Technological Solutions for the Monitoring and Enforcement of Urban Logistics Activities: Av. Guerra Junqueiro case study

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Abstract:

One common problem of all cities is traffic. And traffic can be caused by many different situations, but the focus of this dissertation goes to the problematic of the high density of freight vehicles within the city center, that often result on problems while proceeding with loading or unloading activities. If we could monitor and regulate these delivery operations, these problems could be mitigated resulting in traffic improvements and less conflicts with other public space users.

The objective of this work was to study the process of monitoring and enforcing loading and unloading activities in urban context, and the case study was in Lisbon's Guerra Junqueiro Avenue. It was studied the implementation of two different technologies to monitor these activities, one alternative consisted in using adapted parking meters that issued a parking ticket for freight vehicles that expired after 30 minutes after using a contactless card, and the other alternative was the implementation of sensors on the ground of the parking places of the loading/unloading parking bays that could monitor the entrance and exit of vehicles.

It was analysed the performance of these two technologies, based on their costs and benefits, in order to determine which solution was better suited to attend the needs of the public company responsible for on-street parking in Lisbon, EMEL. To study the results given by the case study, it was used an adaptation of the methodology of Cost-Benefit Analysis (CBA) suggested by the European Commission. This adaptation was made due to the small dimension of the case study and because some indirect impacts could not be measured (or were not available). Two periods of observations on site were conducted in order to give an overview of the situation in the avenue before and after the implementation of both technological solutions. The evaluation with the CBA method was performed with a time-horizon of 15 years, which gave the Net Present Value (NPV) of both alternatives at the end of that period. It was also predicted what to expect if the technologies would be implemented on all loading and unloading parking bays (LUPBs) in the city of Lisbon.

The conclusions of this work indicate that for the same amount of benefits for EMEL, the alternative with the adapted parking meters gives a higher NPV, but the alternative with the sensors has the advantage of being able to monitor the loading and unloading activities permanently and automatically.

Keywords: Cost-Benefit Analysis; Intelligent Transport Systems (ITS); Loading and Unloading Activities; Urban Freight; Urban Parking.

1 City Logistics

1.1 Definition

Defining City Logistics (CL) is not an easy task, because there is not a unanimous consistent definition of the concept. In fact, there have been used many different terms to refer to the transport of urban supplies (e.g. "Urban Goods Movement" and "Urban Logistics"), which is an evidence of the various different interpretations of the concept. Therefore, the concept of city logistics has to be considered in the broadest sense of the term. There are many different authors' opinions on what city logistics refers to.

Recently Stathopoulos et *al.* has stated that "City logistics studies the problems relating to freight movement, such as congestion, time-window regulations, on street loading/unloading, parking and environmental emissions caused by freight vehicles" (Stathopoulos *et al.*, 2012, pg. 34). This definition is congruent with the author's understanding of CL and therefore applied in the present work because it clearly describes the essence of the CL concept.

1.2 Stakeholders, increasing significance and challenges

The relevant stakeholders that have an important influence on the movement of goods within the cities can be roughly divided into five groups [2]–[4]: Carriers; Public authorities; Receivers; Residents; and Shippers. All these institutions, organizations and people involved in CL have their own objectives and interests. The *carriers* are the private or public stakeholders that are responsible for delivering the goods that the *shippers* send to the *receivers*. Their objective is to be competitive by providing the best possible service. *Shippers* have the objective of minimizing the transport costs paid to freight *carriers*. They select which freight carriers they want, and request them to deliver the goods. The *public authorities* represent local, regional or nationwide authorities. Their objective is to resolve conflict between city logistics actors, while facilitating sustainable development of urban areas. The *receivers* are mainly the owners of shops in city centers that are interested in short and reliable deliveries. The *residents* want an attractive and sustainable city with minimum negative effects of urban freight transport.

Despite the idea of dealing with urban freight issues is a relatively new concept, it is important to note that it is older than what most people think. During the times of the Roman Empire, the emperor Julius Caesar thought that it was needed to move freight deliveries to the off-hours so he promulgated an edict, in 45 BC, that banned commercial deliveries during daytime [5]. There is also evidence that, 70 years ago, some business organizations already used co-operative delivery actions, such as consolidation, to mitigate the negative externalities of urban goods movement [6]. However the significance and complexity of CL has been, and still is, growing. The scientific literature indicates that the prime factors responsible for this increase of importance and complexity of logistics in urban areas are:

Dynamic inventory management: service level is now considered as a value for the product – because factors such as lead time and attendance can be the difference between two services – and retailers adopt policies of continuous inventory replenishment – because they have less available space inside stores and want to reduce their inventories – which enhances *dynamic inventory management* [7], [8].

E-commerce: this type of business has led to the increase of home deliveries and intensification of transporting freight through inner-city areas [9]–[11].

Evolving environmental awareness: city planning has been focused primarily on passenger transport, but due to the negative impacts that urban freight transport has on the urban environment, it is necessary to achieve sustainability in urban freight transport [12], [13].

Growing urbanization: the worldwide urbanization trend is a major contributing factor to the increase of the already significant volume of freight movements in urban areas [14]–[16].

The increase of complexity of CL leads to a growth of freight volumes and delivery frequencies, which cause several challenges in urban areas. And according to the literature [11], [17]–[21] there are seven major problems related to CL: Inefficient use of land; Physical hindrances; Congestion; Traffic accidents; Low capacity utilization; Waste of energy; and Environmental pollution.

Urban goods movement have these negative effects that can occur due to insufficient infrastructure, presence of large trucks, *inefficient use of land* used for offstreet and onstreet loading/unloading of goods on vehicles. The presence of freight vehicles causes *congestion* and accessibility problems for other road users, since they act as *physical hindrances*, and they are also a significant cause of accidents, due to their size, maneuverability and on-road loading/unloading operations [17]. According to Ambrosini et al. (Ambrosini et al. 2010) there are two types[1] of freight vehicles, the light goods vehicles (LGV) with a mass lower than 3.5 tons and heavy goods vehicles (HGV) with more than 3.5 tons. Despite having different levels of impact, both types of vehicles have negative effects. Browne et. al [20] states that since LGVs are mostly used in urban areas, they have a greater impact on urban congestion than HGVs, however HGVs are more responsible for noise disturbance, infrastructure damage (roads and bridges) and vibrations leading to building damages, due to their heavier weight. As it was mentioned before, e-commerce and dynamic inventory management policies are significantly growing, accelerating the growth of small package deliveries; and this associated with the lack of coordination between the shippers and carriers of city logistics leads to *low capacity utilization*, *waste of energy* and empty trips [11], [17]. *Environmental pollution* encompasses not only ecological problems, such as air and noise pollution, but also visual intrusion or vibration problems caused by HGVs. Urban freight movements represent a quite low proportion of the total vehicle kilometers (10% - 15%), but is one of the top sources of emissions of air pollutants (16% - 50%, depending on the pollutant) [21], [22].

The growing importance and complexity of city logistics demands the implementation of improvement measures, because if they are not undertaken in the future, there will be the risk of a continuous increase in traffic volumes and a great part (20%) will be due to freight flows [23]. Therefore there is a need for more and new measures that can be implemented with the objectives of reducing (or solving) the negative impacts of urban freight transport.

1.3 European research in City Logistics

The European Commission, under the 7th Framework Programme (7FP), has funded several research activities within the area of transport. This programme allocated €2.22 billion to a total of 620 research and technology projects, from 2007 to 2013, in the area of transport. Within the area of transport, urban mobility is a major priority for the European Union (EU), which is why, since 1998, the EU invested over € 300 million in urban transport research [23]. Among the 620 projects, the most relevant in the area of city logistics, within the 7FP, include a showcase for good practices of cleaner and sustainable urban transportation (C-LIEGE), a comprehensive approach to urban freight solutions that links urban to interurban freight movements (STRAIGHTSOL), there is also a worldwide perspective of urban logistics concepts and practices (TURBLOG) and finally there is an example that by creating innovative vehicle and transport solutions it is possible to make deliveries of goods within cities more sustainable and efficient (CITYLOG). These projects were chosen because they represent four different approaches to overcome the difficulties and mitigate the problems of City Logistics: a better cooperation between public and private entities (C-LIEGE), encouraging the transferability of good practices between Europe and South America (TURBLOG), creation of a new impact assessment framework to evaluate the application of technological and logistical solutions (STRAIGHTSOL), and finally, the creation of new ways to transport goods with the help of technology (CITYLOG).

2 City Logistics Measures

Coherent urban freight transport measures have not been developed to the same extent that they have for passenger transport. However many urban authorities have begun to focus far greater attention, over the last decade, on the efficiency and sustainability of freight transport within cities, due to its economic importance. (Cherrett *et al.*, 2012)

Efficiency improvements of UFT can benefit both freight transport companies and the wider society, because UFT plays a major role in competitiveness of urban areas both in terms of generated income and employment. But on the other hand, adopting policies that ease urban goods movement may increase the volume of freight vehicles in cities, which has negative effects on the environment such as congestion, air pollution, noise and increases the logistics costs, and hence product prices.

The scientific literature reviewed by the author revealed several different measures that are used to improve the logistics of urban freight transport. The author will follow the classification scheme used by Muñuzuri et al. [25] that divides the measures in five groups: Public infrastructure; Land use management; Access restrictions; Traffic management; and Enforcement and promotion.

The *public infrastructure* measures have the objective of developing new or extend existing infrastructures. Introducing an urban hub or new roadways are common measures used to facilitate urban distribution. This group includes measures that aim to encourage modal shift towards more sustainable modes, like the use of railway for long-haul transportations or subway systems for inner city transportations [1], [25].

In European cities, the measures related to *land use management* can be very difficult to implement because

[1] But Dezi et al. [19] alert that there is a third type of vehicle that has been increasingly used to sort goods: the car.

urban areas have narrow streets inherited from the Middle Ages, but there are some examples such as zoning of commercial and residential activities to encourage initiatives such as load consolidation [1]. The first two groups of measures cannot be clearly separated, and examples that support this idea are the loading/unloading parking bays, multiple use lanes or parking space planning [26]. However, in this work, these three examples are going to be included in the group of the *land use management*, because they exemplify a change of the land use in order to provide a better management of the city logistics' activities.

The group of *access restrictions* has many different types of measures. The most popular are related to time restrictions and restrictions referring to capacity utilization, emission levels, size and weight. Regulations on delivery time windows, especially for pedestrian zones, are also common measures used in many cities. These types of measures are imposed by the local authority which impact on freight operations [1], [25].

According to Muñuzuri et al. [26] *traffic management* measures have the purpose of reorganize and facilitate the flow of urban goods movements with the objective of reducing the negative effects associated with traffic congestion. These measures aim to achieve the safe and efficient movement of road users, whether private or commercial; and they are needed because many road users act inappropriately to the road conditions in which they find themselves [27]. Examples of this group of measures include the Intelligent Transport Systems, introduction of delivery lanes or road pricing.

Another important area that can enhance the efficiency of the City Logistics is the *enforcement and promotion*. This group of measures is intended to work together with the others creating combined solutions [25]. Local authorities can use promotion tools to support specific practices without the need to impose them, while the enforcement tools are used to guarantee that the regulations are obeyed. Some examples include law and regulations enforcement [28], however most popular are the measures related to parking enforcement. Other examples of this type of measures include the use of technology to improve parking spaces' monitoring, the use of the internet to schedule the use of loading/unloading bays according to the user needs, and real-time recognition of vehicles with cameras or sensors.

3 ITS Project Evaluation

3.1 Definition of Intelligent Transport Systems (ITS)

The term "Intelligent Transport Systems" (ITS) speaks for itself. ITS stands for intelligent systems that improve the efficiency, security and operational conditions of transport networks. This concept refers to the innovations in transportation that use advanced electronics and information technologies to improve the performance of highways, vehicles and public transport systems. For Gurínová, *"ITS refers to a variety of tools, such as traffic engineering concepts, software, hardware and communications technologies, that can be applied in an integrated fashion to the transportation system to improve its efficiency and safety"* [30, p. 1]. Maccubbin, Staples, & Kabir highlight that ITS improve transportation safety and mobility, and enhance productivity through the use of advanced communication sensors, and information processing technologies encompassing a broad range of wireless communications-based information and electronics [31].

Following these definitions of ITS, we can conclude that the ITS system is based on 3 key elements: the driver, the infrastructure and the vehicle, which interact between them to achieve the objectives purposed [32]. And this idea is based on Benouar because he expressed that *"ITS is a system of systems which includes the driver (behavioral characteristics, human machine interface, etc.), the vehicle (personal, transit, etc.) and the infrastructure"*

3.2 Private versus Public sector evaluation

In most European countries, transport infrastructures are mainly public owned, consequently the majority of investments in this area tend to be oriented in achieving a variety of social objectives, which is the opposite objective of private investment. These public investment projects need the appropriate methods of evaluation to guide the choice of the better alternative and the allocation of scarce resources. According to Bristow & Nellthorp [33] the social objectives of public investment appraisal commonly include: economic efficiency, which is measured using a social cost-benefit analysis; diminishing environmental damage, which is measured by the results of an environmental impact assessment; and other examples related to equity, accessibility, long-term cash-flow or achievement of regional development policies.

As for the privately funded projects, they also need to produce benefits to their developers but in terms of increased sales revenue or company prestige, among others. The private company point of view allows a financial Cost-Benefit Analysis (CBA) (which is a special case of socio-economic CBA) with the main focus on the single stakeholder that is the investor. The private sector has a consistent rational behavior of making decisions for profit-maximizing, but for the public sector the decision is rational if it's made with the objective of maximizing social welfare.

3.3 Cost-Benefit Analysis (CBA)

When evaluating ITS projects, whether it is a private company or a public authority, the most popular evaluation method, despite having some limitations, is the Cost-Benefit Analysis (CBA) (Salling & Leleur, 2011; van Wee, Bohte, Molin, Arentze, & Liao, 2014; van Wee, 2012; Barfod, Salling, & Leleur, 2011; Bristow & Nellthorp, 2000; Riedel & Dziekan, 2006; Lee Jr., 2004; Zhicai, Jianping, & McDonald, 2006). Basically a CBA is an overview of all the pros (benefits) and cons (costs) of a project or policy option. These costs and benefits are as much as possible quantified and expressed in monetary terms. Costs and benefits that occur in different years are discounted and presented as so called net present values (NPV). Final results are often presented in summarizing indicators, such as the difference between costs and benefits, the return on investment, and the benefit-cost ratio. This evaluation method can be used as a stand-alone quantitative method, or within a quantitative and qualitative framework, or even combined with Multi-Criteria Analysis (MCA).

Other methods of evaluation commonly used to assess the implementation of ITS are the Cost-Efficiency Analysis (CEA) and the MCA. However, according to the European Commission, "these approaches [CEA and MCA] cannot be seen as substitutes for CBA but rather as complements for special reasons, or as a rough approximation when actual CBA is impossible" (European Commission, 2008, p. 68).

4 Case-study in Lisbon

4.1 Stakeholders

Since the obstacle of the pursuit of the regulation of loading/unloading activities of the City of Lisbon was due to technological questions, it was needed to ensure, in order to start revising the regulation, that there was an efficient monitoring, in real-time, that didn't encumber the City of Lisbon. Therefore, the Municipality of Lisbon ordered that EMEL would be responsible for the implementation of a pilot project that ensured the appropriateness and feasibility of the technological solutions [37].

The stakeholders affected by the implementation of this pilot project were: authorities (EMEL and Municipality), who would be implementing the demonstration; logistic service providers/transport operators, who expectedly would increase the efficiency in their loading/unloading operations; freight receivers (shopkeepers), who would benefit from more reliable deliveries; citizens and other road users, who at one hand would be less affected by freight deliveries, but on the other hand could face more restricted parking regimes.

4.2 Location and date

The chosen place was the Guerra Junqueiro Avenue, because it has a great diversity of shops (that range from small shops to large ones) and also a variety of loading and unloading practices.

The pilot started on December 5th 2011 and ran until March 17th 2012 (15 weeks); these dates were chosen to cover the Christmas period because it is usually one of the busiest of the year.

4.3 Description of ITS alternatives

4.3.1 To-be Vehicle Detection Sensor (VDS)

The vehicle detection sensor is installed on the ground and detects the magnetic field above, which can be influenced by the proximity of vehicles, but also (although with lower impact) by other smaller magnetic objects (e.g. cans), and even by temperature or humidity. When the magnetic field changes more than a certain value (previously defined), the system interprets that as an entrance or exit of a vehicle in the LUPB.

4.3.2 To-be Adapted Parking Meters (APM)

These parking meters issue special tickets for 30 minutes of free parking for unloading/loading operations. These APM are activated when a person exposes a contactless card that was previously given to shopkeepers and transport operators (see below). The ticket must be put under the windshield to be verified by the parking officers. If the 30 minutes period expires, the parking officer may only notify the driver (as there's currently no regulation for freight operations the driver cannot be fined) [38].

5 Case-study evaluation

5.1 Data limitations

This dissertation faced some problems in obtaining data regarding the impacts that could result from EMEL's implementation of technology to ease the monitoring and enforcement of parking. In order to perform a CBA to the case study it was needed, at least, the following data: parking spaces rotation rates, numbers of the abusive occupancy, operating costs of EMEL, polluting emissions, safety of pedestrians, area of sidewalk available for pedestrians, time-savings for the transport operators, time lost by normal traffic. However the only data that was available in this pilot was the time and date when the vehicles entered and left the LUPBs, which allowed to estimate the parking times, and consequently the number of vehicles that parked for more than 30 minutes (which are seen in this work as infractions).

The **time-horizon** used was 15 years, due to the lifespans of the technologies: the VDS solution has a 5 year lifespan and the APM solution has 7.5 years of lifespan, therefore the least common multiple between the two lifespans is 15 years. With this time-horizon it is assured that both technologies can be compared in equal terms.

In this analysis it will not be used the **residual value** of the equipment, which is defined in the "Guide to Cost-Benefit Analysis of investment projects" of the European Commission as "the present value at year *n* of the revenues, net of operating costs, that the project will be able to generate because of the remaining service potential of fixed assets whose economic life is not yet completely exhausted" (European Commission, 2008, pg. 40) because the lifespan of both types of technologies coincide with the end of time horizon.

The CBA will be done for a **single parking space** of a LUPB in order to analyse the two ITS solutions with dimensionless data, because each side of the avenue has a different number of parking spaces on the LUPBs (9 parking spaces in the East side and 8 on the West side).

When performing a CBA the objective is to maximize the benefits and minimize the costs. In the case of EMEL's pilot, when the **infractions** are regarded as benefits it may lead to the idea that the objective is to maximize the infractions, which is not true.

The mission of EMEL is to perform an effective monitoring and enforcement of the parking spaces in the city of Lisbon. Nonetheless, a minimum number of infractions is always expectable regardless the level of enforcement. Such infractions, if detected and fined, will generate a revenue stream that cannot be ignored. Instead it could be used by EMEL to improve its own mission. Following this assumption, the revenues can be considered as a financial benefit to EMEL and, therefore, the infractions are considered a benefit in the CBA presented in this work.

5.2 Evaluation method used

The case study of this dissertation will be evaluated with a simplified version of the CBA suggested by the European Commission in the "Guide to Cost-Benefit Analysis of investment projects", due to: the small dimension of the project to be analysed; since there were some indirect impacts that were not possible to estimate (these data limitations are better explained in the sub-chapter 6.1); and because the analysis will be based on the financial perspective.

Therefore, the analysis will be a simplified CBA that will follow these steps:

1. Definition of the objectives and project identification;
2. Financial analysis using the DCF methodology and the suggested discount rate of 5%;
   - 2.1. Discount benefits and costs to obtain present values:
     - 2.1.1. $PV(B) = \sum_{t=0}^{n} \frac{B_t}{(1+s)^t}$
     - 2.1.2. $PV(C) = \sum_{t=0}^{n} \frac{C_t}{(1+s)^t}$
3. Where s is the discount rate and t is the year.
   - 3.1. Compute the net present value of each alternative:
     - 3.1.1. $NPV = PV(B) - PV(C)$

4. Sensitivity analysis to identify the critical variables.

The step of economic analysis was not included because the CBA is done through financial perspective, and a risk analysis was not included since the case study of this dissertation has a lack of statistical data that is needed to proceed with an analysis of this type.

5.3 To-be VDS

5.3.1 Variables

The **time-horizon** that is used in this analysis is 15 years, because it is the minimum number of years with which we can compare both technologies, since the sensors have a 5 years lifespan (3 acquisitions) and the APM have 7,5 years (2 acquisitions). The **rate of parking fines in the first year** and **parking fines in the first year** are directly related to the number of parking fines detected during the pilot. When the **rate of parking fines in the first year** is 100% it means that it is expected that the results of the pilot are repeated throughout the year. The number of **parking fines in the first year** is a prediction of the numbers of the pilot for a 52 weeks period (1 year). Since this analysis will be done for a single parking place of the LUPBs, the estimation of this variable was made like this:

- It were detected 120 parking fines during the pilot (15 weeks);
- With this average it is expected to have 416 parking fines per year (52 weeks);
- Since we have 9 parking places, the number of parking fines for each parking place is 47.

The value used for the **discount rate** is 5,0%, as it was used in the Finish "Guidelines for the evaluation of ITS projects" (Kulmala *et al.*, 2002, pg. 45) and it is also the value suggested on the European Commission's "Guide to Cost-Benefit Analysis of investment projects" (European Commision, 2008, pg. 18). During the pilot there were some sensors that were damaged and needed to be replaced, therefore the author created a variable to study the impact of the number of **sensors damaged per year** in the results. With the introduction of an automatic process of detecting infringements, there is the possibility that the number of parking fines is reduced because the drivers are aware that the detection rate is higher, therefore they may be more careful. This possibility can be confirmed by the following examples: with the implementation of monitoring systems in a new area of Lisbon exploited by EMEL in 2012 the number of parking fines decreased 58% from the first year to the second year of implementation. And comparing the numbers of the west side of Guerra Junqueiro Avenue during the pilot (December 2011 – March 2012) with the numbers in the previous year (December 2010 – March 2011) it is possible to conclude that there has been a 57% reduction of the number of parking fines with the implementation of monitoring and enforcement systems. Therefore the variable "**reduction after the 1st year**" was created to simulate this reduction of the number of parking fines from the year of implementation (1st year) to the next. And to simulate this reduction of parking fines after the 2nd year of implementation it was created the variable "**reduction after the 2nd year**", which is, in a first stage, defined at 0%.

Table 1
Variables used in the Simplified CBA for the To-be VDS alternative

Time-horizon	15 years
Rate of parking fines in the first year	100%
Parking fines in the first year	47
Discount rate (s)	5,0%
Sensors damaged per year	0
Reduction after the 1st year	57%
Reduction after the 2nd year	0%

5.3.2 Simplified CBA

The benefits taken into account in this analysis are the money received by EMEL by issuing parking fines. It was estimated that the average of parking fines is 47 per year, therefore, with the value of 60€ of each parking fine, the benefits in the first year are 2.820,00€. And in the following years is applied the reduction of parking fines that was defined on the variables "Reduction after the 1st year" and "Reduction after the 2nd year"

It was considered 4 types of costs: technology acquisition & implementation; communications; human resources; and maintenance.

Since this analysis is made for each parking place, the costs of technology acquisition & implementation are the price of a Vehicle Detection Sensor, i.e. 400€. The costs with communication for each parking place are a fraction (1/9th) of the total costs with communication (3500 ÷ 9 = 388,89€). The costs with human resources take into account the time that EMEL's parking officers spent issuing parking tickets and moving to the LUPB after receiving an alert of an infringement. And finally, the maintenance costs (cleaning, painting, etc.) are 15.97€ per year, as this was the value given by EMEL.

After having the benefits (B) and costs (C) listed and computed it is necessary to compute the present value (PV) of each year:

$$PV_t(B_t - C_t) = \frac{B_t - C_t}{(1+s)^t}$$

Where **s** is the discount rate and **t** is the year.

Finally, we can compute the net present value of the To-be VDS alternative:

$$NPV = \sum_{t=1}^{15} PV_t(B_t - C_t)$$

The results of this Simplified CBA are shown on the summary table below.

Table 2
Summary of Simplified CBA of the To-be VDS alternative

Time-horizon	15 years
Rate of parking fines in the first year	100%
Parking fines in the first year	47
Discount rate (s)	5,0%
Sensors damaged per year	0
Reduction after the 1st year	57%
Reduction after the 2nd year	0%
Total investment in the first year	789 €
Net Present Value (€/year*parking place)	12.356 €

5.3.3 Sensitivity Analysis: discount rate

The results of this analysis show that reducing the discount rate to half (to 2,5%) will cause a 18,1% increase of the NPV, and if the discount rate increases 50% (to 7,5%) the NPV will decrease around 14,1%. We can conclude that a decrease of the discount rate is more significant than an increase of its value, but overall this variable does not have a great influence on the NPV of the To-be VDS alternative. Therefore the use of a discount rate of 5,0% is acceptable in this study.

Table 3
Sensitivity analysis of the: discount rate

	s=2,5%	s=4,0%	s=5,0%	s=6,0%	s=7,5%
NPV	14.594 €	13.182 €	12.356 €	11.609 €	10.618 €
Δ	18,1%	6,7%	0,0%	-6,0%	-14,1%

5.3.4 Sensitivity Analysis: sensors damaged per year

The number of sensors damaged per year has an impact on the NPV of this alternative, because if we have to buy more sensors to replace the damaged ones this will increase the costs, therefore reducing the NPV.

Following the results of the pilot, we have to replace 4 sensors per each 4 months, which gives a total of 12 sensors damaged per year. If we consider the results of this sensitivity analysis, with 12 sensors damaged per year the NPV of the To-be VDS alternative is reduced 5.000€ to a total of 7.353€ after 15 years of implementation, which means a 40% reduction of the NPV.

Table 4
Sensitivity analysis of the number of sensors damaged per year

	0	3	6	9	12	24	28
NPV (€)	12.356	11.505	10.121	8.737	7.353	1.817	-28
Δ	0%	-7%	-18%	-29%	-40%	-85%	-100%

We can conclude that 28 is the number of sensors damaged (which means an average of around 3 sensors replaced on each parking space) that makes the To-be VDS alternative unviable, because the NPV decreases around 100%. Another conclusion is that this variable has a great influence in the NPV, because if the results of the pilot are repeated on the next 15 years, i.e. 12 sensors are damaged on each year, the NPV decreases 40%, but on the other hand throughout the 15 years the technology of the sensors may be improved and the sensors may become more resistant, which can decrease the number of sensors damaged.

5.3.5 Sensitivity Analysis: Reduction of parking fines after the first year and after the second year

To assess the importance of the two variables that simulate the reduction of parking fines over time it was used a 3D surface graph. As the two variables are studied at the same time it is possible to evaluate the best case scenario and also the worst case scenario.

If the number of parking fines stays the same over 15 years (47 parking fines, which means an average of almost 1 parking fine per day) we will have a NPV of 27.421€.

If we reduce the number of parking fines **after the 1st year** 20%, and keeping it for the next 14 years (the **other variable is 0%**), the NPV decreases around 20,4% to 21.838€. But if we do the opposite, fixing the **reduction after the 1st year** at 0% and increasing the variable **reduction after the 2nd year** to 20%, the NPV will decrease 57,6% to the value of 11.631€. We can conclude that the variable **reduction after the 2nd year** has a greater impact on the NPV.

In the worst case scenario, with the **reduction after the 1st year** at 95% and **reduction after the 2nd year** at 25% the NPV is still positive (1.969€), this means that this alternative is worthwhile.

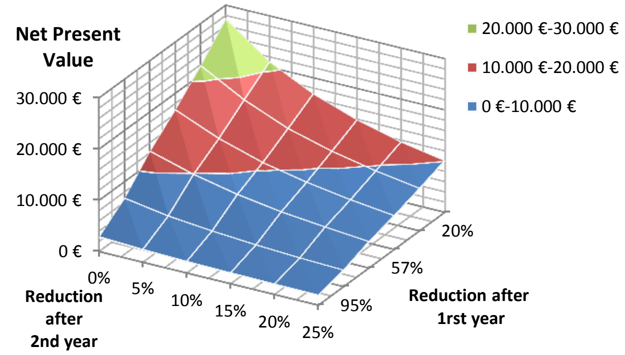

Figure 1- Sensitivity analysis of the To-be VDS alternative: Reduction of parking fines over time

5.3.6 Prediction for all LUPBs in Lisbon

According to EMEL there are 1577 LUPBs in Lisbon, therefore a prediction can be made based on the results of the Simplified CBA that were presented before.

It were considered the results of the sensitivity analysis which led the author to define some variables with different values than the ones used before, with the objective of better simulating what would happen if we would implement the To-be VDS alternative.

The **number of sensors damaged per year** was defined as 6 because the author believes that the pilot's results (12 sensors damaged per year) would decrease over time, and the **reduction after the 2nd year** was fixed at 5% to simulate a reduction of parking fines over time.

This prediction gives a Net Present Value of 12.0 M€ after 15 years of operation, with 1.6 M€ that need to be invested in the first year to implement this technologies on all LUPBs exploited by EMEL in Lisbon.

Table 5
Prediction for all LUPBs in Lisbon - VDS

Time-horizon	15 years
Rate of parking fines in the first year	100%
Parking fines in the first year	74.119
Discount rate (s)	5%
Sensors damaged per year	6
Reduction after the 1st year	57%
Reduction after the 2nd year	5%
Total investment in the first year	1.664.611 €
Net Present Value	**12.067.853 €**

5.3.7 *Critical number of parking fines*

This critical number of parking fines is the lowest number of parking fines that gives a positive NPV at the end of the 15 years. Using the values of the variables defined for the prediction to all LUPBs in Lisbon, the number of parking fines has to decrease to 31% of the prediction made from the results of the pilot (15 parking fines) for the NPV to become the lowest positive possible.

Table 6
NPV of the scenario with the critical number of parking fines

Rate of parking fines in the first year	30,0%	31,0%
Parking fines in the first year	14	15
Discount rate (s)	5,0%	5,0%
Sensors damaged per year	6	6
Reduction after the 1st year	57%	57%
Reduction after the 2nd year	5,0%	5,0%
Total investment in the first year	1.056 €	1.056 €
Net Present Value (€/year*parking place)	-97,17 €	94,45 €
NPV prediction for all LUPBs in Lisbon	-153.234 €	148.945,40 €

5.4 *To-be APM*

5.4.1 *Variables*

The variables used to analyze this alternative are all the same, with only two exceptions. There is not a variable for the number of sensors damaged per year because this alternative doesn't use sensors. And the number of **parking fines in the first year** is different: it is a prediction of the numbers of the pilot for a 52 weeks period (1 year). Since this analysis will be done for a single parking place of the LUPBs the estimation of this variable was made like this:

- It were detected 75 parking fines during the pilot (15 weeks);
- With this average it is predicted to have 260 parking fines per year (52 weeks);
- Since we have 8 parking places, the number of parking fines for each parking place is 33.

Table 7
Variables used in the Simplified CBA of the To-be APM alternative

Time-horizon	15 years
Infraction rate in the first year	100%
Infractions in the first year	33
Discount rate (s)	5,0%
Reduction after the 1st year	57%
Reduction after the 2nd year	0%

5.4.2 *Simplified CBA*

As it was explained before, the benefits taken into account in this analysis are the money received by EMEL by issuing parking fines. It was estimated that the average of parking fines is 33 per year, therefore, with the value of 60€ of each parking fine, the benefits in the first year are 1.980,00€. And in the following years is applied the reduction of parking fines that was defined on the variables "Reduction after the 1st year" and "Reduction after the 2nd year"

It was considered 4 types of costs: technology acquisition & implementation; communications; human resources; and maintenance.

Since this analysis is made for each parking place, the costs of technology acquisition & implementation are a fraction of the total cost of the two Adapted Parking Meters (5000€ each). The two APMs serve a total of 40 parking places, and we have 8 parking places on LUPBs, which gives a cost with APM of 2.000€ for those 8 parking places. To estimate the cost for each parking place we have to divide these 2.000€ for 8, which gives us 250€. This cost we have to repeat every 7.5 years because that is the lifespan of the technology. The costs with communication for each parking place are a fraction (1/8th) of the total costs with communication ($5000 \div 8 = 625{,}00€$). The costs with human resources take into account the time that EMEL's parking officers spent issuing parking tickets and monitoring the LUPBs of the avenue. And finally, the maintenance costs (cleaning, painting, etc.) are 15.97€ per year, as this was the value given by EMEL.

Table 8
Summary of Simplified CBA of the To-be APM alternative

Time-horizon	15 years
Infraction rate in the first year	100%
Infractions in the first year	33
Discount rate (s)	5,0%
Reduction after the 1rst year	57%
Reduction after the 2nd year	0%
Total investment in the first year (€/parking place)	875 €
Net Present Value (€/year*parking place)	**8.340 €**

5.4.3 *Sensitivity Analysis: discount rate*

The results of this analysis show that reducing the discount rate to half (to 2,5%) will cause a 18,7% increase of the NPV, and if the discount rate increases 50% (to 7,5%) the NPV will decrease around 14,5%. We can conclude that a decrease of the discount rate is more significant than an increase of its value, but overall this variable does not have a great influence on the NPV of the To-be APM alternative. Therefore the use of a discount rate of 5,0% is acceptable in this study.

Table 9
Sensitivity analysis of the To-be APM alternative: discount rate

	s=2,5%	s=4,0%	s=5,0%	s=6,0%	s=7,5%
NPV (€)	9.904	8.917	8.340	7.819	7.127
Δ	18,7%	6,9%	0,0%	-6,3%	-14,5%

5.4.4 Sensitivity Analysis: Reduction of parking fines after the first year and after the second year

To assess the importance of the two variables that simulate the reduction of parking fines over time it was used a 3D surface graph. As the two variables are studied at the same time it is possible to evaluate the best case scenario and also the worst case scenario.

If the number of parking fines stays the same over 15 years (33 parking fines) we will have a NPV of 19.015€.

If we reduce by 20% the number of parking fines **after the 1st year**, and keeping it for the next 14 years (the **other variable is 0%**), the NPV decreases around 21% to 15.081€. But if we do the opposite, fixing the **reduction after the 1st year** at 0% and increasing the variable **reduction after the 2nd year** to 20%, the NPV will decrease 58% to the value of 7.911€. We can conclude that the variable **reduction after the 2nd year** has a greater impact on the NPV, so it is in this one that we have to take more time on its calibration if we want to simulate what would happen in reality with the implementation of the To-be APM alternative.

In the worst case scenario, with the **reduction after the 1st year** at 95% and **reduction after the 2nd year** at 25% the NPV is still positive (1.146€), this means that this alternative is worthwhile.

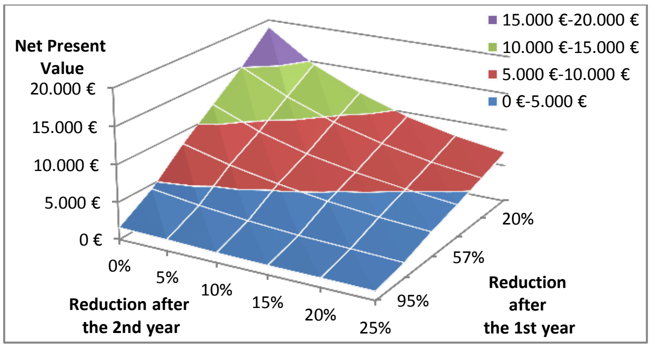

Figure 2 - Sensitivity analysis of the To-be APM alternative: Reduction of parking fines over time

5.4.5 Prediction for all LUPBs in Lisbon

According to EMEL there are 1577 LUPBs in Lisbon, therefore a prediction can be made based on the results of the Simplified CBA that were presented before.

In this alternative it were also considered the results of the sensitivity analysis, which led to the definition of the variable **reduction after the 2nd year** to 5%, in order to simulate a reduction of parking fines over time.

This prediction gives a Net Present Value of around 10.7 M€ after 15 years of the operation, with almost 1.4 M€ that need to be invested in the first year to implement this technologies on all LUPBs exploited by EMEL in Lisbon.

Table 10
Prediction for all LUPBs in Lisbon - APM

Time-horizon	15 years
Infraction rate in the first year	100%
Infractions in the first year	52.041
Discount rate (s)	5,0%
Reduction after the 1st year	57%
Reduction after the 2nd year	5%
Total investment in the first year (€)	1.379.875 €
Net Present Value (€)	**10.534.649 €**

5.4.6 Critical number of parking fines

As it was explained when studying the To-be VDS alternative, the critical number of parking fines is the one that gives the lowest positive NPV. Using the values of the variables defined for the prediction to all LUPBs in Lisbon, the number of parking fines has to decrease to 11% of the prediction made from the results of the pilot (4 parking fines) for the NPV to become the lowest positive possible.

Table 11
NPV of the scenario with the critical number of parking fines

Rate of parking fines in the first year	12,0%	14,0%
Parking fines in the first year	4	5
Discount rate (s)	5,0%	5,0%
Reduction after the 1st year	57,0%	57,0%
Reduction after the 2nd year	5%	5%
Total investment in the first year	875,00 €	875 €
Net Present Value (€/year*parking place)	-134 €	13 €
NPV prediction for all LUPBs in Lisbon	**-211.888€**	**19.983 €**

6 Discussion of results and conclusions

The results of the Simplified CBA show that the To-be VDS alternative gives a higher NPV than the To-be APM alternative. But both ITS solutions pay the investment at the end of the first year of implementation, and both give a positive NPV at the end of the 15 years.

Table 12
Results of the Simplified CBA using a reduction of parking fines after the 2nd year

	To-be VDS using a reduction of parking fines after the 2nd year	To-be APM using a reduction of parking fines after the 2nd year
Time-horizon	15 years	15 years
Rate of parking fines in the first year	100%	100%
Parking fines in the first year	47	33
Total investment in the first year	1.056 €	875 €
Net Present Value	9.888 €	6.680 €
NPV prediction for all LUPBs in Lisbon	15.593.317 €	10.534.649 €

With the sensitivity analysis we can conclude that the variable with greater influence on the NPV of both ITS solutions is the reduction (of parking fines) after the second year of implementation, and the discount rate of 5,0% can be used in this analysis. The results of the Simplified CBA using a reduction of 5% of the parking fines after the 2nd year show that the NPV of both alternatives is much closer than before.

But to compare both alternatives we have to fix the number of parking fines and then compare the NPV given by the analysis of ITS solutions:

Table 13
Results of the Simplified CBA with the same number of parking fines

	To-be VDS	To-be APM
Time-horizon	15 years	15 years
Rate of parking fines in the first year	100%	142%
Parking fines in the first year	47	47
Total investment in the first year	1.056 €	875 €
Net Present Value	9.888 €	10.019 €
NPV prediction for all LUPBs in Lisbon	15.593.317 €	15.799.420 €

We can conclude that with the same number of parking fines, the To-be APM alternative is the one that has a higher NPV after the 15 years. This result is due to the fewer operation costs that this alternative has, when compared to the To-be VDS alternative.

The same conclusion can be drawn when analyzing the critical number of parking fines of both alternatives (
Table 14).

Since the critical number of parking fines of the To-be APM alternative is lower than the other ITS solution, it is expected that with the same number of parking fines the alternative of the APMs has the higher NPV at the end of the time-horizon of the analysis. This means that this alternative needs a lower investment at the first year and it presents a fewer risk of investment, since it needs less parking fines per year to pay the initial investment costs.

	Critical number of parking fines of To-be VDS	Critical number of parking fines of To-be APM	To-be APM with the same number of parking fines
Time-horizon	15 years	15 years	15 years
Rate of parking fines in the first year	31%	11%	45%
Parking fines in the first year	15	4	15
Total investment in the first year	1.056 €	875 €	875 €
Net Present Value	94 €	13 €	2.406 €
NPV prediction for all LUPBs in Lisbon	148.945 €	19.983 €	3.794.893 €

	Critical number of parking fines of To-be VDS	Critical number of parking fines of To-be APM	To-be APM with the same number of parking fines
Time-horizon	15 years	15 years	15 years
Rate of parking fines in the first year	31%	11%	45%
Parking fines in the first year	15	4	15
Total investment in the first year	1.056 €	875 €	875 €
Net Present Value	94 €	13 €	2.406 €
NPV prediction for all LUPBs in Lisbon	148.945 €	19.983 €	3.794.893 €

It is the author’s opinion that the decision between these two ITS solutions should not only be focused on the NPV because the alternatives have different strengths and weaknesses.

The solution with the VDSs still has some errors on detecting the presence of the vehicle, but it can monitor the activities on the LUPBs continuously. The problems with this solution are: the actual lifespan, because it still presents some problems with the batteries and is very vulnerable to vandalism acts; and not being able to identify the vehicles that park on the LUPBs.

The other solution, with the APMs, is more dependent on human resources and goes against one of the objectives: reduce costs with human resources and create a more automatic enforcement system. But has the advantage of identifying all the allowed vehicles that use the LUPBs. One idea of future developments would be to perform a wider search for entities that use the LUPBs, in order to supply more parking cards. And each entity had to provide the actual time needed to perform their loading/unloading activities. During the observations periods it was possible to identify that there are some deliveries that have to take more than 30 minutes to be accomplished (a big truck unloading supplies to a supermarket), and that there are other types of vehicles that use the LUPBs: vehicles that are related to construction works, and even vehicles that belong to street vendors. The author would recommend creating another parking card for deliveries that would take longer than 30 minutes, but this could generate some difficulty in the attribution of these cards, because the majority of the transport operators would want to be considered an exception, i.e. to have more than 30 minutes for doing its loading and unloading activities.

Table 14
Critical number of parking fines of both ITS solutions

The author would recommend a combined solution with both technologies, having the sensors on the ground of the parking place and the adapted parking meters on the nearest sidewalk (serving both types of parking: on LUPBs, and the regular on-street parking), following what was done in Bilbao, on the FREILOT project: sensors are used to detect the presence of the vehicle, the schedule of deliveries is defined on a website and an electronic card identifies the vehicle and tells the driver if he is allowed to park. A prediction of the results of a Simplified CBA applied to a solution of this kind is given below (the costs associated with the website were not taken into account):

Table 15
Estimate of the results of a Simplified CBA of the combined solution

	VDS + APM
Time-horizon	15 years
Rate of parking fines in the first year	100%
Parking fines in the first year	47
Total investment in the first year	1.931 €
Net Present Value	6.397 €
NPV prediction for all LUPBs in Lisbon	10.088.725 €

However, the decision between these two ITS solutions would rely on the decision-maker, and if he/she would think that the NPV would be more important, then the To-be APM would be the chosen one. But if the necessity of an automatic and permanent monitoring system was more relevant, then it would be the To-be VDS alternative that would be implemented.

This work encountered several limitations, which were presented above, which opens the way to new studies and future developments.

Other ITS solutions, using other technologies (or other versions of the technologies used), should be tested in Guerra Junqueiro Avenue to provide different results. Projects like the one in Bilbao or in Treviso could be used as guidelines to these new studies, since they use similar technologies (floor sensors and adapted parking meters) and provided good results in those cities. The example from Treviso implemented the floor sensors below the ground, which is a way to avoid the damaging of the sensors trough vandalism acts. The idea of a monitoring system that uses both adapted parking meters and sensors at the same time could be taken from Bilbao (project FREILOT) and also from the experience in Treviso (i-Park Trevisosta), which used a system that includes sensors, adapted parking meters and also variable messaging signs that gave interesting results.

The study of the pilot could be completed with the data needed to proceed with a complete CBA (and not the simplified version that was used in this work) by proceeding with studies focused on analysing the air quality, parking spaces rotation rates, numbers of the abusive occupancy, operating costs of EMEL, polluting emissions, safety of pedestrians, area of sidewalk available for pedestrians, time-savings for the transport operators, and time lost by normal traffic, just to name a few. This new data could be used to perform a more complete CBA, which could give another perspective of the implementation of the sensors and adapted parking meters that were used in Guerra Junqueiro Avenue.

Finally, the pilot should be extended to other parts of the city of Lisbon with the purpose of testing the technologies in different streets with other characteristics (larger, wider, etc.) and other dynamics.

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