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Smart Parking management in a Smart City: costs and benefits

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Abstract— **Today cities are responsible for more than 75% of waste production, 80% of emissions, and 75% of energy utilization. With regard to Europe, road transportation produces about 20% of the total CO_2 emissions, out of which 40% is generated by urban mobility. It is estimated that vehicles cruising for free parking spaces cause 30% of the daily traffic congestion in an urban downtown area. In this article we attempt to show, through a simulation and an assessment model, how ITS may impact on urban parking management considering both people and freight transportation, and quantified the economic and social benefits which can be obtained. Although some benefits have been already examined by previous authors (e.g. in terms of reduction of time spent in searching a free parking spot), there is still a general lack of quantitative models able to assess the impacts of ITS technologies for urban parking. In this regard, one distinctive contribution of this article is that it combines people and freight transportation modes in a single model. First, we developed a model in order to simulate the urban parking system before and after the adoption of the Smart Parking solution. The output of the simulation model consists in the percentage reduction of the time spent by drivers of cars and vans in searching a free parking spot. Then, this percentage has been used to assess the economic and social benefits of a Smart Parking application in the City of Milan (Italy), in which the "pay and display" parking spots are provided with sensors able to communicate if the space is free or not. The analysis considers two perspectives: on the one hand the parking operator company, which can increase its revenue due to the reduction of people that do not pay for parking. On the other hand, the city-users (i.e. citizens, tourists, off-site students, etc.), who can reduce the time spent for searching a free parking spot, thus reducing fuel consumption and CO_2 emissions. The results obtained showed that these technologies would help each driver to save an average of 77.2 hours every year, 86.5 euros in fuel costs, and the entire city of Milan could reduce CO_2 emissions by 44,470 tons per year (out of a total of 4,144,000 tons annually produced by road traffic in the area of Milan). In addition, these technologies help the parking operator company in improving the total revenue of around 9 million euros per year. If considering the required costs to implement the Smart Parking solution, the Discounted Payback Period for the parking operator is lower than 2 years.**

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I. INTRODUCTION

Urban population is expected to significantly grow in the next decades: from 3.9 billion people that already live in cities (54% of the whole global population) to 6.3 billion by 2050 (i.e. 66%). Today cities are responsible for more than 75% of waste production, 80% of emissions, and 75% of energy utilization [1]. With regard to Europe, road transportation produces about 20% of the total CO_2 emissions, out of which 40% is generated by urban mobility [2]. In recent years, growing attention has been paid to "smart" traffic management in Europe, which is one of the main challenges of the so called "Smart Cities". Smart Cities are considered the natural result of the evolution of cities – from knowledge-based cities, through digital cities (cyber-cities), up to cities based on several technologies used to increase economic development, job growth and quality of life of citizens, considering the urban infrastructure and its components [3] [4] [5] [6] [7]. Digital technologies play a crucial role in the Smart Cities, as they are an enabler to improve attractiveness and sustainability, in terms of social, economic and environmental impact. At the same time, technological propagation is not an end in itself, but only a means to reinventing cities for a new economy and society with clear and compelling community benefit [5].

With regard to sustainable mobility, the optimal management of parking areas represents a fundamental aspect. Parking space is usually very limited in major cities, thus leading to traffic congestion, air pollution, and driver frustration [8]. Indeed, it has been assessed that finding a free parking spot could take more than 20 minutes on average [9]. As highlighted in [10], it has been estimated that vehicles cruising for free parking spaces cause 30% of the daily traffic congestion in an urban downtown area, with a consequent proportion of CO_2 emissions [11]. Furthermore, some drivers, frustrated by the lack of parking spaces, often use the parking spots reserved for people with special needs, such as the disabled, with negative social impacts [12].

In such a complex environment, Intelligent Transportation Systems (ITS) can mitigate these problems, thus improving transportation sustainability by controlling systems more efficiently, facilitating behavioral changes and reducing fuel consumption [13]. More specifically, in recent years new ITS solutions based on Internet of Things (IoT) technologies emerged for parking management. They are typically based on sensors or cameras, wireless communication technologies and smart applications to provide drivers with the information of the free parking spots [14] [15].

It can be observed that articles on ITS for urban parking are mainly focused on technology aspects, neglecting value creation (e.g. cost-benefit analyses) or addressing the topic in a very marginal way (e.g. [16], [17], [18]). For example, in [16] the authors put the focus on the design and implementation of a smart parking management system based on the RFId (Radio Frequency Identification) without assessing the benefits for citizens and local authorities achievable in that context. In [17] the authors proposed a multi-agent model that defined a set of global functioning rules for a flexible governance, adapted to parking management within a city, but they did not put the focus on value creation and on costs and benefits derived by the model.

Moreover, recent technological solutions have been just marginally considered. Specifically, the analyzed articles mainly focused on the use of real-time variable message signs, such as directional arrows, names of the parking facilities and number of available parking spaces in each facility. As a matter of fact, during the past two decades traffic authorities in many cities started to adopt these solutions [19] [20]. More recent articles investigated the opportunities enabled by IoT technologies for parking systems considering the point of view of cars drivers, with the possibility to monitor in real time the nearest free parking spot directly through their smartphone. In this regard, in [12] the authors presented, from a technological viewpoint, a new Smart Parking system based on the jointly use of different technologies, such as RFId, WSN - Wireless Sensor Networks, NFC - Near Field Communication, Cloud, and mobile. It was able to collect, in real time, information about the occupancy state of the parking spaces, and to direct drivers to the nearest vacant parking spot by using a customized software application. Just a few articles considered the point of view of commercial vehicles that move within the urban perimeter in order to find a free parking spot. For example, in [21] the authors tried to understand the truck parking problem in Florida, assessing a technology that can be used to improve parking management, and conducting a pilot project to test a smart truck parking management technology to make better utilization of commercial parking spaces at public rest areas. Once again, the main focus was technology, and just some qualitative considerations about the expected benefits were provided.

Two main research gaps emerged from the analysis of the extant literature. First, most articles just focused on technology: although some benefits have been examined in terms of travel time reduction and environmental effects, there is still a lack of quantitative models to measure the overall impacts of new ITS technologies for parking management [22]. Second, a few papers considered freight transportation, and none of them jointly modeled people and freight transportation. Although a certain number of authors (e.g. [23], [24]) made a first attempt to summarize in a qualitative way the positive effects on citizens due to the adoption of ITS for freight transportation, a quantitative evaluation is still missing. In order to fill these research gaps, this article aims to illustrate how new ITS solutions may impact on urban parking management considering both people and freight transportation, and to quantify the economic and social benefits that can be obtained. A model intended to simulate a parking management system considering both freight and people transportation has been developed. This model has been used to compare a traditional context, in which drivers do not have any information, with an innovative Smart Parking system based on ITS able to provide instructions to reach the nearest free parking place. The simulation model allowed the estimation of the amount of time saved in searching the free parking space. Then, the article presents a quantitative assessment of the costs and the economic and social benefits that can be obtained. The results have been obtained considering a real context (i.e. using the data of the City of Milan, Italy).

II. URBAN SMART PARKING FOR FREIGTH AND PEOPLE TRANSPORTATION: A SIMULATION MODEL

A. *Scope of the analysis*

The purpose of the developed model was to be able to simulate an urban parking management system considering both freight (i.e. trucks) and people transportation (i.e. cars), in order to compare the current AS IS scenario (i.e. considering bottlenecks and queue times), and an innovative Smart Parking system in which ITS are used (TO-BE scenario). In the ITS-enabled scenario several technologies (GPS - Global Positioning Systems, WSN, gateways) were considered in order to support both trucks and cars drivers.

The high number of commercial vehicles and cars in urban areas, largely in peak hours, cause considerable problems in terms of traffic congestion. In a traditional situation, it is impossible to predict where are the nearest available parking spots and how to reach them. This leads not only to a loss of productivity for companies, but also generates negative impacts on car drivers' frustration and on the environment. Using ITS solutions, it becomes possible to significantly reduce both the time and the costs required to reach the destination. Sensors are placed under parking spaces and communicate via a low power wireless network to a gateway. This gateway is connected by broadband to a server that allows transparent access to the sensors. Such sensors are very low cost and non-intrusive. Thus, they are suitable to be deployed on a large scale and have low power consumption [25]. Nevertheless, maintenance costs a lot, and therefore it is necessary to have an efficient way messages can be sent correctly, in order to save the sensors battery life.

B. *Simulation model*

The parking management system was simulated in Arena 10 Rockwell software. This software is a powerful interactive visual modeling and simulation tool that performs business process analyses supporting the optimal allocation and scheduling of resources while attaining real performance improvements (e.g. time, costs, quality, service levels, speed). The model was applied in order to compare the time spent by cars and trucks drivers for searching available parking spots in two scenarios, i.e. traditional (AS IS) vs. innovative Smart Parking based on ITS (TO BE).

The model has been developed based on the following assumptions:

- Vehicles do not leave the system after entering the queues;
- No interruption occurs to the traffic flow because of accidents and breakdowns.

The following paragraphs describe the two scenarios (AS IS and TO BE) in detail.

C. AS IS scenario

The AS IS model (i.e. an urban parking system in which ITS are not adopted) is composed of 54 public modules that can be classified into 6 different typologies (depending on the functionalities enabled), called Create, Assign, Record, Process, Decide and Dispose. First, there are two different entry routes in the system depending on the type of vehicles, i.e. cars or trucks. Traffic congestion is non-stationary, since it varies significantly during the day. As expected, traffic is heavier during the morning (08:00 A.M. - 09:00 A.M.) and evening (05:00 P.M. - 07:00 P.M.) rush hours, and tapers off during off-peak hours. Therefore, among the functions available in Arena, the exponential distribution was used, because it is able to gather this aspect [26]. The input data of the model were collected thanks to several observations made by the authors: TomTom MyDrive tool was used in order to analyze data of cars and trucks drivers (e.g. inter arrival time of cars and trucks, average delay due to traffic congestion) along the main roads of Milan (Italy).

Then, four streets - chosen because they presented average traffic conditions - were modeled through four Process modules, in order to simulate the traffic congestion and the consequent delay of trucks and cars in searching a parking spot. To verify the current number of vehicles in the parking spot queue, two Assign modules were allocated and they were respectively positioned before and after of the search parking Process. In this way, incrementing and decrementing a variable, which represents the number of vehicles currently in the queue, it was possible to quantify the queue and then assign a search parking time according to it (Fig. 1).

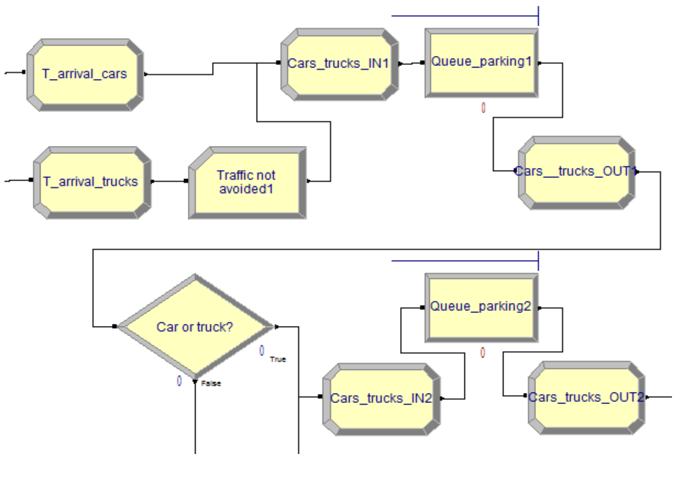

Fig. 1. Simulation model: a portion of the AS IS scenario

D. TO BE scenario

Although formally similar to the previous one, the operation of the TO BE model (i.e. the urban parking system in which ITS are adopted) is completely different. The major difference lies in the choice of the road by the truck and car drivers, which is based on real time information on the nearest available parking spot and the best route to reach it (Fig. 2). In addition, for trucks drivers it is possible to book the parking place. Indeed, the end user is notified of the arrival of truck and then it reserves a parking space that will be accessible only through the recognition of the RFId tags attached to the commercial vehicle.

In order to simulate this situation, two Assign modules, located downstream and upstream of the road transportation process, have been used in order to count in real time the number of vehicles in each queue. Furthermore, two Decide modules were added ("No parking in street1?"), for truck and car drivers respectively. These modules allow the reduction of the time spent for searching a parking spot, by providing real-time information to drivers and suggesting the best route to reach the destination.

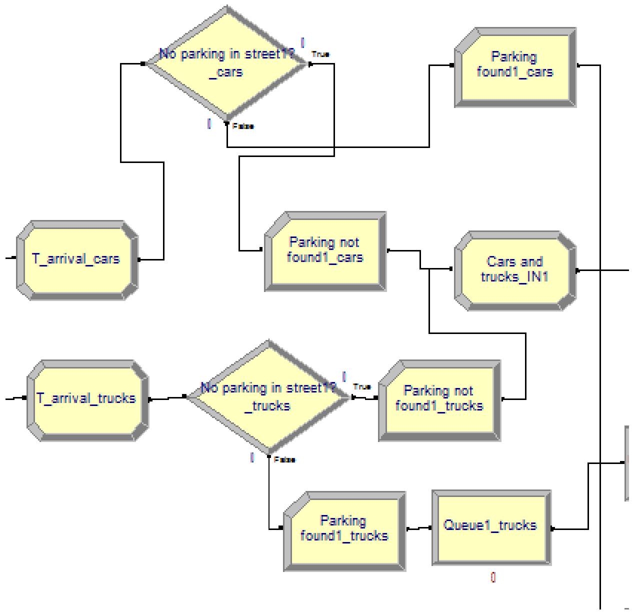

Fig. 2. Simulation model: a portion of the TO BE scenario

In Figure 3 is possible to observe a flow diagram to better understand the logic of the two simulation models (AS IS and TO BE).

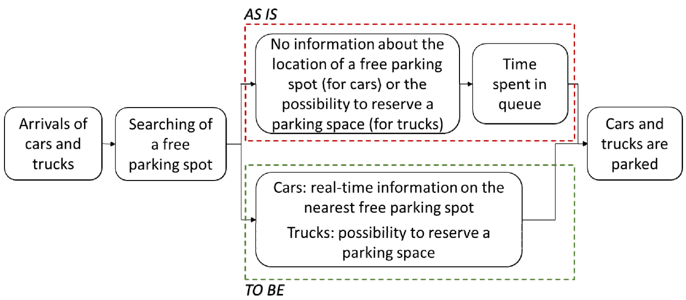

Fig. 3. Flow diagram - AS IS vs TO BE

E. Simulation results

The model was run for 12 hours - in order to replicate a typical day considering the hours with higher traffic flows (e.g. 08:00 A.M. - 08:00 P.M.) - and it was replicated 50 times to reduce the statistical variability. In order to better compare the two scenarios (i.e. AS IS and TO BE), the starting conditions were not changed. As we can see in Table I, a minimum, a maximum and an average value (calculated based on the 50 replications) were measured in order to consider the variability of the replications. As emerged from the results reported in Table I, the time required for a truck to enter and leave the system in the AS IS scenario was on average lower than one hour, while a car took about forty-five minutes to cross the system. In addition, Table 1 summarizes the simulation results in the TO BE scenario: in this case, the time spent in the system became on average thirty-six and twenty-five minutes respectively. On the basis of these results, it was also possible to calculate the reduction of the time spent in the system thanks to the possibility to collect real time information on the nearest available parking spot, which is around 40% for cars, and of 36% for trucks.

TABLE I. SIMULATION RESULTS: TIME SPENT IN THE SYSTEM (AS IS VS TO BE SCENARIO)

	AS IS SCENARIO		
	Minimum value [h]	***Average value [h]***	***Maximum value [h]***
Time spent in the system (cars)	0.23	0.33	1.15
Time spent in the system (trucks)	0.58	0.87	1.34
	TO BE SCENARIO		
	Minimum value [h]	***Average value [h]***	***Maximum value [h]***
Time spent in the system (cars)	0.21	0.28	0.99
Time spent in the system (trucks)	0.49	0.75	1.12
	Δ [h] - Δ [%]		
	Minimum value [h] [%]	***Average value [h] [%]***	***Maximum value [h] [%]***
Reduction of time (cars)	-0,02 (-8,7%)	-0.05 (-15.2%)	-0,16 (-13,9%)
Reduction of time (trucks)	-0,11 (-18,9%)	-0.12 (-13,8%)	-0,22 (-16,4%)

III. *ASSESSING THE BENEFITS AND COSTS OF A SMART PARKING APPLICATION FOR PEOPLE TRANSPORTATION*

A. *Scope of the analysis*

An assessment model was developed in order to reach the second objective of this work, i.e. measuring the costs and the economic and social benefits enabled by ITS for urban parking management considering only cars flows and cars parking spots. In particular, the model was applied considering 80,000 fee-paying car parking spots of the city of Milan The Smart Parking solution considered was composed of:

- 80,000 sensors placed under parking spaces (one for each parking spot) able to communicate real-time information via a low power wireless network to more than 200 gateways;
- a mobile App, in order to suggest to the cars drivers the nearest available parking spot and the best route to reach it;
- more than 1,200 smart parking meters able to recognize potential abnormal situations, e.g. a car that has not paid the ticket after occupying a parking spot.

The model considers on the one hand the viewpoint of the parking operator company, which has to pay the costs of sensors and of connectivity to the low power wireless network and has the possibility - thanks to the Smart Parking solution considered - to increase revenue due to the percentage reduction of people that do not pay for parking. On the other hand, also the viewpoint of city-users (i.e. citizens, tourists, off-site students, etc.) is considered, through the assessing of specific typology of benefits as the reduction of the time spent for searching a free parking spot, the reduction of CO_2 emissions and fuel consumption.

B. *Data input*

The output data obtained from simulation (i.e. percentage reduction of time spent by cars for searching an available parking spot, 15.2% on average) were used as an input for the model. The other input data entered into the model (e.g. percentage of people that usually do not pay for parking, average annual revenues from one parking spot in the city Milan, number of parking meters) derive from:

- interviews with telco operators, utility companies, parking operators, public transportation operators, technology providers;
- secondary sources (i.e. news on the web, official documents of the city of Milan);
- results of other Smart Parking projects.

In particular, the main data collected were reported in Table II.

TABLE II. DATA INPUT

DATA INPUT	**SYMBOL**	**VALUES**
Percentage reduction of time spent by cars for searching an available parking spot	a	15,2 %
Average time to find a fee-paying car parking spot [h]	b	0.33 h
Number of daily cars that search a fee-paying parking spot within the city of Milan [cars/day]	c	1,265,000 cars/day
Number of fee-paying car parking spots of the city of Milan (blue stripes)	d	80,000
Number of parking meters	e	1,210
CO_2 emissions per liter of fuel consumed [$KgCO_{2eq}$ /l]	f	2.4 $KgCO_{2eq}$ /l
Average consumption of fuel for cars during the search of a parking spot [h/l]	g	0.8 l/h
Fuel cost per liter [€/l]	h	1.4 €/l
Percentage of people that usually do not pay for parking	i	10 %
Average annual revenues from one parking spot in the city of Milan [€/year]	l	1,125 €/year
Number of days in a year	m	365 days/year
Average number of daily city-users in the city of Milan who move by cars	n	300,000 city-users/day

C. *Analysis of economic and social benefits for the parking operator company and city-users*

Starting from the data previously showed, it was possible to estimate the economic and social benefits for the parking operator company and the city-users.

In particular, (1) refers to the amount of the annual recovered revenue by the parking operator thanks to the possibility to reduce the percentage of people that currently do not pay for parking. Equations (2), (3) and (4) refer to the sphere of city-users, in terms of recovered time spent in searching a free parking spot (1), reduction of fuel consumption (3) and CO_2 emissions (4).

- Parking operator company - economic benefits

*Annual recovered revenue [€/year] = d * i * l* (1)

- City users - economic and social benefits

*Annual recovered time per city-user [h/year*city-user] =*
*(a * b * c * m) / n* (2)

*Annual reduction cost of fuel per city-user [€/year*city-user] =*
*(a * b * c * g * h * m) / n* (3)

Annual reduction of CO_2 emissions [tCO_2/year] =
*(a * b * c * f * g * m) / 1,000* (4)

The results reported in Table III showed that a Milano's Smart Parking application may potentially help each driver to save an average of 77.2 hours every year, 86.5 euros in fuel costs, and the entire city of Milan could reduce CO_2 emissions by 44,470 tons per year. In addition, these technologies help the parking operator company in improving the total revenue of around 9,000,000 euros per year.

These results underline the importance of new initiatives based on the introduction of ITS in order to increase the efficiency of an urban parking system. Moreover, the possibility to reduce the time spent in traffic roads has not only impacts in terms of time, cost and pollution, but also decrease the frustration and anxiety of car and truck drivers, thus improving their driving experience [27].

TABLE III. THE BENEFITS OBTAINED

BENEFITS	VALUES
Annual recovered revenue [€/year]	9,000,000 €/year
Annual recovered time per city-user [h/year*city-user]	77.2 h/ year*city-user
Annual reduction cost of fuel per city-user [€/year*city-user]	86.5 €/year*city-user
Annual reduction of CO2 emissions [tCO2/year]	44,470 tCO2/year

D. *Analysis of operational and investment costs for the parking operator company*

In order to obtain these benefits, the parking operator company has to sustain several costs, which are reported in Table IV. In particular, it is possible to split these costs in investment (i.e. an expense that a business incurs to create a benefit in the future) and operational (i.e. required for the day-to-day functioning of a business) costs:

- investment costs, as the cost of purchasing and installing each sensor in each one of the 80,000 fee-paying car parking spots of the city of Milan (blue stripes), or the cost of purchasing and installing the 1,210 smart parking meters, or also the cost of developing the mobile App for the city-users;
- operational costs, as the connectivity cost in order to ensure the communication between sensors and the smart parking meters, or the maintenance cost of sensors that include the replacement of 10% of sensors every year.

TABLE IV. OPERATIONAL AND INVESTMENT COSTS

INVESTMENT COSTS	VALUES
Cost of a sensor for Smart Parking - purchasing and installation [€/sensor]	100 €/sensor
Cost of a smart parking meters [€/parking meter]	3,000 €/parking meter
Cost of mobile App [€]	30,000 €
OPERATIONAL COSTS	**VALUES**
Connectivity cost [€/sensor*year]	15 €/sensor*year
Maintenance cost of sensors (10% of sensors have to be replaced every year) [€/year]	800,000 €/year
Software cost [€/year]	50,000 €/year

E. *An assessment of the Discounted Payback Period of the investment*

Finally, comparing investment/operational costs and the economic benefits that parking operator companies may potentially obtain, the model allows them to evaluate the time required to pay back the investment. The Payback Period is no more than the number of periods (years, months and days) necessary to ensure that the cumulated cash flows are equal to the initial investment, as reported in (5) and (6).

Payback Period [years] =
Investment [€] / Cumulated cash flows [€/year] (5)

Where:
Cumulated cash flows [€/year] =
(Recoverable Economic Value - Annual cost) [€/year] (6)

The Payback Period tool has several advantages, especially in complex contexts like Smart City that tends to make relatively small investments: it is easy to apply and easy to understand for most individuals. When used to compare similar investments, it can be very useful in order to understand which Smart City application is more profitable than others, in order to allow the unlocking of investments in Smart City projects. However, at the same time, it has a big limit: this tool does not consider the financial value of time. In other words, it is necessary to consider the cost of capital, "k-value", that is the cost of funds used for financing a business. In this way, the Payback Period becomes the Discounted Payback Period, which is a capital budgeting procedure used to determine the profitability of a project. A Discounted Payback Period gives the number of years it takes to break even from undertaking the initial expenditure, by discounting future cash flows and recognizing the time value of money, as showed in (7).

$$\sum_{t=0,\ DPP} [F_t / (1+k)^t - I_0] = 0 \quad (7)$$

Where:
- DPP is the Discounted Payback Period;
- t is the period (years);
- F is the Cash Flow (Recoverable Economic Value - Annual cost);
- I_0 is the initial investments;
- k is the cost of capital.

In the assessment of the Discounted Payback Period the assumption is that during the first three months of the year 0 there will not calculated benefits and period costs due to the time necessary to create the infrastructure for the functioning of the project. Table V summarizes the main data input needed to the calculation of the Discounted Payback Period and the output achieved. As we can observe, 2 years are necessary to repay the initial investment of more than 11 million euros.

TABLE V. SMART PARKING: THE DISCOUNTED PAYBACK PERIOD

DATA INPUT	VALUES
Annual recovered revenue [€/year]	9,000,000 €/year
Investment costs [€]	11,660,000 €
Operational costs [€/year]	2,050,000 €/year
Discount rate	4 %
Months needed to observe the first benefits [months]	3 months
OUTPUT VARIABLES	**VALUES**
Discounted Payback Period [years]	2 years

IV. CONCLUSIONS

This article analyzed, through a simulation and an assessment model, how Intelligent Transportation Systems (ITS) may impact on urban parking management considering both people and freight transportation, and quantified the economic and social benefits which can be obtained. Although some benefits have been already examined by previous authors (e.g. in terms of reduction of time spent in searching a free parking spot), there is still a general lack of quantitative models able to assess the impacts of ITS technologies for urban parking. In this regard, one distinctive contribution of this article is that it combines people and freight transportation modes in a single model.

The article highlighted that the Smart Parking solution considered can significantly reduce the time spent by cars and trucks driver in searching an available parking spot, allowing the reduction of CO_2 emissions and fuel consumption for city-users, and giving the possibility to the parking operator companies to pay back the initial investment in no more than 2 years. In particular, the simulation model allowed the comparison of a "traditional" urban parking scenario (AS IS, i.e. ITS are not adopted) with a more "innovative" one (TO BE), in which ITS are used to support parking management. As a result, the model provided the percentage reduction of the time spent in searching a free parking spot by cars and trucks in order to reach their destinations. Then, an assessment model was applied in order to measure the costs and the economic and social benefits enabled by ITS considering 80,000 fee-paying car parking spots of the city of Milan. The results obtained showed that these technologies would help each driver to save an average of 77.2 hours every year, 86.5 euros in fuel costs, and the entire city of Milan could reduce CO_2 emissions by 44,470 tons per year. In addition, these technologies help the parking operator company in improving the total revenue of around 9,000,000 euros per year thanks to the possibility to reduce the percentage of people that currently do not pay for parking.

This study has two potential limitation that should be noted, which can be addressed in future research activities. First, the public transportation flows (e.g. buses, trams) were not modeled in the simulation. These types of transportation are very important within the urban mobility context and the ITS technologies could enable specific priority logics in order to reduce the traffic congestion. Second, although efforts were made to be all-inclusive, the assessment model was built in order to assess the ITS-enabled benefits for cars parking management, then considering the area of urban people transportation. Future research should investigate the benefits achievable by using ITS solutions in the field of freight transportation. In this regard, a model aiming to quantify the ITS-enabled benefits (e.g. economic, environmental) is still missing.

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