_2 emissions and air pollution, pushing the citizens to improve the liveability of the city by using alternative transportation means, such as public vehicles or light electric vehicles.

In particular, a general and highly scalable methodology to define the ICT application requirement and architecture is presented, that can be also applied in different contexts. A preliminary version of the application has been developed and tested in the city of Bari.

2.5.1. User requirements, UML diagrams of use case and UML diagram of classes

As common approach used in literature by several authors such as Lucassen et al. (2015), Deeptimahanti and Ratna (2011), Lucassen et al. (2016), Marian (2013), Pohl (2010), Pender (2003), it is defined the functional requirements on the basis of the "use cases" and their representation. This approach can be performed through the UML, according to Rumbaugh et al. (2017). In particular, use cases are adopted to provide a high-level or conceptual scenario for deriving the requirements. This approach allows to identify the process flow, the interactions between a system and one or more actors, and "main" and "alternative flows" of steps/actions, providing a formal specification of the expected requirements. The UML Use Case diagram typically represents actors and use cases, and their interrelations.

A serious game approach for the electro-mobility sector based on UML use case diagram has been developed (Silvestri et al., 2019b).

The diagram in Fig. 2.6 shows how people expect to use the app, by describing the main actors, the functionalities they require from the system and the relations among them. In particular, there are two actors: a) the user who plays with the application, (he/she can define the means of transport, play with the various proposals of the app, and choose among the possible prizes); b) the system which manages and updates the games and the prizes to be offered to the user, and administers the users and their data such as associated transport vehicles and virtual wallet.

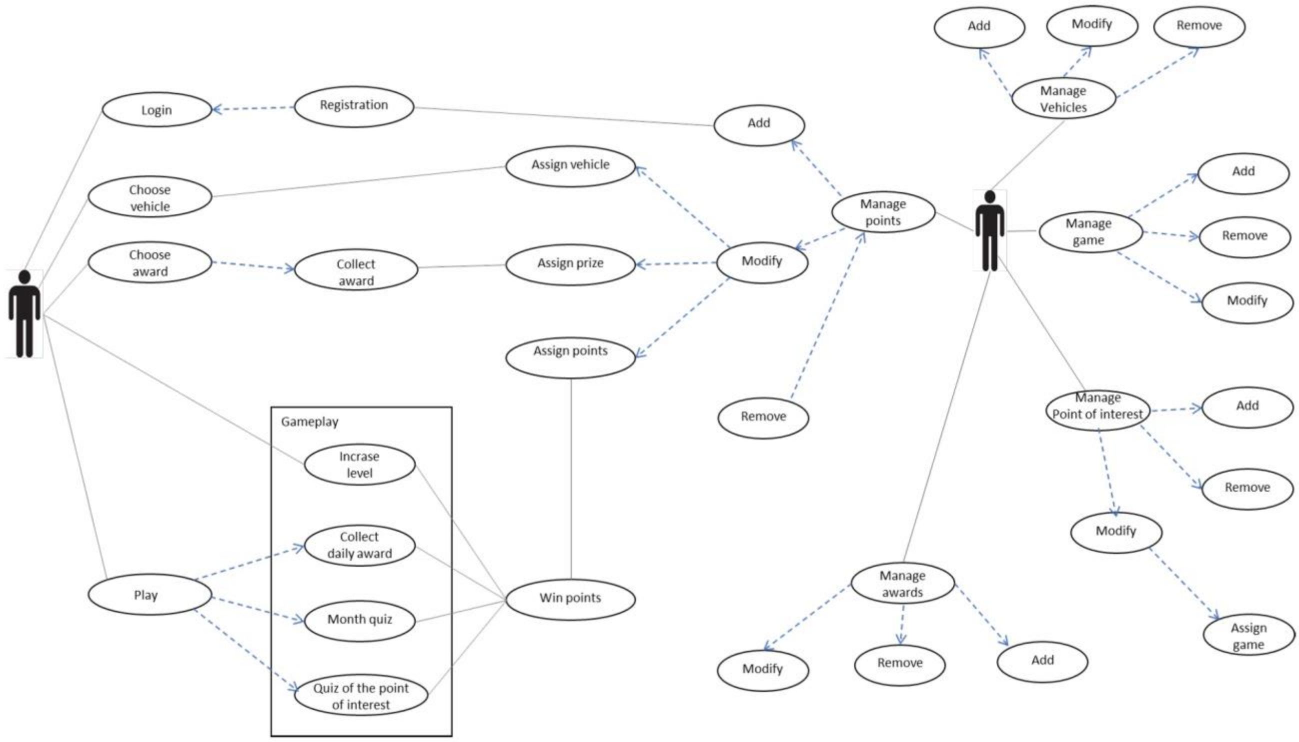

Figure 2.6: *UML diagram of use cases.*

The UML class diagram represents the main classes of the designed application. More in detail, five classes define the SG architecture:

- the data of ELV user and the related trip;
- the characteristics of the ELVs;
- the awards that can be obtained by using the app;
- the points of interest that are the main historical and cultural locations in the city;
- the questionnaires to be answered related to the previous points of interest.

To identify the use cases, the following aspects are analysed:

- functionalities to be included;
- relations between the involved actors;

- identification of the users of each system;
- identification of the dependencies between the involved actors;

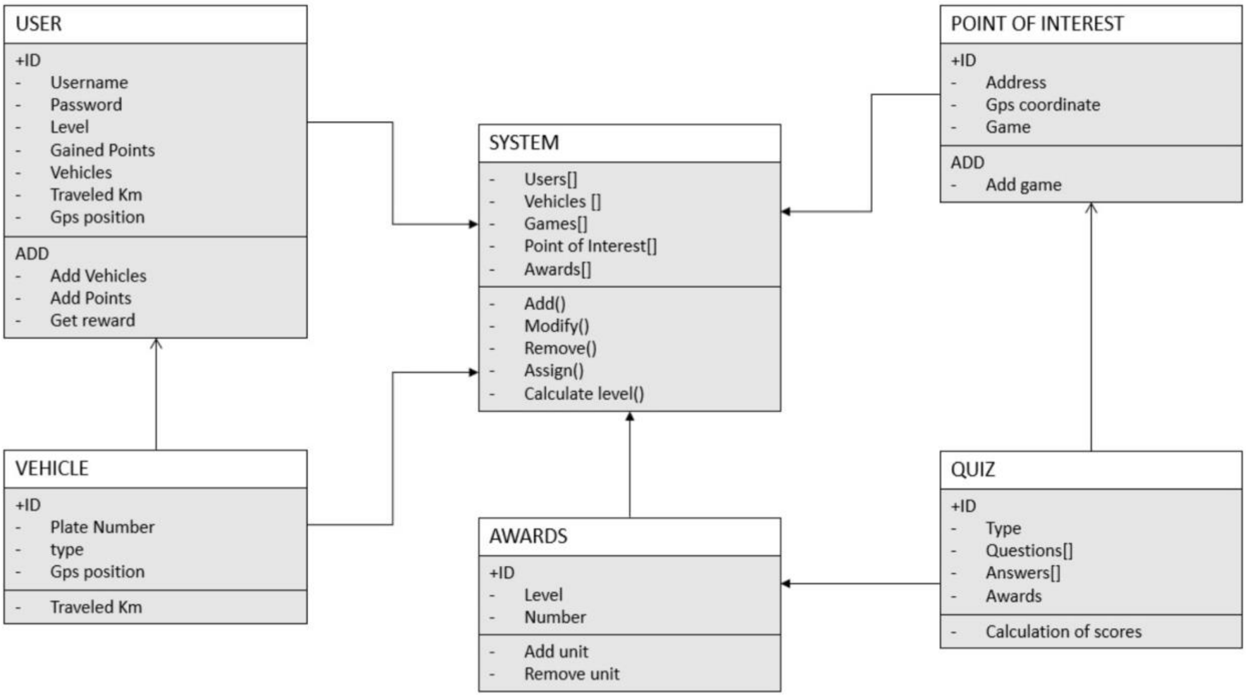

Figure 2.7: *UML diagram of classes.*

The defined use cases to be implemented through the application are the following:

- the user registration/authentication;
- the geolocation;
- the identification of points of interest;
- the access to the game and saving of the game play results.

The serious game proposed is based on two different processes: one linked to the user's GPS coordinates and one related to a continuous offline data flow.

2.5.2. Architecture of the Serious Game App

The adopted methodology to define, design and implement the architecture of the serious game application is presented. The used development environment is Android Studio, an integrated development environment for the development of the Android platform. The chosen programming language is Java, an object-oriented programming language designed specifically to be as independent as possible from the execution platform. The application consists of a total of about 20 activities, which are the core components of an Android application. The way in which the activities interact with each other constitutes the application's working model. Each Activity consists of a Java file and an eXtensible Markup Language (XML) file. The Manifest Android file is implemented for the structure of the app and includes some information such as: the permissions requested from the user, the Activity used, app theme and customization. The App contents are completely customized by using XML files. Then four XML files will be used by the App:

- LocationList.xml contains the points of interest defined in the demo site which will trigger quizzes. The number of places of interest, the related questions and the points (general or topic-related) for each correct answer are different for each city. Also, each achievement reached may lead to incentive points for the user.
- Geolocation.xml includes the following parameters: Id, name, GPS position, distance at which quiz is triggered, Id of the message shown when triggered.
- GameSettings.xml: contains the main indicators for local customization: languages, topics of the quizzes, achievements foreseen.
- MessagesList.xml: contains all the quizzes and messages that can be shown to the user during the game.

The geo-location function of the mobile device allows to activate the questionnaires when the user is near the monuments of the city included in the game. The main purpose of the data collection by the app is to have a clear vision of how much knowledge and experience of the electric vehicles and electro-mobility in general the citizens have. In particular, the scores obtained by the questionnaire answers will be linked to the incentives and awards. These data will be used to understand the awareness level of the citizens on the sustainable mobility with particular reference to the electro-mobility sector and how much the serious game helps to increase the willingness to use EVs and ELVs for the future.

The platform used for authentication and data storage (Fig. 2.8 and 2.9, respectively) is Google's Firebase: it is a platform that integrates a set of features for mobile apps on iOs and Android. These features can be divided into 4 groups: analytics, development, growth and monetization. In the Authentication section of the platform, it is possible to view registered users, identified by the user ID, as well as being able to check when these users have accessed the platform.

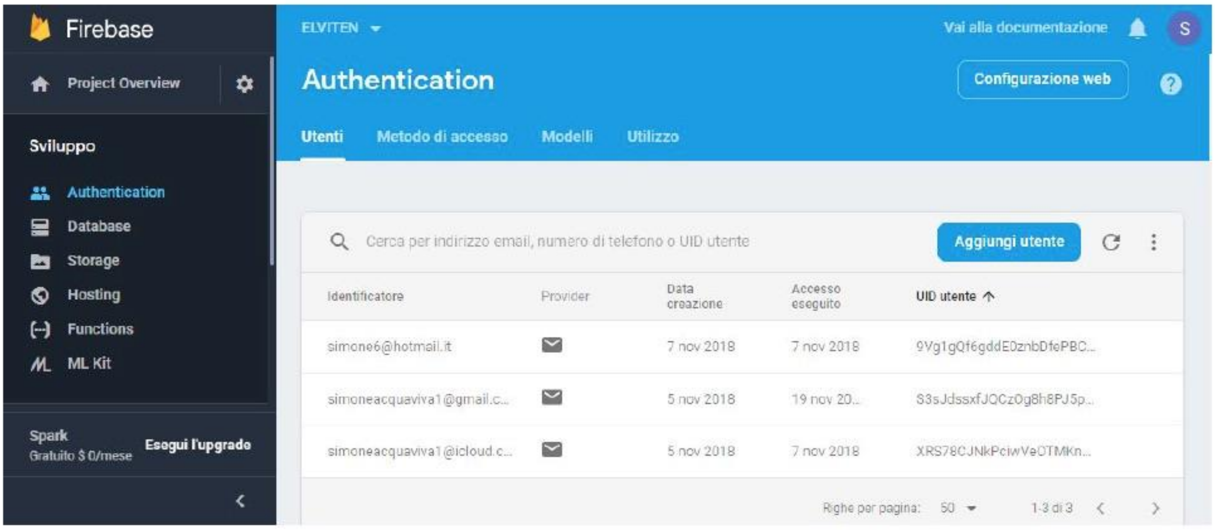

Figure 2.8: *Authentication page.*

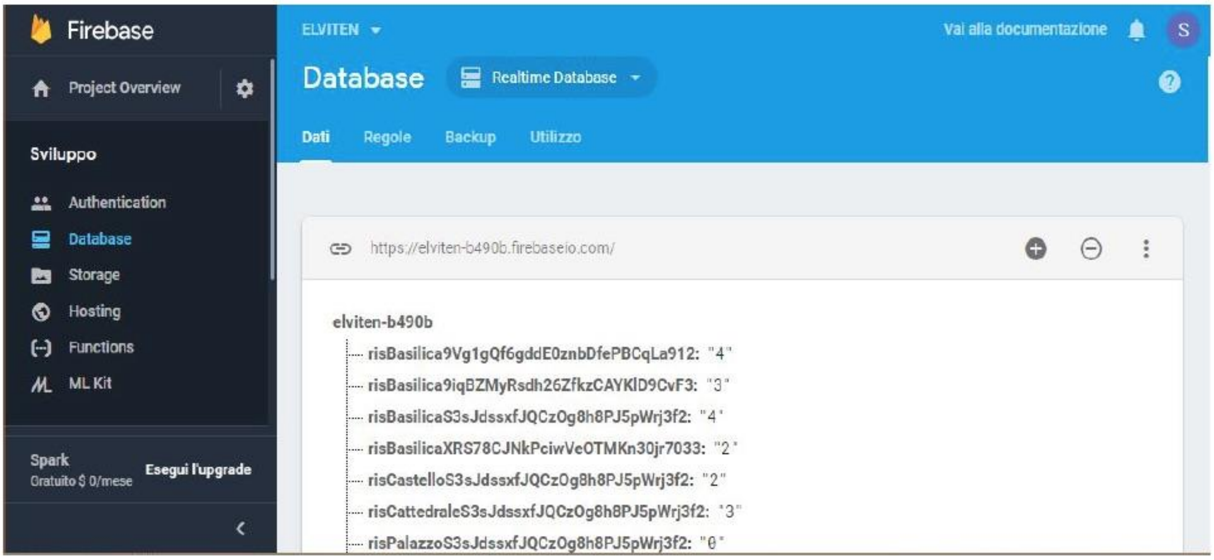

Figure 2.9: *Database layout.*

2.5.3. Serious Game rules and functionalities

The main functions implemented in the designed serious game are the following:

1. The user has the possibility to create his own account, which is identified by e-mail, username and password. The login and registration functions are implemented within the application itself and the data are saved online on the Google Firebase service. Invalid registration/login values are communicated to the user by a Toast

message. The user who logs in will remain logged in automatically: there is no need to authenticate each time the application is opened.

2. In a dedicated activity, the application captures the user's position and tracks it in real time. The position is marked on a map by a red marker that identifies and displays the address in which the user is located.
3. Places of interest are marked on the map, each one with a different colored marker. By clicking on one of them the user can connect directly to the Google Maps application and see the shortest route to reach the desired attraction.
4. When the user is less than 200m from one of these points, the application automatically detects it and starts the corresponding multiple-choice questionnaire. This method requires three parameters: 1) starting point (latitude and longitude); 2) end point (latitude and longitude) and finally a float vector.

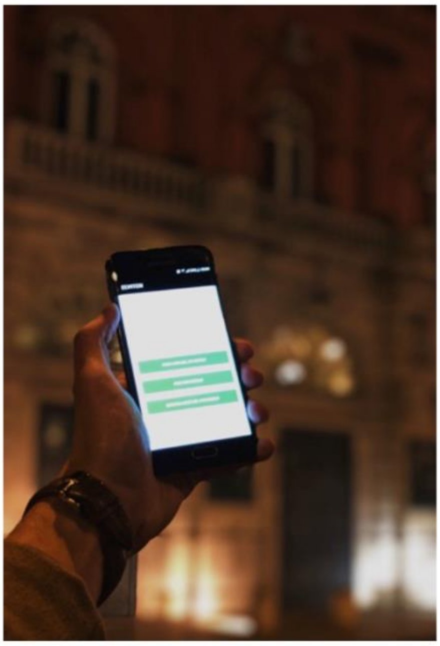

Figure 2.10: *Activated questionnaire.*

5. At the end of the questionnaire the application shows a customized message that depends on the number of correct answers selected. The SG allows saving the results in the Firebase database. Each response saved on the database can be changed only if the same user repeats the questionnaire and decides to modify the previous result.

6. On the main page of the application there is a link to the "Your results" activity. Here the user reads the saved score for each questionnaire. If the questionnaire has never been completed, the score field will be empty. The results of the questionnaires are visible in the Database section. Automatically, when a user decides to save a result, a unique string is created, defined by the name of the questionnaire that was linked to the user ID, which is unique.

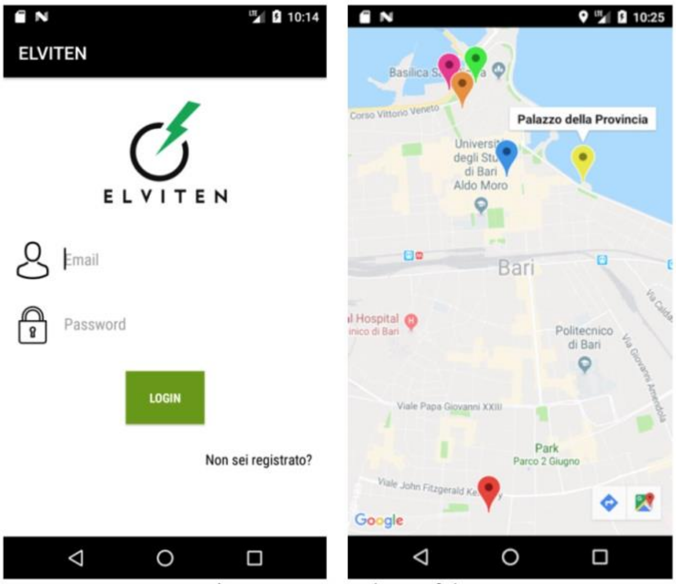

Figure 2.11: *Screenshots of the Serious Game*

2.6. Conclusion on the results obtained

People mobility is undergoing significant changes in recent years. Several innovations are proposed to improve environmental aspect, reduce externalities and ensure quality of service for users.

The new vehicles have no emissions, because they are based on electric powertrain and in the coming years they will also be safer with autonomous driving systems. The new policies and regulation, also based on ICT and big data systems, are able to reduce externalities and issues in the city through limited speed areas, urban pricing, smart light and mobility management, mobility credits and incentive systems. ICT systems are one of the most important innovations in the transport sector because they are allowing and will allow the integration of services in real time also thanks to App that can be used with smartphones.

Moreover, the new vision of mobility as a service needs a cultural change of users. It is unthinkable to use only prohibition policies, albeit necessary, but there must be methods that can involve users in this process. Gamification and incentive system are the recent innovations that support this users behavioural change.

In the second part of the chapter some of the innovations concerning the people mobility mentioned above, are described by application cases. In particular new approach with ICT tools useful to support people in the use of sustainable mobility and electro-mobility are presented. A baseline analysis of Key Performance Indicators in elettro-mobility sector with innovative approach is shown and a serious game approach with ICT tool is described.

In addition, the relocation problem in a EVs sharing system, station based, is discussed as an introduction to the next chapter.

2.7. Chapter references

Antolic, Z. (2008). An Example of Using Key Performance Indicators for Software Development Process Efficiency Evaluation. R&D Center Ericsson Nikola Tesla.

Barr, S. (2018). How to set a KPI Baseline to Monitor Improvement. 10 January, online document, https://www.staceybarr.com/measure-up/set-kpi-baseline-monitor-improvement/

Bianchessi, A. G., Cugola, G., Formentin, S., Morzenti A. C., Ongini, C., Panigatti, E., Rossi, M., Savaresi, S. M., Schreiber, F. A., Tanca, L., Vannutelli Depoli, E. G.(2014). Green Move: A Platform for Highly Configurable, Heterogeneous Electric Vehicle Sharing. IEEE Intelligent Transportation Systems Magazine vol. 6, issue 3, pp. 96-108.

Damm, S., Tello, C.I., Ritz, T. (2014). Connecting a pedalec to "the cloud" as basis for gamification in multi modal mobility planning, Proceedings of the IEEE 2nd IEEE International Conference on Services, and Engineering (MobileCloud), 8 - 11 April, Oxford, UK.

Dange, G.R., Paranthaman, P. K., Bellotti, F., Berta, R., De Gloria, A., Raffero, M., Neumeier, S. (2017). Deployment of Serious Gaming Approach for Safe and

Sustainable Mobility, Proceedings of the IEEE Intelligent Vehicles Symposium (IV), 11 - 14 June, Los Angeles, CA, USA.

Deeptimahanti, D. K., Ratna, S. (2011). Semi-automatic generation of UML models from natural language requirements. 4th India Software Engineering Conference, ACM, p. 165-174.

EU project ASCENS. url: http://www.ascens-ist.eu

EU project ELVITEN (2017). url: https://www.elviten-project.eu/it/

EU project NEMO (2016). url: https://nemo-emobility.eu

Fanti, M.P., Rinaldi, A., Roccotelli, M., Silvestri, B., Porru, S., Pani, F.E. (2018). Software Requirements and Use Cases for Electric Light Vehicles Management. IEEE International Conference on Systems, Man, and Cybernetics (SMC), 7-10 October, Miyazaki, Japan.

Guide to Key Performance Indicators, Communicating the measures that matter (2007). PriceWaterHouseCoopers.

Kazhamiakin, R., Marconi, A., Perillo, M., Pistore, M., Valetto, G., Piras, L., Aversani, F., Perri, N. (2015). Using Gamification to Incentivize Sustainable Urban Mobility, Proceedings of the IEEE first International Smart Cities Conference (ISC2), 25-28 October, Guadalajara, Mexico.

Kuganathan, K.V., Wikramanayake G.N. (2014). Next generation smart transaction touch points. Proceedings of the International Conference on Advanced in ICT for Emerging Regions (ICTer), 10-13 December, Colombo, Sri Lanka.

Lorenzini, C., Brondi, R., Carrozzino, M., Nistico, M., Evangelista, C., Tecchia, F. (2014). LawVille: A Collaborative Serious Game for Citizenship Education", 6th International Conference on Games and Virtual Worlds for Serious Applications (VS-GAMES), 9-12 September, La Valletta, Malta.

Lucassen, G., Dalpiaz, F., Martijn, J. can der Werf, E.M., Brinkkemper, S. (2015). Forging High-Quality User Stories: Towards a Discipline for Agile Requirements. IEEE 23rd International Requirements Engineering Conference (RE), 24-28 August, Ottawa, ON, Canada.

Lucassen, G., Dalpiaz, F., Martijn, J. can der Werf, E.M., Brinkkemper, S. (2016). The use and effectiveness of user stories in practice. International Working Conference on Requirements Engineering: Foundation for Software Quality, Springer, Cham.

Marian. P. (2013). UML in practice." Proceedings of the International Conference on Software Engineering. IEEE Press.

Piela, J. (2017). Key Performance Indicator Analysis and Dashboard Visualization in a Logistic Company. Master's Thesis, Lappeenrante University of Technology, Helsinki, Finland.

Pender, T (2003). .UML bible. Book. John Wiley&Sons, Inc.

Petri, M., Frosolini, M., Lupi, M., Pratelli, A. (2016). ITS to change behaviour: A focus about bike mobility monitoring and incentive – The SaveMyBike System, Proceedings of the IEEE 16th International Conference on Environmental and Electrical Engineering (EEEIC), 7- 10 June, Florence, Italy.

Petrovic, O., Harnisch, M. J., Puchleitner, T. (2013). Opportunities of mobile communication system for applications in last-mile logistics. Proceedings of the IEEE International Conference on Advanced Logistics and Transport (ICALT), 29-31 May, Sousse, Tunisia.

Pohl, K. (2010). Requirements engineering: fundamentals, principles, and techniques. Springer Publishing Company, Incorporated.

Rumbaugh, J., Grady, B., Ivar, J. (2017). The unified modeling language reference manual. Book. Addison Wesley.

Sciuto, D. (2012). Research in smart cities: mobility, energy, infrastructure. Proceedings of meeting "The construction of a Smart City: model for the sustainability of medium-size cities", 20 April, Piacenza, Italy.

Shen, J. (2013). Investigation of how to implement successful KPIs for organizations – based on an empirical study at an international organization. Master Degree Project, Royal Institute of Technology, Stockholm, Sweden.

Shreenath, V. M., Kornevs, M., Raghothama, J., Meijer, S. (2015). A Feasibility Study for Gamification in Transport Maintenance. 7th International Conference on Games and

Virtual Worlds for Serious Applications (VS-Games), 16-18 September, Skovde, Sweden.

Sierpinski, G., Staniek, M. (2018). Platform to support the implementation of electromobility in smart cities based on ICT applications - concept for an electric travelling project. Scientific Journal of Silesian University of Technology. Series Transport 100: 181-189.

Silvestri, B., Rinaldi, A., Roccotelli, M., Fanti, M.P. (2019a). Innovative Baseline Estimation Methodology for Key Performance Indicators in the Electro-Mobility Sector. IEEE International Conference on Control, Decision and Information Technologies (CoDIT), 23-26 April, Paris, France.

Silvestri, B., Rinaldi, A., Berardi, A., Roccotelli, M., Acquaviva, S., Fanti, M.P. (2019b). A Serious Game Approach for the Electro-Mobility Sector Baseline Estimation Methodology for Key Performance Indicators in the Electro-Mobility Sector. IEEE International Conference on Systems, Man, and Cybernetics (SMC), 6-9 October, Bari, Italy.

Soe, R.M., Mikheeva, O. (2017). Combined model of smart cities and electronic payments, Proceedings of the International Conference for E-Democracy and Open Government (CeDEM), 17-19 May, Krems, Austria.

Solow, D. (2017). How to set KPI Baselines", October 10th, online document, https://www.esmgrp.com/blog/how-to-set-kpi-baselines.

Wang, Y., Hu, W. (2017). Analysis about serious game innovation on mobile devices. 16th International Conference on Computer and Information Science (ICIS), 24-26 May, Wuhan, China.

Werther, B., Hoch, N. (2012). E-Mobility as a Challenge for New ICT Solutions in the Car Industry. Proceeding of the 6th international Symposium on Trustworthy Global Computing (TGC'11). 09 – 10 June 2011, Aachen, Germany. pp. 46-57.

West, J., Prahlad, S. (2015). How baselines, thresholds, and Key Performance Indicators work together to generate events in the operator console. 26 october, online document, https://docs.bmc.com/docs/display/public/tsim10/How+baselines%2C+thresholds%2C+and+Key+Performance+Indicators+work+together+to+generate+events+in+the+operator+console

Yu, Y., Pan, Y., Song, J. (2008). An improved baseline acquisition approach for real-time performance monitoring based on support vector machines. The Journal of China Universities of Posts and Telecommunications. 15 (Suppl.), pp. 59-63

3. Optimization of EVs and ELVs relocation in the sharing system

EVs sharing system is an innovative approach to reduce externalities in urban areas and consists of EVs used as a public transport mean by individual users according to their needs for a short time period. One of the main issues of sharing systems is to maintain a high level of the service efficiency despite the dynamic reconfiguration of the system, obtained by periodic relocations of vehicles generating both internal and external costs. In this chapter, innovative strategies defined with the aim to involve users in vehicles relocation are detailed. Potential economic and environmental savings are demonstrated.

3.1. Vehicles relocation problems in the sharing systems

The vehicles relocation problem in the sharing system is an interesting topic and several studies have been carried out. The main rental strategies used in the sharing system are two (Clemente et al., 2018): i) the one-way rental or station based; ii) the two-way rental. In the first strategy, the most widespread among sharing systems, users or operators are allowed to pick up and return the rented vehicle in different parking areas. In this case, the distribution of the vehicles can become unbalanced during the day due to the variable demand. In the second strategy, the car sharing users or operators have to return the car to the pick-up station. In this way, the number of vehicles per station can remain constant but the user has no flexibility in their travels. Therefore the relocation is more important and frequent in the first strategy than in the second one. A third rental strategy, named free floating vehicles sharing, is used in the recent years: users or operators are allowed to pick up and return the rented vehicle in every parking lots in the delimited area of the city (normally all the city). Also in this case, the distribution of the vehicles can become unbalanced during the day.

Several authors such as Clemente et al. (2018), Kek et al. (2009), Nourinejad and Roorda (2014), Bianchessi et al. (2013) analyse the problem in a station-based approach. Weikl and Bogonberger (2012) propose relocation strategies and algorithms for free floating car sharing systems, while Cocca et al. (2018) study the free floating electric car sharing.

One of the main issues of sharing system is to maintain a high level of the service efficiency despite the dynamic reconfiguration of the system that cyclically occurs during its operation. Indeed, periodic relocation of vehicles between stations becomes necessary to ensure that there are sufficient vehicles that are spread geographically across the stations to serve user demands according to Kek et al. (2009).

User-based approaches that aim at incentivizing the users to participate in the relocation activities, balancing the vehicles among the parking areas is proposed by Clemente et al. (2018), Nourinejad and Roorda (2014), Deng and Cardin (2018). In this case, users that travel are involved in the vehicle relocation, mainly through a Decision Support System.

In the operator-based approaches, the staff relocates the vehicles when it is necessary. In this case, additional trips without customers are needed by the operators to relocate the vehicles.

A further classification of vehicle sharing relocation strategies can be done based on relocation time: off-line, such as Homem de Almeida Correia and Antunes (2012), Boldrini et al. (2017), Bruglieri et al. (2014), Nourinejad et al. (2015a), Santos et al. (2017), or real-time, such as Clemente et al. (2018), Kek et al. (2018), Nourinejad and Roorda (2015b), Nourinejad and Roorda (2014), Zakaria et al. (2014), Bianchessi et al. (2013), Jorge et al. (2014), Schulte and Vob (2015), Di Febbraro et al. (2019), Angelopoulos et al. (2016), Deng and Cardin (2018), Xu et al. (2018). In the off-line approach, relocation activities are performed at a fixed time regardless of the actual equilibrium conditions of the system (e.g. at the end of the working day). In real time approach, relocations are performed based on the current state of the system.

Pal and Zhang (2017), propose a classification of relocation or rebalancing strategies of station based vehicle sharing systems in: i) operator and, ii) user based strategies. In the first group are considered static and dynamic rebalancing. The second group use incentives with static or dynamic pricing. In figure 3.1 is presented the rebalancing strategies.

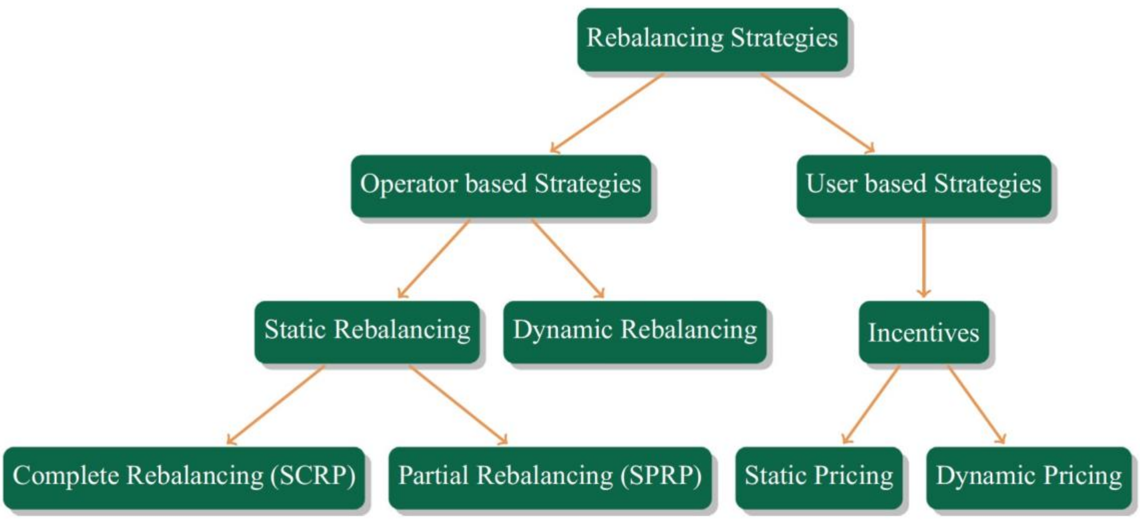

Figure 3.1: *Classification of rebalancing strategies*

The analysis of literature shows several works on the vehicles relocation problem in a sharing system, but few of them consider EVs. EVs since autonomy limitations and recharge time have to be considered.

Rental strategies	Relocation approach	Relocation time	Paper, year	Title
One-way rental or Station base approach	User based approach	Real Time	Clemente et al. (2018)	A Decision Support System for User-Based Vehicle Relocation in Car Sharing Systems
			Nourinejad and Rooda (2014)	A dynamic car-sharing decision support system
			Deng and Cardin (2018)	Integrating operational decisions into the planning of one-way vehicle-sharing systems under uncertainty
		Off-line	Boldrini et al. (2017)	Relocation in car sharing systems with shared stackable vehicles: Modelling challenges and outlook
	Operator based approach	Real Time	Kek et al. (2009)	A decision support system for vehicle relocation operations in car sharing systems
			Bianchessi et al. (2013)	Active fleet balancing in vehicle sharing systems via Feedback Dynamic Pricing
			Jorge et al. (2014)	Comparing Optimal Relocation Operations With Simulated Relocation Policies in One-Way Car sharing Systems
			Schulte and Vob (2015)	Decision Support for Environmental-friendly Vehicle Relocations in Free-Floating Car Sharing Systems: The Case of Car2go,
			Di Febbraro et al. (2019)	One-Way Car-Sharing Profit Maximization by Means of User-Based Vehicle Relocation
			Angelopoulos et al. (2016)	Incentivization schemes for vehicle allocation in one-way vehicle sharing systems
			Zakaria et al.(2014)	”Car relocation for car sharing service: Comparison of CPLEX and greedy search
			Xu et al. (2018)	Electric vehicle fleet size and trip pricing for one-way car sharing services considering vehicle relocation and personnel assignment
		Off-line	Homem de Almeida Correia and Antunes (2012)	Optimization approach to depot location and trip selection in one-way car sharing systems
			Bruglieri et al. (2014)	The Vehicle Relocation Problem for the One-way Electric Vehicle Sharing: An Application to the Milan Case
			Nourinejad et al. (2015a)	Vehicle relocation and staff rebalancing in one-way car sharing systems
			Santos et al. (2017)	Vehicle relocation problem in free floating carsharing using multiple shuttles
Free floating			Weikl and Bogonberger (2012)	Relocation strategies and algorithms for free-floating Car Sharing Systems
			Cocca et al. (2018)	Free Floating Electric Car Sharing in Smart Cities: Data Driven System Dimensioning
Two-way rental		Real Time	Nourinejad and Rooda (2015)	Car sharing operations policies: A comparison between one-way and two-way systems

Table 3.1: *Classification of papers on the vehicles relocation in the sharing systems.*

3.2. Relocation problem in the EVs and ELVs sharing system

Clemente et al. (2018) consider mobility sharing system with EVs or ELVs as one of the most popular solution today, based on the possibility for an EV to be used as a public transport means by individual user that can autonomously rent the EV according to his/her needs, usually for a short time period. The use of EVs or ELVs in the sharing system adds further constraints in the relocation problem.

The EVs sharing system (EVRP) is an innovative approach to reduce externalities in urban areas. The EVRP has been faced in Dror et al. (1998), which proposes an algorithm to manage auto transport trucks, based on a Tabu search approach and a savings. The algorithm is applied to a car sharing service with fifty EVs and five stations, offered in the French town of Saint Quentin en Yvelines. The car sharing service offered in the same location was studied also by Hafez et al. (2001), which have determined the required number of car transporters with an exact algorithm, and then minimize the total travel time of relocation, studying three different heuristics. Bruglieri et al. (2014) propose a method to forecast the unbalancing of a car-sharing system with EVs.

Ren et al. (2019) indicate that it is possible to shift the usage of shared EVs through a well-designed Dynamic Pricing Scheme, with the objective of maximizing the system operator's total profit, considering vehicle relocation.

The diffusion of shared mobility services is limited due to the price for the end users, the limited users' information and the lack of experience in using such new mobility systems and EVs. In order to reduce the cost for the users of sharing services, and at the same time guaranteeing the economic sustainability of the company, Kek et al. (2009) applied the following main strategies: i) reduction of operating costs; ii) increase of the daily usage rate of vehicles.

In this context, EVRP is important to increase the quality level of the sharing service with EVs and ELVs, making vehicles available in different stations/areas at demand peaks daytime. However, the vehicle relocation is an expensive task for the company that needs to be reduced. Indeed, the reduction of this cost will increase the company profitability and will allow to reduce the price of the sharing service for the customers.

3.3. Innovative strategies for the EVRP in a sharing system with optimization approaches

In this Section an innovative approach with incentive system for the relocation of EVs or ELVs in the sharing service is proposed. The aims are not only the reduction of the relocation costs for a mobility sharing company and of the external costs for society, but also at attracting and retaining customers through an incentive mechanism. The customers that use the mobility sharing service for their trips can also become active part of the relocation process with direct benefits for both the sharing company and the users.

The idea here is to ask users to move a vehicle from one station to another being rewarded. In particular, users who agree to participate in the vehicle relocation will travel for free and will receive trip credits to be used in the sharing service. It is remarked that, the cost of providing trip credits to customers is lower than the cost of the relocation service for the sharing company. In addition, only EVs with battery autonomy that allows to accomplish the relocation trip can be relocated. Nowadays, mobility sharing companies provide their services through an IT application for smartphone, therefore the proposed approach can be developed with the same tool.

The proposed user incentivization approach can be provided through an IT application and can be described by the following procedure. First, an incentive bid is notified to all users who want to participate in the relocation activities. At this stage, two cases can occur: i) at least one user per vehicle to be relocated accepts the incentive proposal, pick-up the vehicle at the departure station and goes to the destination station and receives the reward at the end of the relocation activity (the reward is loaded on his/her sharing service account); ii) no user accepts the incentive proposal and a new notification is broadcast to all users with an increased incentive bid. Note that step ii) can be repeated several times based on the incentive levels that the company propose (e.g. 3 levels of incentives mean that step ii can be repeated at most three times). After that, if no user accepts the incentives proposals, the company will use internal staff to perform the relocation service. On the other hand, the standard service fee and no incentive will be applied to users who accept the incentive proposal but deliver the vehicle to a different station.

The proposed incentive mechanism allows reducing operational costs of vehicle relocation or at worst to keep them unchanged. The EV relocation incentive-based process for a sharing company is depicted in Fig. 1. Let us introduce the set of incentive proposals (levels) $U \in Z^{+}$, with cardinality $|U|$. It is supposed that $u \in U$, u = 1, ... , |U| - 1 are the incentive levels planned by the company to the users.

Furthermore, we assume that the last element of U does not represent an incentive for users but it is the cost of the relocation process carried out by the company staff.

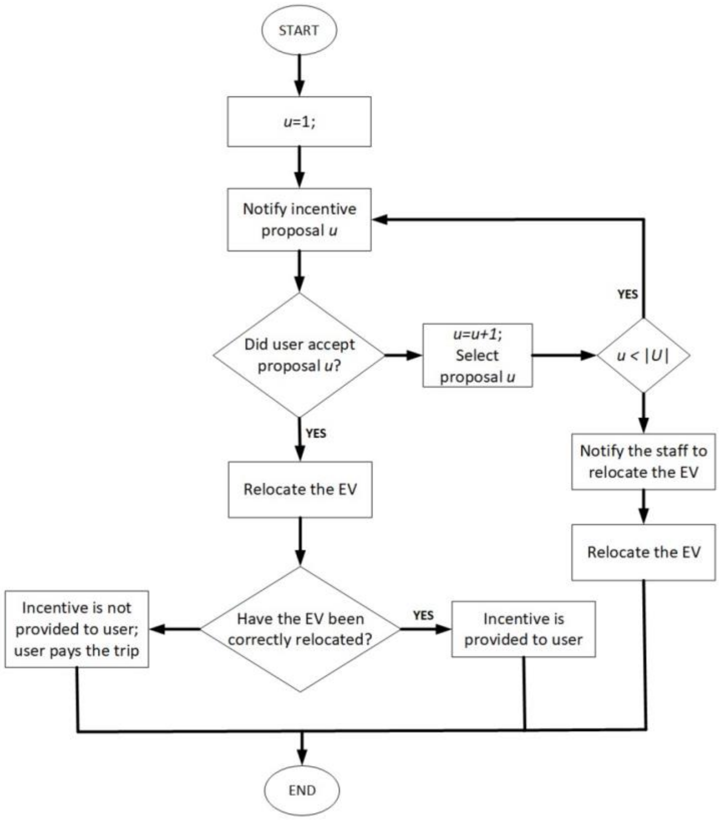

Figure 3.2: *The incentive base relocation process*

In the proposed relocation approach are considered both electric cars and ELVs such as e-bikes, or of EVs such as segway and electric kick scooters. These last categories can be relocated even in case of low battery autonomy but only by the company staff. Indeed, due to their size it is possible pick them up on a van.

The optimization approach adopted to solve the EVRP for a sharing company in a station-based framework or restricted area considered as a station, involve users with incentive proposals. The optimization model is formulated under the following assumptions:

- company relocation cost is proportional to the distance between stations with a defined destination-source matrix. It is a variable cost for the company and does not include the fixed;
- in the relocation process involving users, EVs travel the shortest route and users use only the EVs indicated by the company;
- the daily number of relocated EVs does not change whether it is performed by company staff or by users;
- EVs battery autonomy is a known value;

the relocation process is off-line: it is assumed that all EVs are in the stations before the start of the relocation process.

3.3.1. Incentive schemes

Incentives systems are applied to modify people behaviour. They can be applied in electro-mobility sector. Thaler and Sustein (2008) propose the "nudge's theory" as a concept in behavioural science, political theory and behavioural economics which states that people normally make non-rational decisions and these decisions would be different if they acted in rational way or were well-informed. Incentive schemes are an application of this theory. Brög et al. (2009) contest the assumption that modal shift is only possible through "hard" system-based measures, or through regulation. They analyse the voluntary travel behaviour change initiatives as a strategy to reduce car trips and promote public transport.

The incentive schemes in the mobility sector are a useful tool able to modify the users' behaviour in a routine activity. The approach is related to involve users in the use of sustainable mobility such as public transport, bike and EVs instead of ICE vehicles. The users perceived incentive as a positive factor, unlike charges and prohibitive rules. Therefore, it is very important to design a correct incentive system, able to engage users. This approach is based on awarding points or credits for virtuous behaviour that can be spent on prizes. The positive incentive can be developed through a robust ICT system with a platform and a dedicated App to use with a smartphone. It is essential for a correct management.

The incentive system is a research topic in several projects and countries, such as Pfrommer et al. (2014) that propose the dynamic vehicles redistribution, based on online price incentives in a shared mobility system. It is likely that a mix of prices, financial and social incentives may be strong enough to induce users to reduce urban mileage by a significant percentage or shift to other modes, in an environmental view.

According to Troglia (2018), the incentives are sets of material and virtual objects that help modifying the behaviour of an individual. Incentives can also be defined as the credits that can be spent to get the benefits resulting from the change in behaviour.

The incentive system approach is based on four pillars. In mobility sector they can develop as follow:

- rules (or measures): stimulate the adoption of eco-mobility behaviours and, if met, permit to gain incentives. Normally defined by Local Mobility Authority or Public Administration;
- incentives: such as discount on tickets and fares, on local taxation, on city services, free and/or extended access to Limited Traffic Zones, parking lots reserved for private cars and freight vehicles, discounted insurance, and also social incentives not directly related to money;
- measurement: verify if the rules are respected to assign incentives;
- distribution of incentives to users: how users can spend incentives.

The incentive system in mobility sector can increase the use of sustainable mobility by citizens and at the same time, the new mobility behaviour reduces the externalities in urban area.

Particular forms of incentives are the Mobility Credits, an idea using also for EU Emission Trade Scheme: make a property rights over public assets, limited to the maximum using of it. In a free market model, the rights can be exchanged between users according to personal needs, with an optimal allocation.

3.3.2. Centralized optimization approach

EVRP for the company staff

The relocation process performed by company staff is formulated in this subsection as an integer linear programming (ILP) problem considering the company cost minimization as objective. Given the set $K \in Z^+$ of EVs to be relocated, with cardinality |K|, and the set $I \in Z^+$ of stations, with cardinality |I|. Considering a day period, the relocation service cost is related to the number of EVs to be relocated and t the distance among the stations, which are assigned. The binary decision variables are $x_{i,j,k}$, $\forall\, i, j \in I$, $\forall\, k \in K$, where the departure station is labelled with i, the arrival station is labelled with j and the EV is labelled with k.

The integer variables are $s_j, \forall\, j \in I$, indicating the number of EVs in each station after the relocation process. Moreover, we define $NK_{i,j} \in N_0$ the set of EVs that can be relocated from station i to station j, based on the battery autonomy, with cardinality $|NK| = nk_{i,j}^{max}$

The known parameters of the problem are the following: $\hat{s}_j$, is the number of EVs in station j before the relocation process; $\hat{s}_i$ is the number of EVs in station i before the relocation process; the maximum and minimum number of EVs to be guaranteed at each station, are respectively defined as $N_{max} \in Z^+$ and $N_{min} \in Z^+$.

Hence, the following variables and parameters are defined:

RC is the total relocation cost for the EVs sharing company [€/day];

c is the kilometre cost for the relocation process [€/km];

$D_{i,j}$ is the distance from station *i* to station *j* [km];

$x_{i,j,k}$ is the binary decision variable indicating the *k-th* EV moving from the station *i* to station *j* in a day [day^{-1}];

$x_{j,i,k}$ is the binary decision variable indicating the *k-th* EV moving from station j to station *i* in one day [day^{-1}];

s_j is the number of EVs in station *j* after the relocation process;

$\hat{s}_j$ is the number of EVs in station *j* before the relocation process;

$v_{i,k}$ = 1 means that EV k has sufficient battery autonomy to move from station i to station *j*;

$a_{i,k}$ is the battery autonomy of *k-th* EV in station *i* [km];

N_{max} is the maximum admissible number of EVs in the *j* station;

N_{min} is the minimum admissible number of EVs in the *j* station;

$nk_{i,j}^{max}$ is the maximum number of EVs with sufficient battery autonomy to move from station *i* to station *j*. It is calculated as:

$$nk_{i,j}^{max} = \sum_{k=1}^{\hat{s}_i} v_{i,k}, \qquad \forall\, i \in I, \tag{3.1}$$

with

$$v_{i,k} = \begin{cases} 1, if\ a_{i,k} - D_{i,j} \geq 0 \\ 0, otherwise \end{cases}$$

The ILP (3.2)-(3.7) is formulated as follows:

$$RC = \min(c + e) \sum_{i=1}^{|I|} \sum_{j=1, i \neq j}^{|I|} \sum_{k=1}^{|K|} D_{i,j} \cdot x_{i,j,k} \tag{3.2}$$

subject to:

$$s_j = \hat{s}_j + \sum_{i=1}^{|I|} \sum_{k=1}^{|K|} x_{i,j,k} - \sum_{i=1}^{|I|} \sum_{k=1}^{|K|} x_{j,i,k}, \quad \forall\, j\ \in I \tag{3.3}$$

$$s_j\ \leq\ N_{max}, \quad \forall\, j\ \in I \tag{3.4}$$

$$s_j\ \geq\ N_{min}, \quad \forall\, j\ \in I \tag{3.5}$$

$$\sum_{k=1}^{|K|} x_{i,j,k}\ \leq\ nk_{i,j}^{max}, \quad \forall\, i,j\ \in I, i \neq j \tag{3.6}$$

$$x_{i,j,k} \in \{0,1\} \tag{3.7}$$

$i, j\ \in I, \qquad k\ \in K$

Variables number: |I| x (|I| x | K | + 1)

Constraints number: |I| x (|I| + 2)

It should be noted that, in the case EVs couldn’t be relocated due to low battery capacity level - constraints (3.6) - it is possible the unfeasible solution since the constraints (3.4) and (3.5) could be unverified. The use of specific ELVs as e-bikes, segway and electric kick scooters, allows to relax constraints (3.6) because company staff through the vans can relocate these EVs. Otherwise, to reach a feasible solution with the use of other EVs categories not relocatable with vans is possible by accurately decreasing N_{min} and/or increasing N_{max}.

EVRP involving users

The proposed approach involves the users in the relocation process with an incentive scheme; therefore, it is necessary to formulate a new optimization problem based on the ILP1. Considering the levels of incentive described in Section II, we define $N_c \in N$ as the number of user available in the relocation process. The user acceptance is considered with a defined acceptance rate based on the values of the incentive levels. In particular, a user acceptance rate $r_u \in R^+$ is introduced for each incentive level. The number of EVs able to relocate is $evr_u = N_c * r_u$, u = 1, ... , |U| - 1. It is emphasized that the relocation process, in the proposed method, is performed both by users and by company staff, with the objective to reduce the total relocation cost. In addition, in the relocation process are considered only EVs with necessary state of charge (SoC) able to complete the trip.

Now, the following variables and parameters are defined:

RCI is the total relocation cost for the mobility sharing company including the incentive for users [€/day];

in_u is the incentive rate for the incentive level u;

$x_{i,j,k,u}$ is the binary decision variable indicating the k-th EV moving from station i to station j under incentive level u in one day [day^{-1}];

$x_{j,i,k,u}$ is the binary decision variable indicating the k-th EV moving from station j to station i under incentive level u in one day [day^{-1}];

$nk_{i,j,u}^{max}$ is the maximum number of EVs with sufficient battery autonomy to move from station i to station j under incentive level u.

It is calculated as:

$$nk_{i,j,u}^{max} = \sum_{k=1}^{\hat{s}_i} \sum_{u=1}^{|U|} v_{i,k,u}\,, \qquad \forall\, i \in I, \tag{3.8}$$

with

$$v_{i,k,u} = \begin{cases} 1, if\ a_{i,k} - D_{i,j} \geq 0 \\ 0, otherwise \end{cases}$$

The second optimization problem is formulated as the following ILP2 (3.9)-(3.15):

$$RCI = \min(c + e) \sum_{i=1}^{|I|} \sum_{j=1, i \neq j}^{|I|} \sum_{k=1}^{|K|} \sum_{u=1}^{|U|} (in_u \cdot D_{i,j} \cdot x_{i,j,k,u}) \tag{3.9}$$

subject to:

$$s_j = \hat{s}_j + \sum_{i=1}^{|I|} \sum_{k=1}^{|K|} \sum_{u=1}^{|U|} x_{i,j,k,u} - \sum_{i=1}^{|I|} \sum_{k=1}^{|K|} \sum_{u=1}^{|U|} x_{j,i,k,u}, \quad \forall\, j\ \in I \tag{3.10}$$

$$s_j\ \leq\ N_{max}, \quad \forall\, j\ \in I \tag{3.11}$$

$$s_j\ \geq\ N_{min}, \quad \forall\, j\ \in I \tag{3.12}$$

$$\sum_{k=1}^{|K|} x_{i,j,k,u}\ \leq\ nk_{i,j,u}^{max}, \quad \forall\, i,j\ \in I, i \neq j, \qquad \forall\, u\ \in U \tag{3.13}$$

$$\sum_{i=1}^{|I|} \sum_{j=1}^{|I|} \sum_{k=1}^{|K|} x_{i,j,k,u}\ \leq\ evr_u, \quad \forall\, u\ \in U \tag{3.14}$$

$$x_{i,j,k} \in \{0,1\} \tag{3.15}$$

$i,j\ \in I,\ \ k\ \in K, \qquad u\ \in U$

Variables number: |I| x (|I| x | K| x | U| + 1)
constraints: |I| x (|I| + 2) + 2 x |U|

As mentioned above in ILP1 for the constraints (3.6), also in ILP2 the constraints (3.13) can exclude the unfeasible solution only in the case of EVs travelled by company staff with a van; in the other case this condition cannot be assured.

The relocation cost reached by solving ILP2 will be less than or at most equal (in case no user accepts the relocation task) to the results reached by solving ILP1.

Applying the proposed method in a real case to solve the EVRP in a sharing system with station-based strategy a reduction of relocation cost will be achieved. The proposed formulation allows using any categories of EVs (i.e. electric bike, electric kick scooter, electric car and others).

3.3.3. Distributed optimization approach

A distributed optimization approach to solve the EVRP in a sharing system involving users with an incentive scheme is proposed. In particular, a distributed algorithm based on the iterative solution of two ILP problems is presented. The two problems are solved by means a station together with its neighbours only by considering local information. The former ILP is the local version of ILP2 (3.9)-(3.15): it permits to relocate all the EVs involved in a local optimization by satisfying the same set of constraints as in (3.9)-(3.15) in a local approach. The latter ILP aims at redistributing EVs among the stations involved in a local optimization, in the case the first optimization problem is not feasible, in order to iteratively reach a feasible vehicle relocation.

In the distributed relocation, at each iteration t of the distributed algorithm, the randomly selected station $n \in I$ solves a local optimization with its neighbours in M_n that denotes the set of neighbours of station $n \in I$ and therefore the set of stations involved in the local optimization initialized by station n is denoted by $I_n = n \cup M_n$. It is denoted by $x_{i,j,k}(t)$ the vehicle relocation vector associated to stations $i, j \in I$ at iteration t > 0. Moreover, the set of vehicles that can be relocated in the station in I_n at iteration t > 0 is defined as $T_n(t) = \{k \in K | x_{i,j,k}(t-1) = 1, i, j \in I_n\}$.

Furthermore, $x_{i,j,k}(t)$ denotes the vehicle relocation at time t ≥ 0. Now, we introduce the L-ILP problems that are necessary to relocate the vehicles among the stations.

At each iteration t, a station $n \in I$ is randomly selected among the stations belonging to the neighbours of the station selected at iteration t - 1. Then, the following L-ILP problem, named L-ILP1, is performed by the stations $i \in I_n$ in order to optimize the vehicle assignment vectors $x_{i,j,k}$:

L-ILP1

$$CRI = \min(c + e) \cdot k \sum_{i=1}^{|I_n|} \sum_{j=1}^{|I_n|} \sum_{k=1}^{|T_n(t)|} (D_{i,j} \cdot x_{i,j,k}(t)) \tag{3.16}$$

subject to:

$$s_j(t) = s_j(t-1) + \sum_{i=1}^{|I_n|} \sum_{k=1}^{|T_n|} x_{i,j,k}(t) - \sum_{i=1}^{|I_n|} \sum_{k=1}^{|T_n|} x_{j,i,k}(t), \quad \forall\, j \in I \tag{3.17}$$

$$s_j(t) \leq N_{max,j}, \quad \forall j \in I_n \tag{3.18}$$

$$s_j(t) \geq N_{min,j}, \quad \forall j \in I_n \tag{3.19}$$

$$\sum_{k=1}^{|T_n(t)|} x_{i,j,k,u}(t) \leq nk_{i,j,u}^{max}(t), \quad \forall i,j \in I_n, i \neq j, \qquad \forall u \in U \tag{3.20}$$

$$x_{i,j,k}(t) \in \{0,1\} \tag{3.21}$$

$$i,j \in I_n, k \in T_n(t), u \in U$$

The objective function of the L-ILP1 aims at minimizing the cost of vehicle relocation performed by the stations $i \in I_n$ while locally satisfying constraints (3.10)-(3.15). The L-ILP1 is not always feasible because it can occur that constraints (3.19) are not verified: a) the vehicles available in the stations $j \in I_n$ are not enough; b) constraints (3.20) do not allow to move enough vehicles from station i to station j with $i, j \in I_n$. In these cases, the randomly chosen station n solves with its neighbours a different L-ILP, denoted by L-ILP2, where constraints (3.19) is relaxed, that is defined as follows:

L-ILP2

$$CRI2 = max \sum_{j=1}^{|I_n|} N_{min,j} \cdot s_j(t) \tag{3.22}$$

subject to:

$$s_j(t) = s_j(t-1) + \sum_{i=1}^{|I_n|} \sum_{k=1}^{|T_n|} x_{i,j,k}(t) - \sum_{i=1}^{|I_n|} \sum_{k=1}^{|T_n|} x_{j,i,k}(t), \quad \forall j \in I \tag{3.23}$$

$$s_j(t) \leq N_{min,j}, \quad \forall j \in I_n \tag{3.24}$$

$$\sum_{k=1}^{|T_n(t)|} x_{i,j,k,u}(t) \leq nk_{i,j,u}^{max}(t), \quad \forall i,j \in I_n, i \neq j, \qquad \forall u \in U \tag{3.25}$$

$$x_{i,j,k}(t) \in \{0,1\} \tag{3.26}$$

$$i,j \in I_n, k \in T_n(t), u \in U$$

The L-ILP2 is always feasible and aims to guarantee the minimum number of vehicles in each station $j \in I_n$, by maximizing the relocation of vehicles in the stations with more necessities.

Let $x^*_{i,j,k}$ with $i, j \in I_n, k \in T_n(t)$ be the solution provided by the L-ILP problems at iteration t. In figure 3.3 the steps of Algorithm 1 that is based on the defined L-ILP problem solutions are depicted.

Algorithm 1:

Step 1. **Set** $t = 0$ and **select** a station $n \in \mathcal{I}$ at random.
Set the initial vehicle distribution $x_{i,j,k}(0) = 0$, $\forall\, i, j \in \mathcal{I}$, and $s_j(0) = \hat{s}_j$

Step 2. **Set** $t = t + 1$ and
$T(t) = \{k \in \mathcal{K} \,|\, x_{i,j,k}(t-1) = 1, \forall i, j \in \mathcal{I}\}$.

Step 3. **If** constraints (19) and (20) are verified
then solve the L-ILP1 problem,
If $CRI1^* = CRI1(t-1)$
then set $x^*_{i,j,k} = x_{i,j,k}(t-1)$
End If
else solve the L-ILP2 problem,
End If

Step 4. Set $x_{i,j,k}(t) = x^*_{i,j,k}$, $\forall\, i, j \in \mathcal{I}_n$
$x_{i,j,k}(t) = x_{i,j,k}(t-1)\ \forall\, i, j \notin \mathcal{I}_n$

Step 4b. If $\exists\, k \in T(t) \,|\, x_{i,j,k}(t-1) = 1$ AND
$x_{i',j',k}(t) = 1$ AND $j = i'$
then set $x_{i,j',k}(t) = 1$

Step 5. Select at random a station $\hat{\imath} \in M_n$,
Set $n = \hat{\imath}$ and **go to** Step 2.

Figure 3.3: *Algorithm 1 in the distributed optimization approach*

At Step 1, Algorithm 1 starts at t = 0 by selecting a station $n \in I$ at random and by considering an initial vehicle distribution in the considered stations. At each iteration, a station $\hat{\imath} \in M_n$, belonging to the set of neighbours of the previously chosen agent, is randomly selected to perform a local optimization (Step 5) with its neighbours. The stations involved in the local optimization have to relocate the vehicles $k \in T(t)$, defined in Step 2 (i.e., the vehicles assigned to each station $i \in I$ at time t – 1). Now, if L-ILP1 is not feasible, then the stations in I_n have to solve the L-ILP2 problem (Step 3).
If L-ILP1 is feasible, then the stations solve the local optimization and Algorithm 1 checks if the solution improves the local objective function. In any case, the algorithm proceeds by updating the vehicles distribution (Step 4) and selecting randomly a new station belonging to M_n (Step 5).
At the end of Algorithm 1 and on the basis of its results, Algorithm 2 is executed, as described in the following, to assign the incentive levels to the performed relocation trips

according to the criterion adopted in the ILP1 and ILP2 problem that aims at minimizing costs for the sharing company and external costs for the society.

```
    Algorithm 2:
Step 1. Set i, j, k, u, h = 1, tmp_u = evr_u
Step 2. If D_{i,j} > D_{m,p}, ∀m, p ∈ 𝒥_n, m ≠ i, p ≠ j AND
        tmp_u ≠ 0
        then set MD_h = D_{i,j}, MDI_h = u, D = D\D_{i,j},
h = h + 1, tmp_u = evr_u − 1,
Step 3. If tmp_u = 0 then
            If u < |𝒰| − 1 then set u = u + 1
            End If
        End If
Step 4. If j < |𝒥_n|, then set j = j + 1 AND
        go to Step 2
        elseIf i < |𝒥_n|, then set i = i + 1 AND
        go to Step 2
        End If.
```

Figure 3.4: *Algorithm 2 in the distributed optimization approach*

3.3.4. Numerical experiments with EVs

This section shows numerical experiments of the EVRP in sharing systems solved with the proposed methods. The centralized optimization approaches are used, with ILP formulated in the previous sections.

The formulated ILP problems are solved by a standard solver, i.e. MatLab (LinProg), on an Intel-Core i5, 2,7 Ghz CPU with 8 GB RAM. The results of the ILP1, ILP2 and ILP3 are obtained in few seconds.

The simulation is designed with two scenarios considering different EVs:

electric car;

electric bike.

In each scenarios ILP1, ILP2 and ILP3 are solved. The parameters are the same in the two scenarios:

number of vehicles: $|K| = 60$;

number of stations: $|I| = 6$;

maximum number of parking slots and charging point per station: $N_{max} = 20$;

minimum number of EVs available per station: $N_{min} = 5$;

number of user available in the relocation process: $N_c = 200$;

the number of vehicle in each station before the relocation process: $\hat{s}_j$, are present in Table 3.2;

the relocation cost per kilometre is: c = 1 [€/km];

the distances between all the stations, for each departure station i and arrival station j, $D_{i,j}$, are reported in Table 3.3;

the values of the battery autonomy of each *k-th* EV, in station i, $a_{i,k}$ are reported in Table 3.4.

Comparing Table 3.3 and Table 3.4 is possible to identify unfeasible relocation trips.

In the case of relocation with users involvement with incentive scheme, these additional parameters are considered:

number of incentive levels equal to 3

incentive rate i_{nu} for the each level is respectively equal to: i) 50%, ii) 70% and iii) 90% of the relocation cost performed by company staff;

user acceptance rate r_u for each incentive level reported in Table 3.5.

The cardinality of the incentive levels set is |U| = 4, with the last element referred to the relocation performed by company staff. In this case a value equal to 100% of the relocation cost is considered.

The external costs in table 3.6, are based on values proposed in van Essen et al. (2019), according the following assumption: with the use of car it is considered values for passenger car, fuelled by petrol, small, Euro 3 used in urban area and in urban road; while the Light Commercial Vehicle (LCV) considered is fuelled by petrol, Euro 3. In addition for noise pollution night and thin traffic situation is considered; for congestion, near capacity traffic situation and trunk road is used.

The use of car is considered in the staff relocation process performed in the EVs sharing system. Indeed the LCV is considered in the staff relocation process performed in the ELVs sharing system.

	EVs initial number (ŝ)
Station 1	18
Station 2	14
Station 3	2
Station 4	4
Station 5	3
Station 6	19

Table 3.2: *Initial number of EVs/ELVs per station*

	S1	S2	S3	S4	S5	S6
S1	-	5	8	4	4	9
S2	5	-	6	7	10	10
S3	8	6	-	3	8	5
S4	4	7	3	-	3	2
S5	4	10	8	3	-	4
S6	9	10	5	2	4	-

Table 3.3: *Distance between stations in km*

Station	EV	Autonomy km	Station	EV	Autonomy km	Station	EV	Autonomy km
1	1	4	2	21	5	5	41	4
1	2	1	2	22	4	6	42	1
1	3	2	2	23	5	6	43	1
1	4	1	2	24	4	6	44	1
1	5	1	2	25	3	6	45	1
1	6	2	2	26	2	6	46	1
1	7	3	2	27	4	6	47	1
1	8	2	2	28	3	6	48	1
1	9	3	2	29	10	6	49	1
1	10	2	2	30	10	6	50	1
1	11	3	2	31	10	6	51	1
1	12	3	2	32	10	6	52	1
1	13	2	3	33	2	6	53	1
1	14	2	3	34	2	6	54	1
1	15	3	4	35	3	6	55	1
1	16	3	4	36	3	6	56	1
1	17	3	4	37	3	6	57	1
1	18	2	4	38	3	6	58	1
2	19	5	5	39	4	6	59	1
2	20	5	5	40	4	6	60	2

Table 3.4: *EVs/ELVs battery autonomy*

	Acceptance rate of users	Relocatable EVs (evr_u)
Incentive level 1	0,5%	1
Incentive level 2	0,5%	1
Incentive level 3	1%	2

Table 3.5: *User acceptance rate and relocatable EVs/ELVs*

	Company relocation with car [€/km]	Company relocation with LCV [€/km]
Congestion (Table 48 in van Essen et al. (2019))	0,174	0,261
Accidents (Table 12 in van Essen et al. (2019))	0,0141	0,0076
Air pollution (Table 19 in van Essen et al. (2019))	0,0017	0,003
Noise Pollution (Table 37 in van Essen et al. (2019))	0,021	0,074
Climate change (Table 28 in van Essen et al. (2019))	0,0105	0,034
Well-to-tank emissions (Table 53 in van Essen et al. (2019))	0,0039	0,0128
Total External Costs	0,2252	0,3904

Table 3.6: *External costs for the relocation task of EVs and ELVs*

SCENARIO 1 – Electric car sharing system

An electric car sharing system is considered in the first scenario. Firstly, we solve the relocation problem in the case of only company staff with ILP1. In this scenario is considered the company staff travel with a car in the same distance of the relocation EVs to pick-up the operator. The relocation cost including external costs for the sharing company is 41,66 €/day. The performed process is shown in figure 3.5 where lines and red numbers indicate the relocation task from one station to another by the company staff.

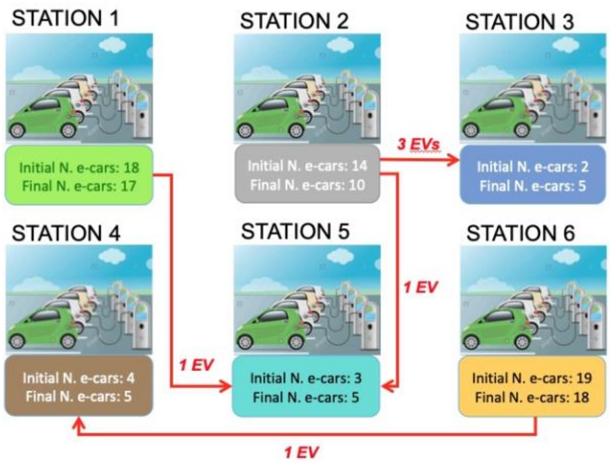

Figure 3.5: *Electric car relocation process with company staff (Scenario 1)*

The relocation process involving users in the centralized optimization approach is solved by ILP2. The total relocation cost, including external costs, is 31,86 €/day. This value also included the reward for users equal to (i_{nu} * $C_{i,j}$) =20 €/day. We note that the total company relocation cost is cut of about 24%. The performed process is shown in figure 3.6 where lines and red numbers indicate the relocation task from one station to another by the company staff and the lines and green numbers indicate the relocation task from one station to another by users.

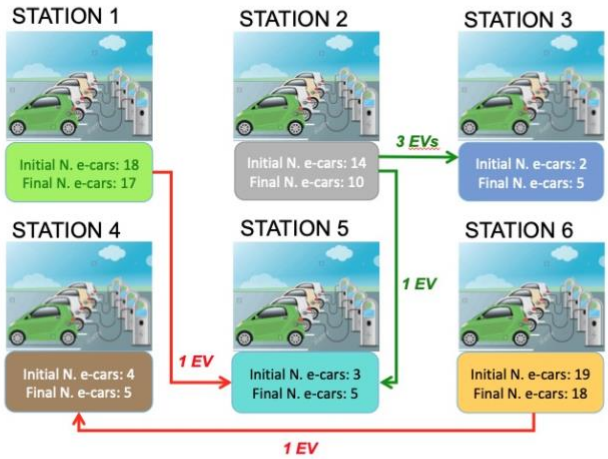

Figure 3.6: *Electric car relocation process with user involvement (Scenario 1)*

3.3.5. Numerical experiments with ELVs

SCENARIO 2 – Electric bike sharing system

An electric bike sharing system is considered in the second scenario. The relocation with only company staff is performed with ILP1. The total relocation cost, including external costs is 34,76 €/day. The performed process is shown in figure 3.7 where lines and red numbers indicate the relocation task from one station to another by the company staff.

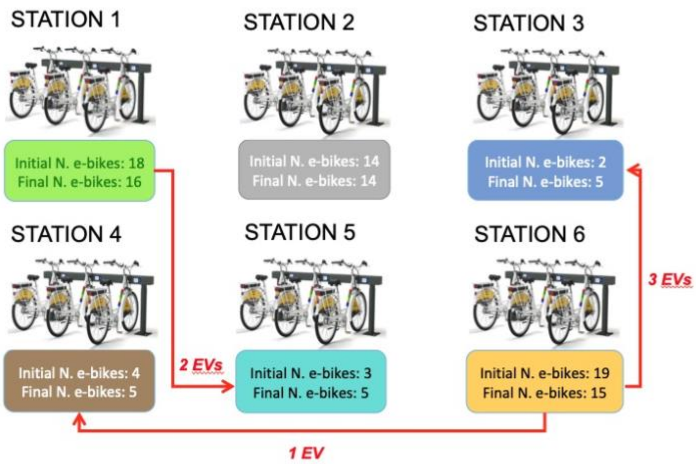

Figure 3.7: *Electric bike relocation process with company staff (Scenario 2)*

The relocation process involving users in the centralized optimization approach is solved by ILP2. The total relocation cost, including external costs, is 30.87 €/day. This value also included the reward for users equal to (i_{nu} * $C_{i,j}$) = 16.20 €/day. We note that the total company relocation cost is cut of about 12%. The performed process is shown in figure 3.8 in which lines and red numbers indicate the relocation task from one station to another by the company staff and the lines and green numbers indicate the relocation task from one station to another by users.

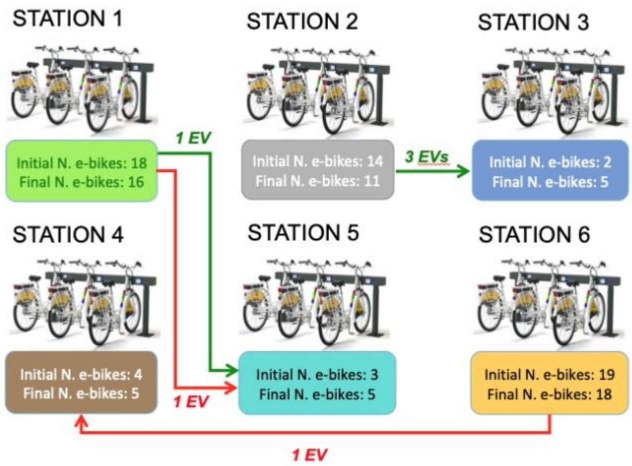

Figure 3.8: *Electric bike relocation process with user involvement (Scenario 2)*

3.3.6. Benefits of the users involvement approach

The simulations in the two scenarios to solve the EVRP in a sharing system with users involvement propose significant results: the sharing company reduces the total relocation cost (including external costs) or at least has the same value. The results achieved are based on a new concept widely used in recent years, namely crowd-sourcing paradigm. The users involvement, changes the vision of the service, and considers customers of the sharing service, from consumer to prosumer, with an incentive scheme able to involve them in the relocation task. Moreover, the incentive scheme proposed is not a full cost for the sharing company because the rewards are credits to use the sharing service; hence the mechanism engage the users to the service.

In addition, the proposed approach ensures the same high level of service provides to the company in the case of relocation with staff only. A further result with the proposed approach is the optimization of the EVs relocation among the available stations.

The outputs of the simulation in Scenarios 1 are present in Table 3.7.

	Relocation by staff [€/day]	Relocation with user involvement [€/day]
Total Relocation Cost	41,66	31,86
Relocation cost for the company	34,00	26,00
Relocation External Costs	7,66	5,86
Incentive for users	-	20,00

Table 3.7: *Results of EVs relocation simulation (Scenario 1) with ILP1 and ILP2.*

The outputs of the simulation in Scenarios 2 are present in Table 3.8.

	Relocation by staff [€/day]	Relocation with user involvement [€/day]
Total Relocation Cost	34,76	30,87
Relocation cost for the company	25,00	22,20
Relocation External Costs	9,76	8,67
Incentive for users	-	16,20

Table 3.8: *Results of ELVs relocation simulation (Scenario 2) with ILP1 and ILP2.*

Different outcomes values are highlighted due to EVs and optimization approach considered: the use of electric car does not allow to relocate the vehicles with a van for company staff but driving the vehicle; therefore if some electric cars have low SoC, they can't use in the relocation process. Indeed the e-bikes and other ELVs or EVs transportable by van, can be relocate also with a low SoC. In addition, the use of centralized and distributed optimization approaches to solve the EVRP in sharing system, involving users is another factor.

3.4. Computational complexity analysis

The proposed method use several parameters and in case of a huge system, especially for metropolitan city, these numbers increasing considerably.

This is not an uncommon case as the spread of EVs sharing system is taking place mainly in large urban areas. Therefore the number of stations or EVs reaches high values quickly and with other parameters, especially in the ILP2, the complexity increase.

A study on the computational complexity of the centralized optimization problem formulated is performed. The analysis considers a different number of the two main parameters: i) stations; ii) EVs. In the following table, a trend of the computational complexity is shown with different number of these parameters.

		Number of Evs		
		100	500	1000
Number of stations	5	1	1	1.1
	10	1	1.15	1.85
	20	1.14	2.57	7.5
	30	1.55	10.5	88
	50	5.36	88	-

Table 3.9: *Computational time of centralized optimization problem with different number of stations and EVs.*

The analysis shows an exponential computational complexity related to the number of parameters considered. In the last case, with 50 stations and 1000 EVs, the calculator cannot compute the problem. Therefore, in case of high number of parameters, it may be appropriate to use a different optimization approach, in order to avoid problem with solver.

The use of distributed optimization approach allows to considerably reduce the computational complexity of the problem with a very significant advantages: the optimization process is performed offline; therefore in some case is necessary to implement the output more time. A faster calculation process would allow more advantages.

3.5. Conclusions on the results obtained

In this chapter the EVRP with an innovative methodology based on an incentive system to involve users is formalized and solved (Fanti et al., 2019).

An innovative electric vehicle (EV) relocation method to minimize the total relocation costs, including external costs, in a sharing system involving users with is defined. The method is based on an incentive approach that offers users an increasing incentive bid as long as some users agree. In the case no user accepts, the company relocation staff perform the process, without any disservice. To this aim, the centralized and distributed optimization approaches are formulated as Integer Linear Programming problems. In particular, the ILP1 allows to solve the EVRP with the company staff, while the ILP2 upgrades ILP1, by involving customers in the relocation process with an incentive scheme. In case of ILP2, a distributed optimization is formalized. It is adopted in order to face with a large number of variables (EVs, stations), since in these cases the high computational complexity does not allow to solve the problem by means of a centralized optimization approach (see table 3.8). The distributed optimization can be used in very large contexts where the calculator is unable to produce results, as mentioned in the previous paragraph. The EVs sharing users can travel for free and receive rewards to accept and complete correctly the relocation of the vehicle. The approach adopted is based on the crowd-sourcing paradigm, which allows to perform the EVs relocation at a lower cost. It is an advantage both for sharing company, for society (lower external costs) and for users that can use the credits for the sharing service. The methodology allows ensuring the same quality of service in the sharing system also in case no user is availability for the relocation task since in this case the company staff performs it. The numerical experiment shows the benefits of the proposed methodology to the company relocation cost in two scenarios, with EVs (e-cars) and ELVs (e-bikes).

3.6. Chapter references

Angelopoulos, A., Gavalas, D., Konstantopoulos, C., Kypriadis, D., Pantziou, G. (2016). Incentivization schemes for vehicle allocation in one way vehicle sharing systems. IEEE International Smart Cities Conference (ISC2), Trento, Italy, pp. 1-7.

Bianchessi, A. G., Formentin, S., Savaresi, S. M. (2013). Active fleet balancing in vehicle sharing systems via Feedback Dynamic Pricing. 16th International IEEE Conference on Intelligent Transportation Systems (ITSC 2013), The Hague, Netherlands pp. 1619-1624.

Boldrini, C., Incaini, R., Bruno, R. (2017). Relocation in car sharing systems with shared stackable vehicles: Modelling challenges and outlook. IEEE 20th International Conference on Intelligent Transportation Systems (ITSC), Yokohama, Japan, pp. 1-8.

Bruglieri, M., Colorni, A., Lu`e, A. (2014). The Vehicle Relocation Problem for the One-way Electric Vehicle Sharing: An Application to the Milan Case," Procedia - Social and Behavioural Sciences, vol. 111, pp. 18-27.

Brög, W., Erl, E., Ker, I., Ryle, J., Wall, R. (2009). Evaluation of Voluntary Travel Behaviour Change: Experiences from Three Continents. Transport Policy, vol. 16, no. 6, pp. 281–292.

Clemente, M., Fanti, M. P. , Iacobellis, G., Nolich, M., Ukovich, W. (2018). A Decision Support System for User-Based Vehicle Relocation in Car Sharing Systems. IEEE Transactions on Systems, Man, and Cybernetics: Systems, vol. 48, no. 8, pp. 1283-1296, August.

Cocca et al. (2018). Free Floating Electric Car Sharing in Smart Cities: Data Driven System Dimensioning. IEEE International Conference on Smart Computing (SMARTCOMP). 18-20 June, Taormina, Italy.

Deng, Y., Cardin, M.-A. (2018). Integrating operational decisions into the planning of one-way vehicle-sharing systems under uncertainty. Transportation Research Part C: Emerging Technologies, vol 86, pp. 407-424.

Di Febbraro, A., Sacco, N., Saeednia, M. (2019). One-Way Car-Sharing Profit Maximization by Means of User-Based Vehicle Relocation. IEEE Transactions on Intelligent Transportation Systems, vol. 20, no. 2, pp. 628-641, February.

Dror et al. (1998). Dror, M., Fortin, D., & Roucariol, C. (1998). Redistribution of self-service electric cars: a case of pickup and delivery. Rapport of research n. 3543, INRIA.

Fanti, M.P., Mangini, A. M., Roccotelli, M., Silvestri, B., Digiesi, S. (2019). Electric Vehicle Fleet Relocation Management for Sharing Systems based on Incentive Mechanism. IEEE 15th International Conference on Automation Science and Engineering (CASE2019), 22-26 August 2019, Vancouver, Canada.

Hafez et al. (2001). H afez, N., Parent, M., & Proth, J.M. (2001). Managing a pool of self service cars. Proceedings of the IEEE Intelligent Transportation Systems Conference Proceedings – Oakland (USA).

Homem de Almeida Correia, G., Antunes, A. P. (2012). Optimization approach to depot location and trip selection in one-way carsharing systems. Transportation Research Part E: Logistics and Transportation Review, vol. 48, Issue 1, pp. 233-247.

Jorge, D., Correia, G. H. A., Barnhart, C. (2014). Comparing Optimal Relocation Operations With Simulated Relocation Policies in One-Way Carsharing Systems. IEEE Transactions on Intelligent Transportation Systems, vol. 15, no. 4, pp. 1667-1675, August.

Kek, A. G. H., Cheu, R. L., Meng, Q., Fung, C. H. (2009). A decision support system for vehicle relocation operations in carsharing systems. Transportation Research Part E: Logistics and Transportation Review, vol. 45, Issue 1, pp. 149-158.

Nourinejad, M., Roorda, M. J. (2014). A dynamic carsharing decision support system. Transportation Research Part E: Logistics and Transportation Review, vol. 66, pp. 36-50.

Nourinejad, M., Zhu, S., Bahrami, S., Roorda, M. J. (2015a). Vehicle relocation and staff rebalancing in one-way carsharing systems," Transportation Research Part E: Logistics and Transportation Review, vol. 81, pp. 98-113.

Nourinejad, M., Roorda, M. J. (2015b). Carsharing operations policies: A comparison between one-way and two-way systems. Transportation, vol. 42, no. 3, pp. 497-518.

Pal, A., Zhang, Y. (2017). Free-floating bike sharing: Solving real-life large-scale static rebalancing problems. Transportation Research Part C: Emerging Technologies, vol. 80, pp. 92-116.

Pfrommer, J., Warringtion, J., Schildbach, G., Morari, M. (2014). Dynamic Vehicle Redistribution and Online Price Incentives in Shared mobility Systems. IEEE Transactions on Intelligent Transportation Systems, Vol. 15, Issues 4, pp. 1567-1578.

Ren et al. (2019). A novel dynamic pricing scheme for a large-scale electric vehicle sharingnetwork considering vehicle relocation and vehicle-grid-integration.

Santos, A. G., Càndido, P. G. L., Balardino, A. F., Herbawi, W. (2017). Vehicle relocation problem in free floating carsharing using multiple shuttles. IEEE Congress on Evolutionary Computation (CEC), San Sebastian, Spain, pp. 2544-2551.

Schulte, F., Voß, S. (2015). Decision Support for Environmental-friendly Vehicle Relocations in Free-Floating Car Sharing Systems: The Case of Car2go," Procedia CIRP, vol. 30, pp 275-280.

Thaler, R. H. , Sunstein, C. (2008). Nudge: Improving Decisions about Health, Wealth, and Happiness. Book, Yale University Press, April.

Troglia, M. (2018). EPPI – Enhanced Platform for Positive Incentives. Presentation in the ELVITEN Workshop, Quaeryon, 27 September, Genoa, Italy.

van Essen, H.P., van Wijngaarden, L., Schroten A., Sutter, D., Bieler, C., Maffii, S., Brambilla M., Fiorello, D., Fermi, F., Parolin, R., El Beyrouty, K. (2019). Handbook on the external costs of transport. Version 2019. CE Delft. European Commission, Directorate-General for Mobility and Transport.

Xu, M., Meng, Q., Liu, Z. (2018). Electric vehicle fleet size and trip pricing for one-way carsharing services considering vehicle relocation and personnel assignment. Transportation Research Part B: Methodological, vol. 111, pp. 60-82.

Weikl and Bogonberger (2012). Relocation strategies and algorithms for free-floating Car Sharing Systems. 15th International IEEE Conference on Intelligent Transportation Systems. 16-19 September 2012. Anchorage, AK, USA.

Zakaria, R., Dib, M., Moalic, L., Caminada, A. (2014). Car relocation for carsharing service: Comparison of CPLEX and greedy search. IEEE Symposium on Computational Intelligence in Vehicles and Transportation Systems (CIVTS), Orlando, FL, pp. 51-58.

4. Optimization of last mile logistics

The optimization of the last mile logistics is a challenge in the freight transport. Last mile logistics is the less efficient stage of the supply chain and comprises up to 28% of the total delivery cost. Therefore, the improvement of the last mile logistics and a significant externalities reduction are very important challenges. In this chapter a new incentive-based optimization approach for the goods relocation and cross-distribution in urban areas is presented. Numerical experiments show the internal and external costs reduction achievable by adopting the proposed approach.

4.1. Last mile logistics

City logistics, according to Taniguchi et al. (2001), is defined as the process of totally optimizing the logistics and transport activities by private companies with the support of advanced information systems in urban areas; here, the optimization considers the traffic environment, the traffic congestion, the traffic safety, and the energy savings within the framework of a market economy. Taniguchi (2014) studies the application of innovative technologies of ICT and Intelligent Transportation System (ITS) in a city logistics concept: urban freight transport management and joint delivery systems are the main outcomes.

Today, last mile logistics is based on a new vision of the freight transport, defined smart logistics, according to the development of the smart mobility. It is based on the new ICT technologies and sensors able to monitor several parameters in real time, systems and innovative approaches to improve load factor, to increase the system efficiency and to reduce externalities in the cities. Almost all these innovations have been developed in the Industry 4.0 framework, and are fundamentals of the smart logistics. Ablola et al. (2014) and Schau et al. (2015) analyse the great potential of the smart logistics with EV and ICT systems in urban areas, in order to reduce transport externalities.

4.2. Literature review on the last mile logistics innovations

The analysis carried out on the scientific literature of the last five years about last mile logistics in urban area and in smart cities allows to classify the innovations able to reduce transport externalities costs into five main categories: innovative vehicles, the proximity stations or points, collaborative urban logistics, optimization of transport management and routing, and innovations in public policies and infrastructures. They are detailed in the following Section.

4.2.1. Recent vehicles in the last mile logistics

Commercial EVs

The commercial EVs are important features to reduce urban externalities produced by last mile delivery activities. Menga et al. (2013) propose a reduction externalities evaluation with commercial EVs in the urban area, while Lebau et al. (2013) present a performance assessment and comparison between electric and diesel truck. Sachs et al. (2016) analyse the considerable interest of the market for commercial ELVs. Davis and Figliozzi (2013) study the economic aspect related to commercial EVs: purchase costs are more expensive than conventional diesel trucks, but the operating costs of conventional trucks are higher than EVs with benefits in log-term. Feng and Figliozzi (2013) consider that the EV maintenance is related to life and long-term costs of batteries as well as limited distance without recharging. In addition, Mirhedayatian and Yan (2018) propose an assessment of support policies for EVs in urban freight transport.

Industry 4.0

ICT technologies are very useful tools in the freight transport and in the last mile delivery. Barreto et al. (2017)

The new vehicles are equipped with several ICT technologies and sensors in order to manage real time all parameters and provide useful information to the driver such as predictive maintenance if some parameters are out of standard, routing optimization for accidents or deliveries change, and so on.

Autonomous Vehicles

Autonomous and Unmanned Systems are new vehicles with autonomous driving, named also drones. Transport and delivery companies have tested drones to deliver parcels: DHL with PaketKopter (2013), Amazon with Amazon PrimeAir analysed by Welch (2015), Google with Project Wing (2012), and recently GeoPoste with GeoDrone (2015). In according to Asma et al. (2017), new issues in logistic support services for drones in urban delivery are opened. Another interesting project is YAPE (2017), where a ground drone-robot is used in the last mile logistics for parcels delivery in urban area. In addition, other projects with the same objective are developing, as the project STARSHIP (2014).

4.2.2. Proximity stations or points

The use of proximity stations or proximity points is an innovative strategy to improve the last mile delivery efficiency, particularly to distribute small and medium goods size. This approach, according to Edwards et al. (2009), is based on the use of little depot stations (electronic self-service locker) where goods can be stored when the customers are not at home until they can pick them up, thus avoiding the risk of unsuccessful delivery.

The proposed idea reduces the distance travelled by trucks in the delivery activities and increases their load factor. Moreover, the stations can be filled during the night, when the traffic is low. This approach leads to both economic and environmental benefits. ICT give all information automatically in real time: parcel location, availability in the locker and pick up.

Dell'Amico and Hadlidimitriou (2012) propose a study on the modular bento box system, removable modules, with a fix part and a chassis subdivided in a few modules, similar to the idea of proximity stations. This system is delivered in transhipment areas, closing to the customers, from depot, in order to reduce the delivery route.

A similar strategy are the parcel lockers; they achieved great use in recent years as in the case of Polish InPost Company system as shown by Iwan et al. (2016); these systems have been adopted by many logistics operators such as DHL for customers delivery, Austrian Post with Post24 Parcel Machines, Amazon with Amazon locker and others. In addition, several e-seller companies (e.g, Amazon, eprice and others) are expanding the concept of the proximity point considering also other places such as picks & pay point.

International retailers using online sailing channels (e.g. MediaWorld, Zara and others) give to the customers the opportunity to buy on website and pick up the goods, after some days, in the physical store without home delivery.

Wang et al. (2016) propose an innovative approach of proximity station, with the pick-own-parcel station (pop-station). The idea is based on the use of stations and ICT to delivery parcels and on the crowd-workers to enhance the last mile delivery. A certain amount of money will be rewarded to a worker for the delivery according to the additional travel cost from his/her historical route patterns. The goal is to assign all the parcels in the pop-stations to the most convenient workers so as to minimize the total reward paid by the logistic companies. As in other sharing economy scenario, the main aim of this application is to maximize the resource use on the base of a collaborative approach.

4.2.3. Collaborative and cooperative urban logistics

The Collaborative urban logistics concept is an important aspect in the last mile delivery process able to better consolidate and synchronize the existing resource. Cooperative urban logistics concept is based on the sharing of the resource and the revenue in the last mile delivery. Gunasekaran et al. (2015) state that the coordination is a key element in this process to ensure a synergy between the actors. In an eco-friendly vision it is significant in order to reduce externalities: the main concept is sharing the resources, infrastructures and vehicles to make the last mile delivery in urban area. Several authors propose different approaches to improve this strategy: de Souza et al. (2014) suggest an idea similar to the service of codeshare agreement among different airline companies in the airports. The main advantages are: investments and management the costs saving, better use of resources, performance improvement of deliveries in urban areas. Liakos and Delis (2015) propose an interactive freight pooling service to reduce undesirable effects and the cost of freight transport in urban area. The use of Urban Consolidation Centre (UCC) is the first application of this strategy in the early 1970s. New organizational model and ICT tools for the last mile delivery are improving the use of the UCC in many cities. Handoko et al. (2014) propose an interesting approach based on tasks and a profit-maximizing auction mechanism, to determine the amount of the demand to be fulfilled. Zunder et al. (2016) suggest the use of UCC in a medium-size city with ICT tools with a Design and Monitoring Framework methodology to engage stakeholders with policy, vehicles and IT technology to improve the sustainability of urban freight delivery.

Chatterjee et al. (2016) indicate a variant of the collaborative and cooperative urban logistics concept, in which the delivery of small and medium size packaged goods is carried out using public transport means.

The urban deliveries of parcels, especially in the food sector, have seen the growth of two main kinds of online platforms: "aggregators", emerged about 15 years ago, and "new delivery" players, appeared in 2013. Both allow consumers to place orders from a variety of restaurants. Aggregators simply take orders from customers and route them to restaurants, which handle the delivery themself. In contrast, Hirschberg et al. (2016) analysed that new delivery players build their own logistics networks, providing delivery for restaurants that do not have their own fleets. In this context, several new delivery players have been set up, such as Deliveroo, Just-eat, foodpanda, UberEATS, and they use bikes as means of transport.

4.2.4. Public policies and infrastructures

The use of specific policies and regulation is fundamental to reduce externalities, in particular congestion, noise and air pollution, produced by delivery activities in urban area. The ICT and Industry 4.0 can be used to control smart cities, in particular video and data on vehicles, flows, and traffic allow the municipal authorities to be able to modify the traffic conditions in real time. Djahel et al. (2015) propose examples of different approaches to the traffic management systems for smart cities, such as a traffic management system able to collect data from several sensors, processing and aggregating data to improve the system. Moreover, a smart traffic light management system is an interesting research field, since the synchronization of multiple traffic light systems at adjacent intersections is a complex problem given the various parameters involved. Ghazal et al. (2016) propose an approach to solve this problem using Infra-Red sensors and accomplishing dynamic timing slots with different levels. However, more research is still needed on this topic because there are several open issues.

Many cities adopt the time windows in city centre are to reduce freight transport externalities. Routing and scheduling studies allow to improve the delivery performance with time windows.

Urban pricing area and mobility credits are recent solutions adopted in many cities to reduce the number of vehicles in the city centre or in specific city zones. Based on the

European principle of "pay for use", different urban pricing systems have been developed: i) pricing area, ii) cordon pricing and iii) distance-based pricing are the main forms. They differ for the application of the charging cost: in the first case the vehicle pays for a daily access to the restricted area; in the second case the vehicle pays for every cross of the restricted area; in the third case the cost is related to the distance travelled by the vehicle in the restricted area. Mobility credits are a particular form of incentives based on permits and not on restrictions: a limited budget is allocated to every citizen by public administration and a self-regulation system is adopted. Cities currently adopting these systems and regulations for last mile delivery are still few, and their potentialities deserve to be more investigated in the scientific literature.

4.2.5. Optimization of transport management and routing

The developing of ICT and industry 4.0 with a large number of information (big data) provided by sensors and IoT, can be processed to optimize environmental, economic and social performance. Taniguchi et al. (2015) consider big data and analysis, Decision Support Systems, Energy saving technologies, Co-modality, land use and freight, road pricing as technological innovations and practices allowing optimizing the city logistics.

Pal and Kant (2016) present optimization strategies in urban delivery adopting Autonomous Electric Vehicles (AEV). The proposed model is based on the traveling salesman problem, pickup and delivery problem and ride-sharing problem.

Erdogan and Miller-Hooks (2012) formulate and solve a green vehicle routing problem to aid organizations with alternative fuel-powered vehicle fleets in overcoming difficulties that exist as a result of limited vehicle driving range and limited refuelling infrastructure. In addition, the use of EVs in last mile delivery needs to consider the autonomy of vehicles, the charging point position and the recharging time. In the scientific literature, EVRP (also named green vehicle routing problem) is solved using two different approaches: fixed autonomy and recharging option. Neaimeh et al. (2013), and Van Duin et al. (2013) propose the first approach, aims to ensure energy for vehicles to return to the depot. In the second approach, a vehicle routing problem (VRP) with pick-up and delivery is solved, and the number of required recharges is computed by dividing the total distance by the vehicle range. Thanks to the increase of EV capacity, the last approach has been less investigated in the recent years.

Some studies show that delivery activities can have the same performance even with time windows, if it is used a correct setting of the VRP: Schneider et al. (2014) present and solve the EVRP with time windows and recharging stations. Hiermann et al. (2016) propose and solve a mix vehicle routing problem with time windows, recharging stations, and electric fleet with different battery capacity vehicles and purchase cost. Rezgui et al. (2015) propose the electric modular fleet size and mix vehicle routing problem with time windows in which the recharging at customer location is considered; genetic algorithms-based approach to solve the problem is formulated.

Recent research findings on last mile delivery issue classified into the five categories above discussed are in the Table 4.1.

Logistics Innovation	Paper, year	Research finding
Innovative vehicles	Menga et al. (2013)	Assessment of the potential benefits of electric vehicles, especially in the urban delivery goods
	Lebeau et al. (2013)	Assessment of the electric vehicles in an urban delivery centre by means of a discrete event model simulation and different scenarios
	Schau et al. (2015)	Assessment of the small and medium size fully electric vehicles used for the last mile in freight transport handling with ICT-support
	Ablola et al.(2014)	Multi-dimensional drivers and challenges of the use of electric freight vehicles in urban areas
	Sachs et al. (2016)	Assessment of the market of light electric vehicles and the potential application with a forecast scenario
	Davis and Migliozzi (2013)	Analysis of the economic and technological factors for electric commercial vehicles compared with diesel trucks for several scenarios
Proximity station	Wang et al. (2016)	A crowd-tasking model based on large-scale mobile with citizen workers is used in the last-mile delivery
	Dell'Amico and Hadlidimitriou (2012)	Innovative logistics model for urban deliveries: using two vehicles typology (freight bus and delivery van) and modular BentoBox
	Iwan et al. (2016)	Analysis of the efficiency in parcel lockers as last mile delivery solution
Collaborative and cooperative logistics	de Souza et al. (2014)	Synchronized last mile concept with multi-objective planning
	Liakos and Delis (2015)	A model of delivery network through interactive interfaces
	Handoko et al. (2014)	Regulation and thinning profit margin in the Urban Consolidation Centre
	Chatterjee et al. (2016)	A system model which uses existing Public Transport facility of a city of packaged goods
Public policies and infrastructures	Djahel et al. (2015)	Improve the efficiency of Traffic Management Systems through advances in sensing, communication and dynamic adaptive technologies
	Ghazal et al. (2016)	System to evaluate the traffic density using IR sensors and accomplishes dynamic timing slots with different levels
	Schneider et al. (2014)	Electric vehicles routing problem with time windows and recharging stations
	Hiermann et al. (2016)	Mix vehicle routing problem with time windows, recharging stations, and electric fleet with different capacity vehicles
	Rezgui et al. (2015)	Adoption of an electric modular fleet size and mix vehicle routing problem with time windows
Optimization of transport management and routing	Pal and Kant (2016)	Minimization of empty vehicles kilometers with automated electric vehicle to provide both people transport and fresh food delivery
	Taniguchi (2014)	Application of innovative technologies of ICT and ITS to city logistics
	Taniguchi et al. (2015)	New opportunities and challenges for city logistics
	Erdogan and Miller-Hooks (2012)	A green Vehicle Routing Problem
	Neaimeh et al. (2013)	Accurate range prediction for electric vehicles in a routing system that could extend driving range of electric vehicles
	Van Duin et al. (2013)	Determination of the optimal fleet size to transport a known demand of cargo, located at a central depot, to a known set of recipients using vehicles of different types

Table 4.1: *Last Mile Logistics innovations to reduce externalities in urban areas.*

4.3. Goods relocation and cross-distribution in the last mile logistics

The goods relocation activity is a significant process in the last mile logistics. In urban areas, there are several shops and retailers that sell the same products to the citizens. In recent years, the phenomenon of opening more stores of the same company in the same city has spread. Jansson and Power (2010) explain that several brands opened different stores in many cities, to ensure their customers the same items. The different stores of the same brand in the city are different: some are smaller stores, while others are larger ones and used by the company as a hub to supply other stores.

It is often necessary to move the goods from one store to another, even in the same day, in case of lack of products in some stores, different model and limited edition in some retailer. Goods relocation management is a very important daily activity to provide consumers with a more efficient sales service. Therefore, frequently company trucks are used to carry out this logistic service and so the goods relocation among retailers located in the same city causes transport externalities in urban area. In many cases, the relocation activity is carried out with heavy and polluting vehicles. The fashion retailers in the city are an example of stores where the goods relocation is a significant activity.

The delivery of some goods requires the use of appropriate transport vehicles and procedure to ensure the integrity of the products. Perishable goods and drugs are examples of this. Rijpkema et al. (2014), Bogataj et al. (2005), Al Shamsi et al. (2014), Le et al. (2013), Hsu et al. (2007) analyse the transport problems of perishable goods related to the stability and perturbations of parameters to have the appropriate quality (with acceptable levels of product waste). Furthermore, the inventory routing problems of perishable goods to reduce environmental impact and CO_2 emissions from vehicles using time-windows are considered. Pal and Kant (2016) propose a transport model based on the adoption of automated electric vehicles for both people transport and fresh food delivery that minimizes empty kilometres, while meeting the constraints on passenger transit time and food freshness, in a smart urban area.

The goods cross-distribution in the case of an automated city warehouse for the delivery of specific goods, as mentioned, is carried out with trips between the warehouse and the individual stores. The pharmacy sector is a sensitive industry in which drugs delivery is a significant activity. Nowadays, the supply chain for the drugs distribution is efficient and widespread. It allows to deliver the required medicines in few hours, but to increase the service quality and reduce the cost, new strategies are needed. In the last years, several technological changes have been proposed in the pharmacy sector. Automated dispensing systems are available in pharmacy for over a decade and have been applied to a range of repetitive technical processes with high risk of error, including record keeping, item selection, labelling and dose packing. Most of the applications of this technology have been proposed at local level, such as in hospital, pharmacies or single-site community pharmacies until today. However, Spinks et al. (2016) suggest that the widespread implementation of a more centralised automated dispensing model, such as the 'hub and spoke' model currently being debated in the United Kingdom, could cause a 'technology shock', delivering industry-wide efficiencies, improving medication accessibility and lowering costs to consumers and funding agencies.

The goods relocation and distribution in urban area can be improved thanks to the new strategies and approaches. An IT-enabled open innovation is the crowdsourcing. Chesbrough (2003) and West et al. (2014) consider open innovation as a paradigm in which organizations systematically look for outside ideas relevant to their internal problems and/or external ways to market their own ideas. Howe (2006) and Howe (2008) define crowdsourcing as a process in which organization outsources tasks that have traditionally been performed by the organization's members to a crowd of external individuals. Estellés-Arolas and Gonzalez Ladron de Guevara (2012), based on a review of more than 200 definitions, proposes the definition of crowdsourcing as a type of participative online activity in which an individual, an institution, a non-profit organization, or a company proposes to a group of individuals of varying knowledge, heterogeneity, and number, via a flexible open call, the voluntary undertaking of a task.

The crowdsourcing paradigm can be applied to improve the goods relocation and distribution in urban area involving customers and users. In literature there is a gap on this topic and in-depth studies need to be developed.

In order to contribute to the reduction of the externalities caused by last miles logistics activities in urban areas, innovative models of both good relocation and cross-distribution in the cities have been developed. According to the classification proposed in Section 4.2, models of goods relocation proposed belong to the research category of "optimization of transports management" (Section 4.4). In "proximity stations" and "collaborative and cooperative logistics" categories can be classified the innovative models of goods cross-distribution developed (Section 4.5).

4.4. Innovative goods relocation models with optimization approaches

Increasing the efficiency of the goods relocation activity would lead to an improvement in environmental terms and a decrease in urban externalities.

The goods relocation problem is dealt with an innovative incentive system approach, based on crowdsourcing paradigm, which aims to reduce the transport externalities in urban area, relocation costs for the company, and attracting and retaining customers. The loyal customers of a brand become active part of the relocation process with awards for both company and customers. The idea here is to offer loyal customers a prize in the form of a discount on the purchase of goods in the retailers as a reward for the package delivery from one store to another (Silvestri et al., 2019c).

The proposed loyal customer incentive system can be provided through an IT application for smartphone and is illustrated by the procedure in Fig. 4.1. In the first phase, an incentive value is proposed to the loyal customers who want to participate in the goods relocation process. Two cases can happen: 1) at least one user agrees to pick-up the goods from one store and leave them to another one for a reward in the form of voucher on purchases within the stores of the same brand (if more than one user wants to participate in the relocation, the proposed method will choose the first one has accepted); 2) no user agrees in the relocation process, therefore a new increased incentive value is proposed to all users with a notification (this step can be repeated several times if the company proposes more incentive levels). If the second step is concluded and no user has accepted the incentive, the company will use the trucks to perform the relocation activity.

The goods relocation service is implemented only with loyal customers to avoid problem with deliver and with the integrity of items. The company has all info about these customers and if problems are encountered, they will charge the goods value and will no longer involve them in the relocation process.

The goods relocation cost can be reduced by the proposed incentive system or at least keep them unchanged. The goods relocation process in city retailers with an incentive system is shown in Fig. 4.1.

The set of incentive proposals (levels) is $U \in Z^{+}$, with cardinality |U|. The incentive levels designed by the company are $u \in U$, u = 1, ... , |U| - 1. In addition, the last element of U does not represent an incentive value for customer but it is used to enable the relocation process performed by the company trucks.

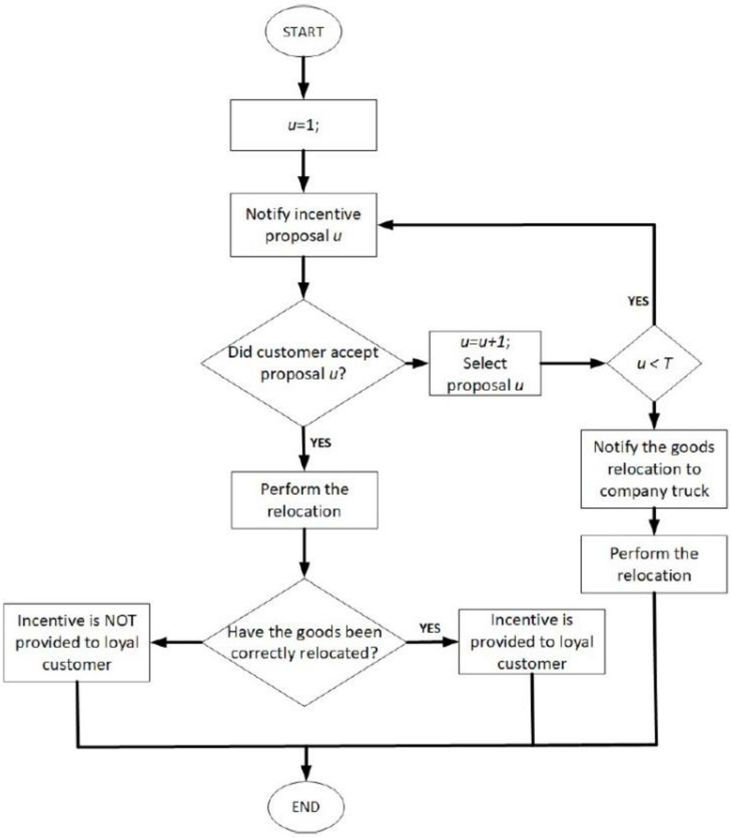

Figure 4.1: *Algorithm of incentive system process*

4.4.1. Goods relocation incentive schemes

The incentive schemes in the goods relocation can be applied as a useful tool able to involve loyal customers in this activity. The incentive system is designed with defined rules, based on awarding points or credits for virtuous behaviour that can be spent in the form of voucher to purchase goods in the retailers. The incentive scheme is developed through a platform and a dedicated App for smartphone based on a robust ICT system. The proposed approach allows to reduce externalities in urban area, involving loyal customers in the goods relocation process. Loyal customers who move from one area of the city to another can deliver the goods assigned to them, with a consequent reduction in the travel of the company's trucks. The incentive proposed to loyal customers is lower than the cost of relocation for the company, therefore the relocation activity perform by customers in areas far from their paths is uneconomical.

4.4.2. Goods relocation centralized optimization approaches

In this Section an optimization approach to solve the goods relocation problem for city retailers involving loyal customers with incentive system is proposed. The optimization models are formulated under the following assumptions:

- the relocation cost related to the company truck is proportional to the distance from one store to another based on a destination-source matrix; it is a variable cost and does not include the fixed relocation cost of the company;
- the number of daily relocations is always the same both in case of using only company truck and in case of involving loyal customers;
- the relocation process involving loyal customers is performed from one store to another through the shortest route;
- the capacity constraint is not considered both for trucks and loyal customers;
- the goods to be relocated are only the ones indicated by the company.

Goods Relocation problem performed by company trucks

The goods relocation problem is formulated as an ILP problem that aims to minimize the total cost of the goods relocation, including external costs, performed by company trucks. Given a set $K \in Z^{+}$ of goods to be relocated, with cardinality $|K|$, and the set $I \in Z^{+}$ of stores, with cardinality $|I|$, the cost of the goods relocation process is related to the number of relocation and from the distance among the stores. The binary decision variables are $x_{i,j,k}$, $\forall\, i,j\, \in I$, $\forall\, k\, \in K$, where the departure store is identified with i, and the arrival store is identified with j and the good is identified with k, and $Y_{i,j}$, $\forall\, i,j\, \in I$, to linearize the problem. It represents the package of goods $x_{i,j,k}$, to relocate from *i* to store *j*.

The integer variables are $r_j, \forall\, j\, \in I$, denoting the number of goods to relocate in each retailer after the relocation process. The known parameters of the problem are:

- $\hat{r}_j$ is the number of goods in retailer *j* before the relocation process;
- $\hat{r}_i$ is the number of goods in retailer *i* before the relocation process;
- the minimum number of fashion goods in each retailer is defined as $N_{min} \in Z^+$.

Thus, the following variables and parameters are defined:

- TRC is the total relocation cost, including the external costs [€/day];
- c is the cost per kilometer for the relocation task [€/km];
- e is the external costs per kilometer for the relocation task [€/km];
- $D_{i,j}$ is the distance from retailer i to the retailer j [km];
- $x_{i,j,k}$ is the binary decision variable indicating the k-th good relocated from retailer i to retailer j in a day;
- $Y_{i,j}$ is the binary decision variable indicating the relocation of the package with goods from retailer i to retailer j in a day;
- r_j is the number of goods in the retailer j after the relocation process;
- $\hat{r}_j$ is the number of goods in the retailer j before the relocation process.

On this basis, the ILP1 (4.4.1)-(4.4.6) is formulated as following:

$$TRC = \min(c+e)\sum_{i=1}^{|I|}\sum_{j=1, i\neq j}^{|I|} D_{i,j}\cdot Y_{i,j} \tag{4.4.1}$$

subject to:

$$kY_{i,j} \ \geq \ \sum_{k=1}^{|K|} x_{j,i,k}, \quad \forall\, i,j\, \in I \tag{4.4.2}$$

$$r_j = \hat{r}_j + \sum_{i=1}^{|I|}\sum_{k=1}^{|K|} x_{i,j,k} - \sum_{i=1}^{|I|}\sum_{k=1}^{|K|} x_{j,i,k}, \quad \forall\, j\, \in I \tag{4.4.3}$$

$$r_j \ \geq \ N_{min}, \quad \forall\, j\, \in I \tag{4.4.4}$$

$x_{i,j,k} \in \{0,1\}$ (4.4.5)

$Y_{i,j} \in \{0,1\}$ (4.4.6)

$i, j \in I, \quad k \in K$

The problem always admits feasible solution. This is demonstrable because the conditions to the problem do not impose conflicting constraints on each other in any case. The computational complexity is exponential.

Goods Relocation problem performed by loyal customers involvement

Involving loyal customers in the relocation activities leads to a new mathematical formulation of the optimization problem (4.4.1)-(4.4.4). Considering the incentive proposal levels set, described in Section II, we define $N_{lc} \in N$ as the number of loyal customers in the relocation activities. The acceptance of these customers is based on the proposed level of incentive and in the formulation is considered as a rate of acceptance: $r_u \in R^+$ is the acceptance rate of the loyal customers for each level of incentive. The number of goods relocatable is $Gr_u = N_{lc} * r_u$, u = 1, … , |U| - 1. It is noted that, in the proposed approach, the goods transfer activity can be performed both by loyal customers and company trucks in order to reduce the relocation cost for the company.

The variables and parameters of the problem are defined as following:

- TRC′ is the total daily relocation cost for company including the incentive system [€/day];
- in_u is the incentive rate for the incentive level u;
- $x_{i,j,k,u}$ is the binary decision variable indicating the k-th good relocated from retailer i to retailer j under incentive level u in a day;

The new optimization problem is formulated as the following ILP2 (4.4.7)-(4.4.13):

$$TRC = \min \sum_{i=1}^{|I|} \sum_{j=1, i \neq j}^{|I|} \sum_{u=1}^{|U|} (in_u \cdot D_{i,j} \cdot Y_{i,j,u}) \cdot (c + e_u) \tag{4.4.7}$$

subject to:

$$kY_{i,j,u} \geq \sum_{k=1}^{|K|} x_{j,i,k,u}, \quad \forall\, i, j \in I, \qquad \forall\, u \in U \tag{4.4.8}$$

$$r_j = \hat{r}_j + \sum_{i=1}^{|I|}\sum_{k=1}^{|K|}\sum_{u=1}^{|U|} x_{i,j,k,u} - \sum_{i=1}^{|I|}\sum_{k=1}^{|K|}\sum_{u=1}^{|U|} x_{j,i,k,u}, \quad \forall j \in I \tag{4.4.9}$$

$$r_j \geq N_{min}, \quad \forall j \in I \tag{4.4.10}$$

$$\sum_{i=1}^{|I|}\sum_{j=1}^{|I|}\sum_{k=1}^{|K|} x_{i,j,k,u} \leq Gr_u, \quad \forall u \in U \tag{4.4.11}$$

$$x_{i,j,k} \in \{0,1\} \tag{4.4.12}$$

$$Y_{i,j} \in \{0,1\} \tag{4.4.13}$$

$$i,j \in I, \qquad k \in K$$

The problem always admits feasible solution. The computational complexity is exponential. It is worth noted that it is expected that the relocation cost obtained by solving the ILP2 problem is less or (at least) equal than the same cost obtained by solving ILP1.

The proposed optimization approach can be applied to real cases with different fashion retailers operating in the same city for the relocation of goods.

4.4.3. Numerical experiments with fashion retailers

Numerical experiments are proposed for fashion retailers of the same brand in a city. The simulation is used to demonstrate the advantages of the proposed approaches. The formulated ILP problems are solved by a standard solver, i.e. MatLab (LinProg), on an Intel-Core i5, 2,7 Ghz CPU with 8 GB RAM. All the performed tests are solved in few seconds. The ILP1 and ILP2 problems are solved based on the following parameters: |I| = 5; |K| = 30; N_{min} = 5; N_{lc} = 200; $\hat{r}_j$, ∀j ∈ I as defined in Table 4.2; c = 2 [€/km]; $D_{i,j}$, ∀ j ∈ I, ∀ i ∈ I are defined in a destination-source matrix and reported in Table 4.3.

The proposed incentive system is based on two incentive levels and the rates in_u are set as follows:

i) reward equal to 50% of the company relocation service cost;

ii) reward equal to 80% of the company relocation service cost.

Thus, the cardinality of set U is |U| = 3. In Table 4.4 the acceptance rate of loyal customer, r_u, u = 1, 2 is shown.

The external costs in table 4.5, are based on values proposed in van Essen et al. (2019), with the same assumption of the paragraph 3.3.4. The use of car is considered in the loyal customer relocation process, indeed the LCV for company trucks.

Retailers	Goods initial number
Retailer 1	1
Retailer 2	7
Retailer 3	11
Retailer 4	0
Retailer 5	11

Table 4.2: *Initial number of goods per retailer*

	R1	R2	R3	R4	R5
R1	-	5	12	8	15
R2	5	-	9	4	18
R3	12	9	-	13	30
R4	8	4	13	-	17
R5	15	18	30	17	-

Table 4.3: *distance between retailers in km*

Incentive level	Acceptance rate of loyal customers	Relocatable fashion goods (Gr_u)
1	0,5%	1
2	1%	2

Table 4.4: *acceptance rate of loyal customers and relocatable fashion goods*

	Company truck [€/km]	Loyal customer [€/km]
Congestion (Table 48 in van Essen et al. (2019))	0,261	0,174
Accidents (Table 12 in van Essen et al. (2019))	0,0076	0,0141
Air pollution (Table 19 in van Essen et al. (2019))	0,003	0,0017
Noise Pollution (Table 37 in van Essen et al. (2019))	0,074	0,021
Climate change (Table 28 in van Essen et al. (2019))	0,034	0,0105
Well-to-tank emissions (Table 53 in van Essen et al. (2019))	0,0128	0,0039
Total External Costs	0,3904	0,2252

Table 4.5: *External costs for the goods relocation task*

By solving the ILP1, the total relocation cost (TRC) with the use of the company trucks is equal to 105,18 €/day. The relocation solution is drawn in fig. 4.2: the red line shows the relocation performed by the company trucks. Note that the minimum number of goods required in each store, does not allow to move all the goods from a single store but requires reallocation process from multiple stores.

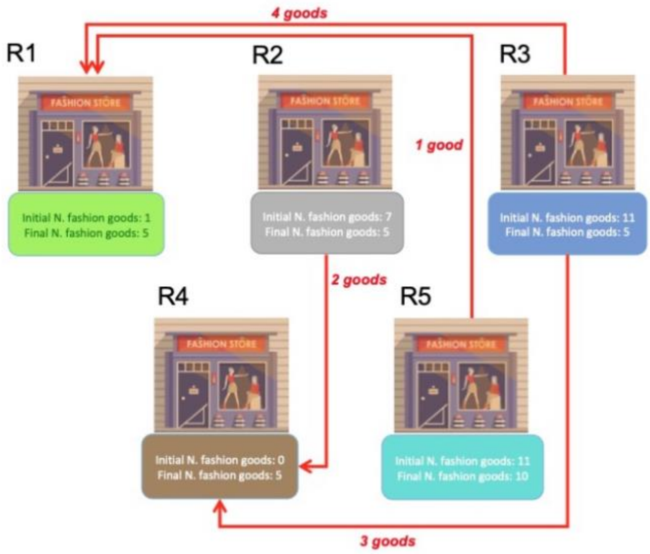

Figure 4.2: *Goods relocation in city fashion retailers by company trucks*

Solving the second problem ILP2, involving loyal customers, the new total relocation cost (TRC') is equal to 70,09 €/day. The incentives which are provided in the form of voucher to purchase goods in the stores of the fashion company are equal to 55 €/day.

The relocation solution of ILP2 is drawn in fig. 4.3: the green lines show the relocation performed by the loyal customers while the red line shows the relocation performed by the company trucks.

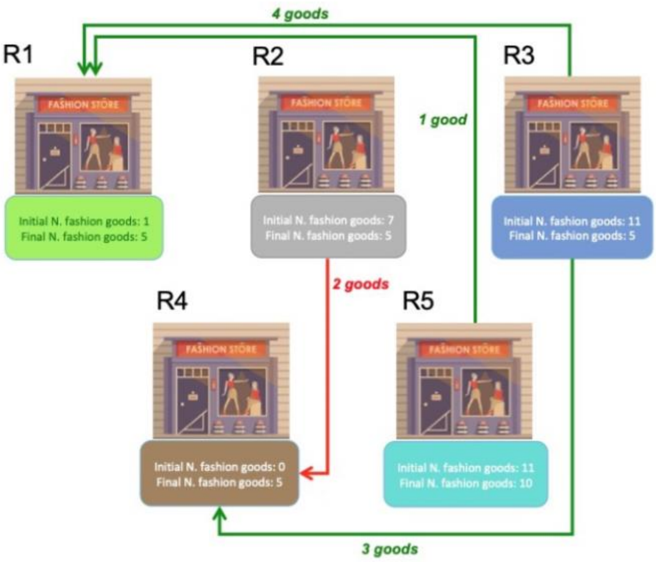

Figure 4.3: *Goods relocation in city fashion retailers involving loyal customers*

Analysing results of the proposed optimization approach to the goods relocation problem, a reduction of the relocation cost for the fashion company is noted. In the simulation case more than 30% of the relocation cost is cut off, involving customers. In addition, the fashion company can increase customer loyalty with more budgets to spend in its stores through the provided incentives.

The outputs of the simulation are present in Table 4.6.

	Relocation by staff [€/day]	Relocation with user involvement [€/day]
Total Relocation Cost	105,18	70,09
Relocation cost for the company	88,00	63,00
Relocation External Costs	17,18	7,09
Incentive for users	-	55,00

Table 4.6: *Results of goods relocation simulation with ILP1 and ILP2.*

It is noted that, in case of customers' unavailability in the relocation process, the fashion company can anyway perform it thanks to the company trucks.

4.5. New cross-distribution models with optimization approaches

The optimization of the cross-distribution in the context of a city warehouse, where shopkeepers can stock up the goods they needs, is an important topic. The UCC method is based on a depot placed close to the city where the goods are stored before being delivered to the stores to reduce the city centre traffic congestion, emissions and externalities. The same concept can also be implemented with refinements in some sectors, such as pharmaceutical, through collaborative urban logistics approaches: an automated drug warehouse managed by city pharmacies, can be established within the city and every pharmacist can access it in order to quickly collect and retrieve the missing drugs. This approach allows reducing the purchasing cost of drugs because the pharmacies can benefit of economic advantages in buying a higher number of drugs, with consequent economies of scale. In addition the supply chain mainly uses heavy and polluting vehicles, such as trucks, to distribute drugs to the pharmacies. Therefore, new transport solutions are needed.

The incentive system approach can be applied to engage the users in the cross-distribution. Based on these concepts, an innovative approach is proposed to distribute the drugs in the different city pharmacies involving pharmacists with an incentive scheme. The proposed approach aims to reduce the transport externalities in urban area, distribution costs for the pharmacies through an incentive mechanism.

The idea here is to offer pharmacists a prize in the form of a purchase vouchers for drugs as a reward for the delivery from warehouse to the receiver pharmacy shop (Fanti et al., 2020). The proposed pharmacist's incentive system can be provided through an IT application for smartphone and it is described by the procedure in figure 4.4. In the first phase, the pharmacists send a request of drugs to warehouse, in order to check their availability. It is assumed that all the necessary drugs are present in warehouse. The system checks if there are pharmacists available to distribute drugs for themselves and to another pharmacy; in this case it sends an incentive proposal to the available pharmacists and info to perform the distribution activity. If the cross-distribution process is completed, the pharmacist that delivers the drugs to another pharmacy receives the credits; otherwise, the delivery pharmacist is charged for the not delivered drugs cost and the receiver pharmacy is notified of the failure. In this case, a self-distribution process is performed by the receiver pharmacy itself if no other pharmacist is available to deliver drugs. The drugs distribution cost can be reduced by the proposed incentive system or at worst it remains unchanged.

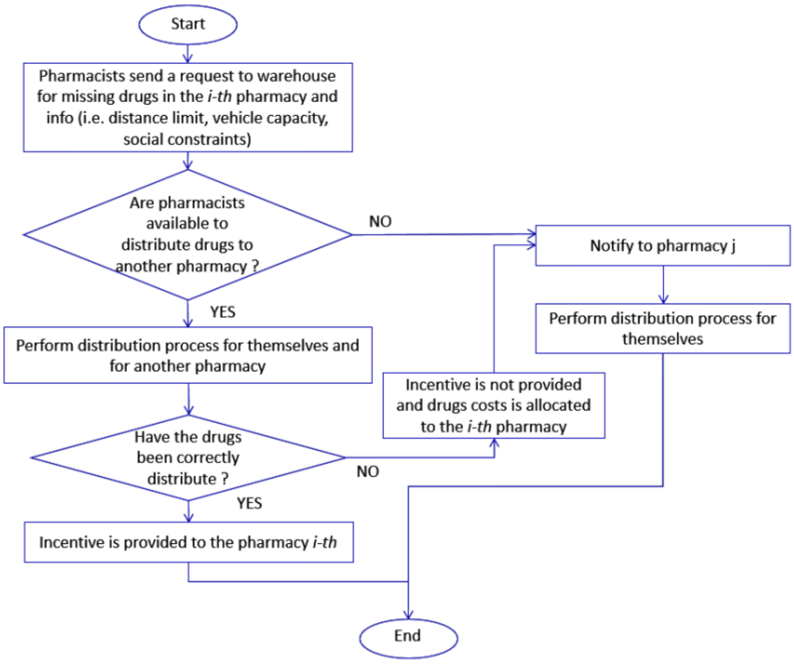

Figure 4.4: *Algorithm of incentive scheme in drugs distribution*

4.5.1. Cross-distribution incentive schemes

The incentive schemes in a cross-distribution with a city warehouse are a useful tool to reduce trips, externalities and engage shopkeepers in this activity.

Defined rules are essential to design an incentive system, based on credits for shopkeepers in the form of a purchase vouchers to purchase goods in the same sector (i.e. drugs).

A platform and a dedicated App for smartphone, based on a robust ICT system, is used to develop the incentive scheme. The proposed approach allows to reduce externalities in urban area, involving shopkeepers in the cross-distribution activity. The incentive value is equal to the cost of the trip that the shopkeepers who receives the goods would have faced to pick it up from the warehouse. The advantage for the shopkeepers who receive the goods is the saving of time at the same cost, while for those who deliver it the incentive received.

4.5.2. Cross-distribution centralized optimization approach

An optimization approach to solve the cross-distribution problem in the context of a city warehouse and involving shopkeepers with incentive system is proposed. The externalities cost related to goods delivery by trucks can be reduced because the shopkeepers use smaller and more efficient vehicles than trucks, such as vans or cars. In the distribution process, each shopkeeper performs at least a round trip from store to warehouse.

The set of P store (i.e. pharmacies) is denoted by $I = \{i = 1, \dots, P\}$ and the warehouse is denoted by 0. The following variables are defined:

- $x_{i,i}$ is the binary decision variable indicating the need to go to the warehouse to get missing goods (i.e. drugs) in the *i-th* store (i.e. pharmacy). By multiplying this variable with the distance $D_{i,0}$ it is possible to obtain the travelled kilometres from pharmacy i to warehouse or vice versa;
- $x_{i,j}$ is the binary decision variable indicating the availability of the *i-th* store (i.e. pharmacy) to distribute goods (i.e. drugs) to another store j (i.e. pharmacy), in the process of withdrawal goods (i.e. drugs) from the warehouse. By multiplying this variable with the distance $D_{i,j}$ it is possible to obtain the travelled kilometres from store i to store j.

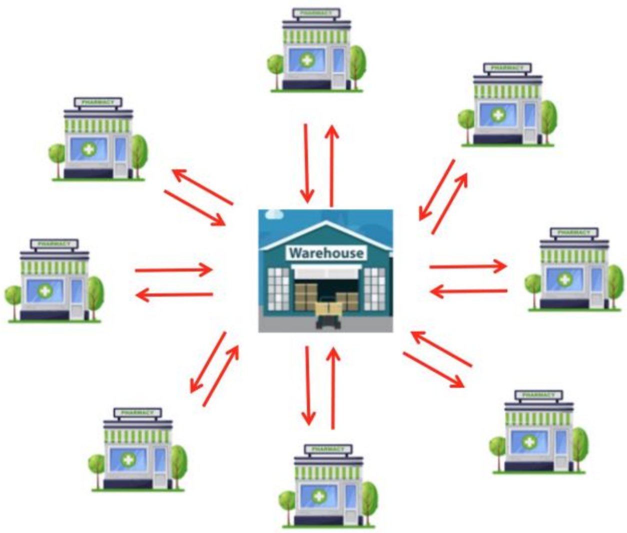

Figure 4.5: *Cross-distribution with warehouse in urban areas.*

Moreover, the Total daily Distribution Cost (TDC) [€/day], includes the external costs that are related to the distance among the pharmacies and the warehouse. The total TDC is obtained as follows:

$$TDC = 2 \cdot (c + e) \cdot \sum_{i=1}^{|I|} D_{i,0} \cdot x_{i,i} \tag{4.5.1}$$

where:

- c is the cost per kilometre [€/km];
- e is the external costs per kilometre [€/km];
- $D_{i,0}$ is the distance between store i (i.e. pharmacy) and the warehouse [km].

The cost of the cross-distribution is related to the distance among the store (i.e. pharmacies) and the warehouse.

Cross-Distribution Problem with incentive

The drugs distribution problem is formulated as an ILP problem that aims to minimize the cost of the distribution involving shopkeepers (i.e. pharmacists) in the activities. The incentive value is paid by the *j-th* shopkeeper (i.e. pharmacist) that receives the goods (i.e. drugs) in the distribution process performed by the *i-th* shopkeeper (i.e. pharmacist) in form of credits. The variables and parameters of the problem are defined as following:

- TDC′ is the total daily distribution cost with incentives, including the external costs [€/day];
- $D_{i,j}$ is the distance between store *i* (i.e. pharmacy) and store *j* (i.e. pharmacy) [km];
- N_i is the number of goods packages (i.e. drugs) required by store *i* (i.e. pharmacy) [package];
- N_j is the number of goods packages (i.e. drugs) required by store *j* (i.e. pharmacy) [package];
- LF_i is the load factor for the vehicle of store *i* (i.e. pharmacy) [package/vehicle].

The incentive provided to the *i-th* shopkeeper (i.e. pharmacist) depends on the trip distance saved by the *j-th* shopkeeper (i.e. pharmacist) and the number of delivered packages. It is computed as follows:

$$IN = \begin{cases} 2 \cdot c \cdot D_{j,0} \cdot x_{j,j} \cdot \dfrac{(LF_i - N_i)}{N_j}, if \dfrac{(LF_i - N_i)}{N_j} \leq 1 \\ 2 \cdot c \cdot D_{j,0} \cdot x_{j,j}, if \dfrac{(LF_i - N_i)}{N_j} > 1 \end{cases} \quad (4.5.2)$$

The rationality of the definition of the incentives is the following:

1) if $(\mathrm{LF}_i - N_i) > N_j$ then store i (i.e. pharmacy) can deliver all the required packages of store *j* (i.e. pharmacy), hence the incentives are proportional to the distance between warehouse and the store *j* (i.e. pharmacy);
2) if $(\mathrm{LF}_i - N_i) \leq N_j$ then the number of goods packages (i.e. drug) that store *i* (i.e. pharmacy) can deliver to the store *j* (i.e. pharmacy) is less than N_j, hence the incentive is decreased by the factor $\frac{(\mathrm{LF}_i - N_i)}{N_j}$.

On the basis of the incentives in (3) it is built the set DC of store (i.e. pharmacy) pairs that do not accept to collaborate for the goods (i.e. drugs) distribution, i.e., $(i, j) \in DC$ if the *i-th* shopkeeper (i.e. pharmacist) is not willing to distribute goods (i.e. drugs) to *j-th* store (i.e. pharmacy), under incentive payment. We assume that the shopkeeper (i.e. pharmacist) of the *i-th* store (i.e. pharmacy) can distribute goods (i.e. drugs) to no more than one store *j* (i.e. pharmacy). In addition, a kilometric distance limit $\overline{\mathrm{D}_\iota}$ is imposed by each store (i.e. pharmacy) in order to accept a cross distribution to another store (i.e. pharmacy).

The optimization problem including incentives is formulated by the following ILP:

$$TDC' = min(c + e) \cdot \left[\sum_{i=1}^{|I|} \sum_{j=1, j \neq i}^{|I|} (D_{i,0} + D_{0,j} + D_{i,j}) \cdot x_{i,j} + \sum_{i=1}^{|I|} 2D_{i,0} \cdot x_{i,i} \right] \quad (4.5.3)$$

subject to:

$$x_{i,j} = 0, \ \forall \, i, j \in DC \quad (4.5.4)$$

$$x_{i,j} \cdot D_{i,j} \leq \overline{D_\iota}, \ \forall \, i, j \in I \quad (4.5.5)$$

$$x_{i,j} \cdot (N_i + N_j) \leq LF_i, \quad for \; i, j = 1, \dots, P \; with \; i \neq j \quad (4.5.6)$$

$$x_{i,i} \in \{0,1\} \quad \forall \, i \in I \quad (4.5.7)$$

$$x_{i,j} \in \{0,1\} \quad \forall \, i, j \in I \quad (4.5.8)$$

$$i, j \in I$$

The social constraints (5) take into account the so called disagree couples $(i, j) \in DC$. The constraints (6) guarantee that the travelled distance between the considered stores (i.e.

pharmacies) does not overcome $\overline{D_i}$. Moreover, constraints (7) impose that the load in the vehicles used by each store (i.e. pharmacy) does not overcome the load capacity. We assume that if the number of packages to be delivered is higher than the load capacity, only part of the packages destined to store j (i.e. pharmacy) will be transported.

The problem admits always the feasible solution because in case no shopkeeper (i.e. pharmacist) accepts to deliver goods (i.e. drugs) to another store (i.e. pharmacy), each store (i.e. pharmacy) staff will perform it by itself.

4.5.3. Numerical experiments with pharmacies

Numerical experiments are proposed in the pharmacy sector with a warehouse and more pharmacy shops in the same city. In this case a centralized approach is proposed to perform the cross-distribution process for drugs. The problem is solved based on the formulation proposed and on the following parameters: P = 6 and are the different pharmacies in the city, characterized by c = 0,50 [€/km] and the destination-source matrix reported in Table 4.7. Moreover, the values of $\overline{D_i}$, for i = 1, …, 6, are reported in Table 4.8; N_i and LF_i are defined in Table 4.9 and Table 4.10, respectively. The external costs in table 4.11, are based on values proposed in van Essen et al. (2019), with the same assumption of the paragraph 3.3.4 and considering the LCV in the cross-distribution activity.

	W0	P1	P2	P3	P4	P5	P6
W0	0	3	4	2	5	4	3
P1	3	0	3	4	8	6	4
P2	4	3	0	2,5	7,5	8	6,5
P3	2	4	2,5	0	5	6	5
P4	5	8	7,5	5	0	6	6,5
P5	4	6	8	6	6	0	2,5
P6	3	4	6,5	5	6,5	2,5	0

Table 4.7: *Distance between pharmacy shops and warehouse in km*

Pharmacy i	$\overline{D_i}$
P1	3
P2	5
P3	4
P4	6
P5	4
P6	5

Table 4.8: *Limit distance imposed by each pharmacist in km*

Pharmacy i	N_i
P1	3
P2	2
P3	5
P4	4
P5	3
P6	2

Table 4.9: *Drugs demand from each pharmacy shop in number of packages*

Pharmacy i	LF_i
P1	5
P2	4
P3	6
P4	5
P5	6
P6	4

Table 4.10: *Load factor for each vehicle of pharmacy shop in number of packages*

	LCV [€/km]
Congestion (Table 48 in van Essen et al. (2019))	0,261
Accidents (Table 12 in van Essen et al. (2019))	0,0076
Air pollution (Table 19 in van Essen et al. (2019))	0,003
Noise Pollution (Table 37 in van Essen et al. (2019))	0,074
Climate change (Table 28 in van Essen et al. (2019))	0,034
Well-to-tank emissions (Table 53 in van Essen et al. (2019))	0,0128
Total External Costs	0,3904

Table 4.11: *External costs for the cross-distribution activity*

A set of scenarios related to the willingness of pharmacy couples to perform or not drugs cross-distribution is obtained by a Monte Carlo simulation, on the basis of the incentive applications. One of the most probable scenarios is reported in Table 4.12. From this Table it is possible determine the set *DC*.

	P1	P2	P3	P4	P5	P6
P1	-	1	0	0	1	1
P2	0	-	0	0	0	0
P3	0	0	-	0	0	0
P4	1	1	0	-	1	1
P5	1	0	0	1	-	1
P6	0	0	0	0	0	-

Table 4.12: *Social constraints: willing to deliver package in the cross-distribution.*

The formulated ILP problem is solved by a standard solver, i.e. MatLab (LinProg), on a Intel-Core i5, 2,7 Ghz CPU with 8 GB RAM. All the performed tests are solved in less than 2 seconds. The total drugs distribution cost (TDC) with the defined data and parameters is equal to 37,40 €. The cost includes the distribution cost and the external costs that are social costs. The proposed methodology allows calculating the total daily distribution cost with incentive scheme (TDC'). Solving ILP, the TDC' is equal to 29,83 €, including external costs. In addition, the provided incentive values are equal to 5 € for pharmacy 1 (provided by pharmacy 2) and 4,75 € for pharmacy 5 (provided by pharmacy 6), respectively.

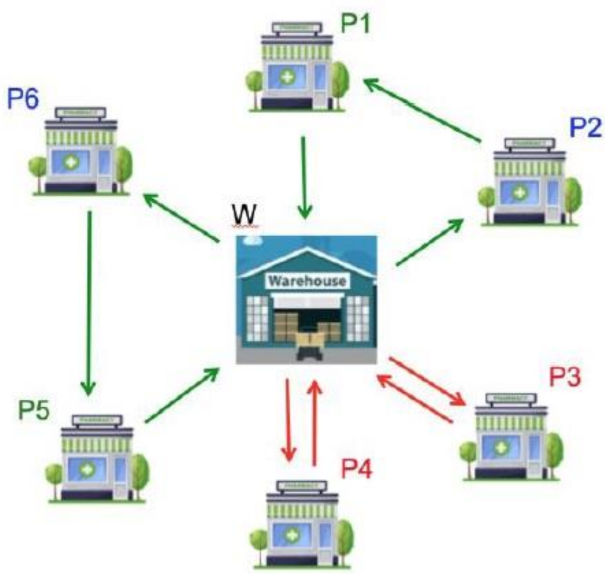

Figure 4.6: *Drugs cross-distribution with warehouse in an urban area*

The solution of ILP is drawn in Figure 4.6: the red lines shows the self-distribution performed by the pharmacies and the green lines represents the cross-distribution performed by pharmacists through the incentives.
Analysing results of the proposed method, the drugs distribution problem solution shows a significant reduction of the external costs and distribution operative cost, equal to over 20% in comparison with the case without incentive scheme as it is shown in Table 4.13.

	Drugs distribution without incentive system [€/day]	Drugs distribution with incentive system [€/day]
Total Distribution Cost	37,40	29,83
Distribution operative cost	21,00	16,75
External Costs	16,40	13,08
Incentive values	-	9,75

Table 4.13: *Results of drugs cross-distribution simulation.*

4.6. Conclusion on the results obtained

In this chapter a thorough literature review of the last mile delivery innovations, able to reduce urban transport externalities, is carried out. The main works are classified into five categories: innovative vehicles, proximity stations or points, collaborative and cooperative urban logistics, public policies and infrastructure, and optimization of transport management and routing. Each of them has strengths and gaps that can be considered as research opportunities. The development of these topics is essential to achieve a sustainable logistics in urban areas.
The goods relocation and the cross-distribution in the same urban area are significant tasks in the last mile delivery for some companies. These activities generate externalities, therefore in this thesis a new approach based on an innovative incentive system and the crowdsourcing paradigm is proposed, aimed at reducing the transport externalities in the urban area.
In the goods relocation, an incentive approach to minimize the total relocation cost for a company with more stores in the same city. It is based on offering loyal customers an increasing incentive bid as long as some users agree, with rewards in form of vouchers to

purchase goods in the company stores. To this aims, two Integer Linear Programming problems are formulated (ILP1 and ILP2). More in detail, the ILP1 allows to model and solve the goods relocation problem performed by the company trucks while the ILP2 upgrades ILP1 by adding the loyal customers in the relocation process through an incentive approach. In this context, the loyal customers can pick-up a package with goods by one retailer and leave it to another retailer receiving rewards. Therefore, the availability of loyal customer will allow the company to perform the relocation process at a lower cost and will generate benefits for the customers. In case of unavailability of the loyal customers the company trucks will ensure the relocation service. The numerical experiment with city fashion retailers demonstrates that the relocation cost for the fashion company is reduced if loyal customers are incentivized to participate in the relocation activities.

In the cross-distribution, a new methodology to distribute goods in stores inside urban areas, with a centralized warehouse, is presented. The proposed approach is based on an incentive scheme to engage shopkeeper in the cross-distribution process with another shop. The rewards are provided to the shopkeeper who delivers in form of credits and can be used to purchase goods from the warehouse. An ILP problem is formulated to model and solve the cross distribution performed under incentive system. The shopkeepers willing to distribute goods to another shop, pick up the good packages from the warehouse and deliver them. In this process, if the load factor of delivery vehicle is equal to the maximum load capacity, the next available shopkeeper will deliver the remaining packages. In case no shopkeeper is available to perform the distribution under incentives, each shop will perform the distribution by its staff. The numerical experiment with pharmacy shops, demonstrates that the proposed method allows to reduce the external costs and the total drugs cross-distribution cost. In addition, the proposed innovative approach improves the resources sharing by using the incentive scheme.

4.7. Chapter references

Ablola, M., Plant, E., Lee, C. (2014). The Future of Sustainable Urban Freight Distribution – a Delphi Study of the Drivers and Barriers of Electric Vehicles in London. Proceedings of the 5th IET Hybrid and Electric Vehicles Conference (HEVC), 5-6 November, London, UK.

Al Shamsi, A., Al Raisi, A., Aftab, M. (2014). Pollution-Inventory Routing Problem with Perishable Goods. Springer, Logistics Operations, Supply Chain Management and Sustainability, EcoProduction, pp. 585-596.

Asma, T., Addouche, S.A., Dellagi, S., El Mhamedi A. (2017). Post-production Analysis Approach for drone delivery fleet. Proceedings of the IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI), 18-20 September, Bari, Italy.

Barreto, L., Amaral, A., Pereira, T. (2017). Industry 4.0 implications in logistics: an overview. Elsevier, Procedia Manufacturing, vol. 13, pp. 1245-1252.

Bogataj, M., Bogataj, L., Vodopivec, R. (2005). Stability of perishable goods in cold logistic chains. Elsevier, International Journal of Production Economics 93-94, pp. 345-356.

Chatterjee, R., Freulich, C., Edelkamp, S. (2016). Optimizing Last Mile Delivery using Public Transport with Multi-Agent based Control. Proceedings of the IEEE 41st Conference on Local Computer Workshop, November 7-10, Dubai, United Arab Emirates.

Chesbrough, H.W. (2003). Open innovation: The new imperative for creating and profiting from technology. Boston, MA: Harvard Business School Press.

Davis, B. A., Figliozzi, M. A. (2013). A methodology to evaluate the competitiveness of electric delivery trucks. Transport Research Part E: Logistics and Transportation Review. Vol. 49, issue 1, pp. 8-23.

de Souza, R., Goh, M., Lau, H. C., Ng, W.S., Tan, P.S. (2014). Collaborative Urban Logistics – Synchronizing the Last Mile. Procedia – Social and Behavioral Sciences 125, pp. 422-431.

Dell'Amico, M., Hadlidimitriou, S. (2012). Innovative logistics model and containers solution for efficient last mile delivery. Procedia – Social and Behavoiral Sciences 48, pp. 1505-1514.

DHL paketkopter (2013) https://www.dpdhl.com/de/presse/specials/dhl-paketkopter.html

Djahel, S., Doolan, R., Muntean, G.M., Murphy, J. (2015). A communications-Oriented Perspective on Traffic Management Systems for Smart Cities: Challenges and Innovative Approaches. IEEE Communications Surveys & Tutorials, vol. 17, issue.

Edwards, J., McKinnon, A., Cherrett, T., McLeod, F., Song, L. (2009). The impact of failed home deliveries on carbon emissions: are collection/deliveries points environmentally-friendly alternative?. Proceedings of the 14th annual Green Logistics Conference, Cardiff, UK.

Erdogan, S., Miller-Hooks, E. (2012). A green Vehicle Routing Problem. Transportation Research Part E: Logistics and Transportation Review, vol. 48, issue 1, pp. 100-114.

Estellés-Arolas, E. and Gonzàlez Ladron de Guevara, F. (2012). Towards an integrated crowdsourcing definition. Journal of Information Science, 38(2), 189-200.

Fanti, M.P., Mangini, A. M., Roccotelli, M., Silvestri, B., (2020). Drugs Cross-Distribution Management in Urban Areas through an Incentives Scheme. 21st IFAC World Congress (IFAC2020). *Paper submitted*.

Feng, W., Figliozzi, M. (2013). An economic and technological analysis of the key factors affecting the competitiveness of electric commercial vehicles: a case study from the USA market. Transportation Research, Part C, 26, pp. 135-145.

GeoDrone (2015). "Projet de drone: le terminal de livraison".

Ghazal, B., ElKhatib, K., Chahine, K., Kherfan, M. (2016). Smart Traffic Light Control System. International Conference on Eletrical, Electronics, Computer Engineering and their Applications (EECEA), Beirut, Lebanon, 21-23 April.

Gunasekaran, A., Subramanian, N., Raham, S. (2015). Green supply chain collaboration and incentives: Current trends and future directions. Transport Research Part E: Logistics and Transport Review, Vol. 74, pp. 1-10.

Handoko, S-D., Nguyen, D. T., Lau, H.C. (2014). An Auction Mechanism for the Last-mile Deliveries via Urban Consolidation Centre. Proceedings of the IEEE International Conference on Automation Science and Engineering (CASE), 18-22 August, Taipei, Taiwan.

Hiermann, G., Puchinger, J., Ropke, S., Hartl, R. F. (2016). The Electric Fleet Size and Mix Vehicle Routing Problem with Time Windows and Recharging Stations. European Journal of Operational Research, pp. 995-1018.

Hirschberg, C., Rajko, A., Schumacher, T., Wrulich, M. (2016). Article “The changing market for food delivery”, Mckinsey,. url: https://www.mckinsey.com/industries/high-tech/our-insights/the-changing-market-for-food-delivery.

Howe, J. (2006). The rise of crowdsourcing. Wired, 14(6), 176-183.

Howe, J. (2008). Crowdsourcing. New York, NY: Crown.

Hsu, C.I., Hung, S.F., Li, H.C. (2007). Vehicle routing problem with time-windows for perishable food delivery. Elsevier, Journal of Food Engineering 80, pp. 465-475.

Iwan, S., Kijewska, K., Lemke, J. (2016). Analysis of Parcel Lockers’ Efficiency as the Last Mile Delivery Solution – The Results of the Research in Poland. Transportation Research Procedia, Vol. 12, pp. 644-655.

Jansson J., Power D. (2010). Fashioning a Global City: Global City Brand Channels in the Fashion and Design Industries. Regional Studies, Vol. 44.7, pp. 889-904.

Liakos, P., Delis, A. (2015). An Interactive Freight-pooling service for efficient Last-mile Delivery. Proceedings of the IEEE 16th International Conference on Mobile Data Management, 15-18 June 2015, Pittsburgh, PA, USA.

Le, T., Diabat, A., Richard, J.P., Yih, Y. (2013). A column generation-based heuristic algorithm for an inventory routing problem with perishable goods. Springer, Optimization Letters, volume 7, issue 7, pp. 1481-1502.

Lebeau, P., Macharis, C., Van Mierlo, J., Maes, G. (2013). Implementing electric vehicles in urban distribution: a discrete event simulation. Proceedings of the Electric Vehicle Symposium and Exhibition (EVS27), 17-20 November 2013, Barcellona, Spain.

Menga, P., Buccianti, R., Bedogni, M., Moroni, S. (2013). Promotion of freight mobility in Milan: Environmental, energy and economical aspects. Proceedings of the Electric Vehicle Symposium and Exhibition (EVS27), 17-20 November, Barcellona, Spain.

Mirhedayatian, S.M., Yan, S. (2018). A framework to evaluate policy options for supporting electric vehicles in urban freight transport. Transport Research Part D: Transport and Environment. Vol. 58, pp. 22-38.

Neaimeh, M., Hill, G. A., Hubner, Y., Blythe, P. T. (2013). Routing systems to extend the driving range of electric vehicles. IET Intelligent Tranposrtation System, 7, (3), pp. 327-336.

Pal A., Kant, K. (2016). SmartPorter: a Combined Perishable Food and People Transport Architecture in Smart Urban Areas. Proceedings of the IEEE International Conference on Smart Computing (SMARTCOMP), 18-20 May, St. Louis, MO, USA.

Project STARSHIP (2014). url: https://www.starship.xyz

Project YAPE (2017). url: http://www.e-novia.it/en/home-delivery/

Project WING (2012). “What is project wing?”. url: https://x.company/projects/wing/

Rezgui, D., Aggoune-Mtalaa, W., Bouziri, H. (2015). Towards the electrification of urban freight delivery using modular vehicles. Proceedings of the IEEE International Conference on Service Operations And Logistics (SOLI), November 15-17, Hammamet, Tunisia.

Rijpkema, W.A., Rossi, R., Van der Vorst, J.G.A.J. (2014). Effective sourcing strategies for perishable product supply chains. International Journal of Physical Distribution & Logistics Management, 44 (7).

Sachs, C., Burandt, S., Mandelj, S., Mutter, R. (2016). Assessing the market of light electric vehicles as a potential application for electric in-wheel drives. Proceedings of the International Electric Drives Production Conference (EDPC), November 30-December 1, Nuremberg, Germany.

Schau, V., Rossak, W., Hempel, H., Spathe, S. (2015). Smart City Logistik Erfurt (SCL): ICT-Support for managing Fully electric Vehicles in the Domain of Inner City Freight

Traffic. Proceedings of the International Conference on industrial Engineering and Operations Management (IEOM), 3-5 March, Dubai, United Arab Emirates.

Schneider, M., Stenger, A., Goeke, D. (2014). The Electric Vehicle-Routing Problem with Time Windows and Recharging Stations. Transportation Science, vol. 48, n. 4, pp. 500-520.

Silvestri, B., Roccotelli, M., Iavaniglio, R.P., Ranieri, L., (2019c). Goods Relocation Management in City Fashion Retailers with an Incentive System. International Conference on Industry 4.0 and Smart Manufacturing (ISM2019), 20-22 November, Rende, Italy. *Paper accepted.*

Spinks, J., Jackson, J., Kirkpatrick, C.M., Wheeler, A.J. (2016). Disruptive innovation in community pharmacy – Impact of automation on the pharmacist workforce. Research in Social and Administrative Pharmacy, 13 (2), 394-397.

Taniguchi, E., Thompson, R.G., Yamada, T. (2001). Recent advances in Modeling City Logistics. In City Logistics II (E. Taniguchi and R.G. Thompson, eds.), Institute of Systems Science Research, Kyoto, Japan. pp. 3-33.

Taniguchi, E. (2014). Concepts of city logistics for sustainable and liveable cities. Procedia – Social and Behavioral Sciences, vol. 151, pp. 310-317.

Taniguchi, E., Thompson, R.G., Yamada, T. (2015). New opportunities and challenges for city logistics. Proceedings of the 9th International Conference on City Logistics, Tenerife, Canary islands, Spain, 17-19 June. Transportation Research Procedia, vol 12, pp. 5-13.

Van Duin, J.H.R., Tavasszy, L.A., Quak, H.J. (2013). Towards E(lectric)- urban freight: first promising steps in the electric vehicle revolution. European Transport, issue 54, (9), pp. 1- 19.

van Essen, H.P., van Wijngaarden, L., Schroten A., Sutter, D., Bieler, C., Maffii, S., Brambilla M., Fiorello, D., Fermi, F., Parolin, R., El Beyrouty, K. (2019). Handbook on the external costs of transport. Version 2019. CE Delft. European Commission, Directorate-General for Mobility and Transport.

Wang, Y., Zhang, D., Liu, Q., Shen, F., Hay Lee, L. (2016). Towards enhancing the last-mile delivery: an effective crowd-tasking model with scalable solutions. Transportation Research Part E, 93, pp. 279-293.

Welch A. (2015). A cost-benefit analysis of Amazon prime air. url: https://scholar.utc.edu/cgi/viewcontent.cgi?referer=https://www.google.it/&httpsredir=1&article=1051&context=honors.

West, J., Salter, A., Vanhaverbeke, W., Chesbrough, H.W. (2014). Open innovation: The next decade. Research Policy, 43(5), 805-811.

Zunder, T., Aditjandra, P., Schoemaker, J., Laparidou, K., Vaghi, C., Osterle, I. (2016). Engaging City Stakeholders to Achieve Efficient and Environmentally Friendly Urban Freight Movements. Book: Towards Innovative Freight and Logistics. Iste and Wiley.

5. Conclusions

5.1. Results of the research

According to the main topics presented in the Abstract of the thesis and to the outlines in evidence at the end of each chapter the concepts addressed are presented.

A preliminary state of art analysis concerning the transport externalities has been carried out in order to identify the gaps and achievable targets in literature, with the aim of reducing negative impacts. According to this, three main topics have been investigated in this thesis: (i) ICT mobility innovations; (ii) optimization of incentive-based relocation in EVs and ELVs sharing systems, and (iii) optimization of incentive-based goods relocation and cross-distribution systems.

In order to contribute to the first topic (i), a user-centric approach has been adopted, with the aim to develop ICT tools for promoting the use of electro-mobility in urban areas and the user acceptance. The proposed method is based on the preliminary collection of user requirements for EVs and ELVs ICT tools, through specific questionnaires and interviews; user requirements are used for the next step, the software requirements analysis definition. This analysis is developed with the UML Use Case approach where Use Case diagram and Activity diagram are implemented to identify ICT requirements. This strengthen the user-centric approach.

The main critical issue assessed in the management of EVs and ELVs sharing systems, due to the reduced battery autonomy and the recharging time, is the optimization of the vehicles relocation (ii), in order to maintain a high level of service for users. In order to overcome such limit, an incentive based approach able to involve users in the relocation activity has been developed: the problem is modelled with mathematical formulations to minimize company and external costs of the EVs relocation. In addition to the reduction of the total relocation cost, this method incentive users to use the sharing system since rewards are in form of mobility credits. The method with users involvement guarantees the same performance compared to the relocation performed only by company staff. To solve the defined problem, mathematic formulations are based both a centralized optimization approach and a decentralized optimization approach, have been developed. The last approach is able to reduce the computational complexity of the problem and, in some cases, to make calculations feasible if the centralized optimization approach does not allow it (i.e. with a very large number of EVs or ELVs and stations exist).

Finally, the reduction of transport externalities in urban areas caused by the last mile logistics has been dealt with. Both goods relocation and cross-distribution in urban areas have been considered. The methods proposed reduce last mile logistics externalities are based on an (iii) incentive-based optimization approach.

The goods relocation between different stores in the same city has been modelled with mathematical formulations to minimize external and company costs. The loyal customers involvement in relocation has a double benefit: it is able to reduce the total relocation cost and to improve their loyalty through rewards in the form of purchase vouchers. The proposed model has been applied through numerical simulations to the case of fashion retailers of the same brand in a city.

The goods cross-distribution between different stores and a warehouse in the same city has been analysed and mathematical formulations to calculate the total costs of the task, including external costs, have been defined. The minimization of these costs has been developed with an incentive-based optimization approach, in which shopkeepers are engaged in the goods cross-distribution process through rewards in the form of vouchers for the purchase of goods. Numerical simulations were carried out by applying this method to the case of an automatic city warehouse, shared and managed by a network of pharmacies to pick-up the missing drugs from it.

5.2. Final considerations on the future developments

As far as future developments of the research presented in this PhD thesis is concerned, it is possible outline further developments for (i) ICT mobility innovations, (ii) optimization of incentive-based relocation in EVs and ELVs sharing systems, and (iii) optimization of incentive-based goods relocation/cross-distribution systems.

The development of a specific Serious Game App (i) to promote electro-mobility in urban areas should be linked to a service able to convert the points collected into prizes that can be redeemed directly online. An incentive system platform should be developed to provide this service. The same platform could also be applied in incentive-based systems developed in order to manage the collection of rewards and the use of credits.

The (ii) optimization of incentive-based relocation in EVs / ELVs sharing system will need to be deepened in the case of large number of EVs / ELVs and stations. This is possible in case of metropolitan areas or in case of a free-floating sharing system (in this case a small area of the city is assimilated to a station, therefore the overall number of stations is very high from a computational point of view). The free-floating sharing system is widely used recently especially with electric scooters and it is highly appreciated because it provides a more flexible service for users than the station based mode; on the other hand, a more intense vehicles relocation is required. The decentralized optimization approach has been chosen in order to reduce computational complexity in these cases and implementation of the approach with numerical experiments is required. In addition, entry and exit rates of EVs / ELVs from station will be included in future works in order to improve the quality level of the sharing service for the end users, while reducing the company's relocation costs.

The goods relocation and cross-distribution (iii) optimization with incentive-based approaches will be implemented with more details in the mathematical modelling in order to consider some previously simplified features (such as capacity constraints of different vehicles, different sizes and weights of the goods, and use of EVs).

The model of the goods relocation in urban area will have to take into account a capacity constraint related to trucks and loyal customers. Finally, the goods cross-distribution model has been developed with pairs of shops; the idea is to generalize the model in order to involve more than two shops in the goods cross-distribution process and to integrate the related routing problem.

Annex

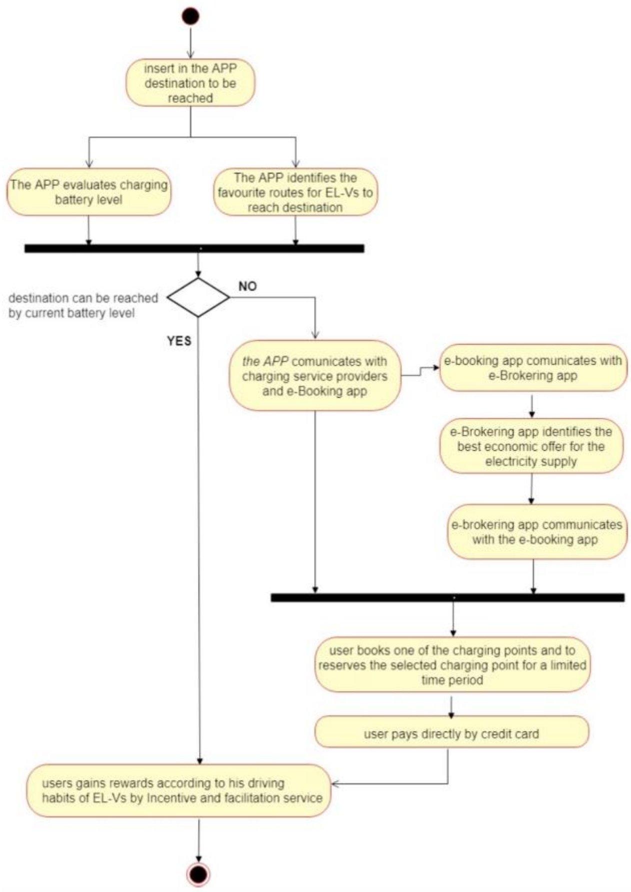

Figure A.1: *Activity diagram related to "Select Reachable Destination" Use Case.*

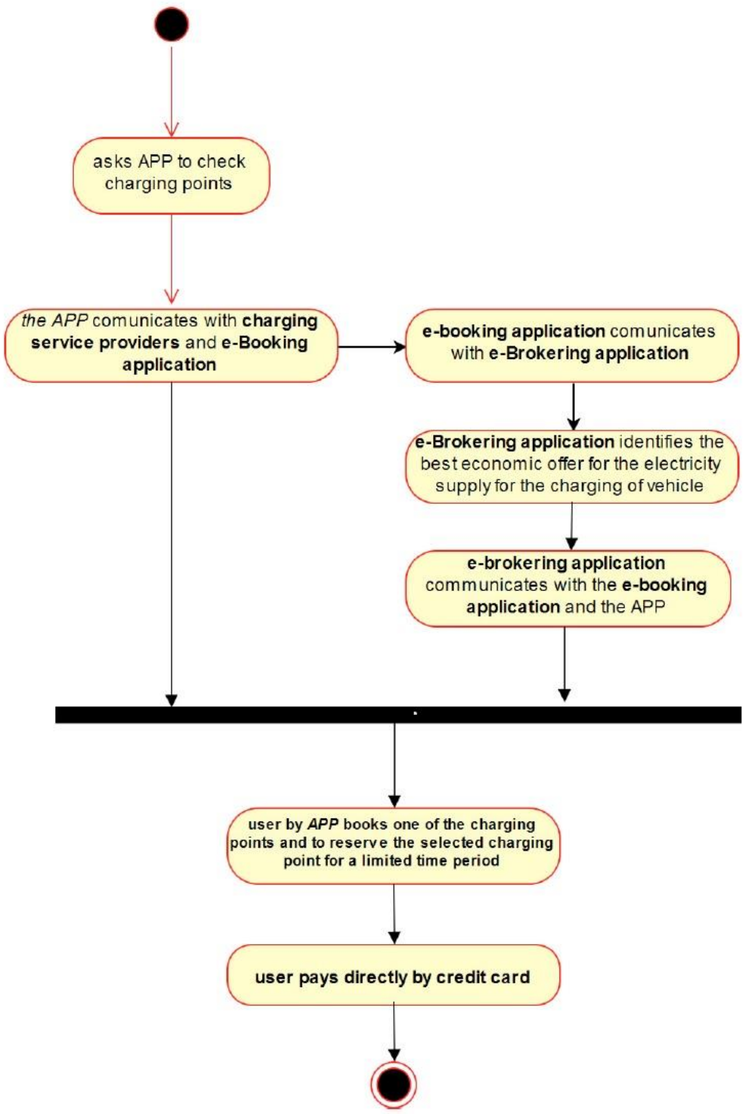

Figure A.2: *Activity diagram related to "Book Charging Points" Use Case.*

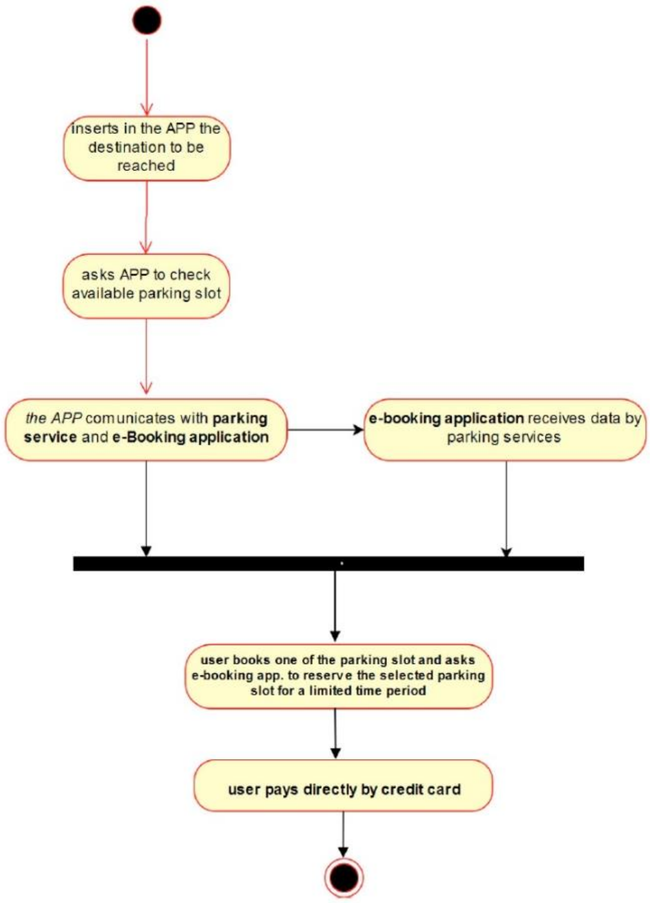

Figure A.3: *Activity diagram related to "Book ELV parking slot" Use Case.*

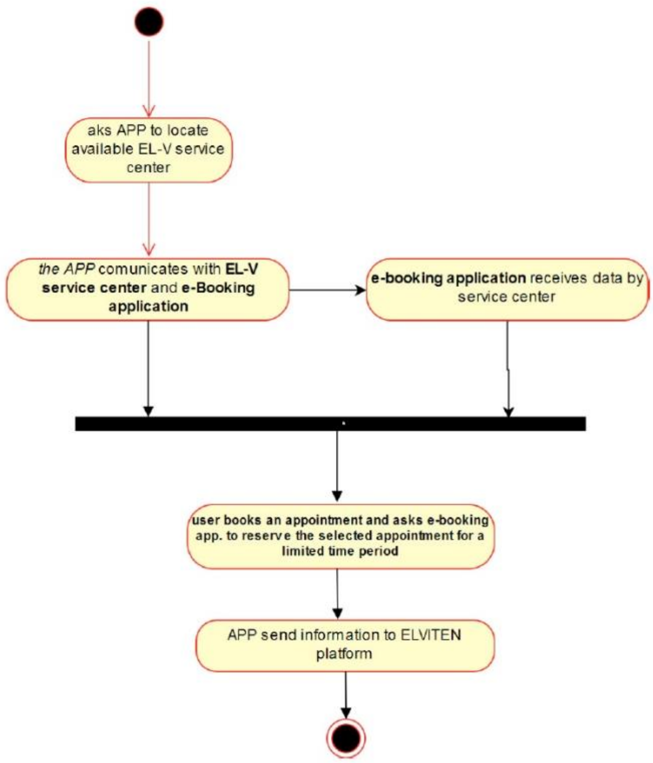

Figure A.4: *Activity diagram related to "Require Assistance" Use Case.*

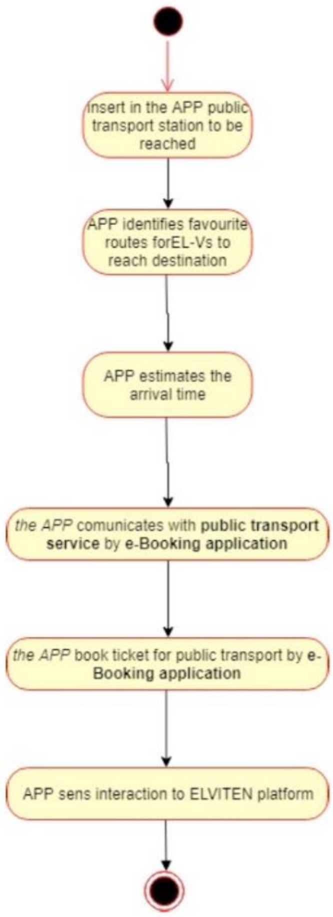

Figure A.5: *Activity diagram related to "ELVs and public transport combination" Use Case.*