Parking Sensor Network: Economic Feasibility Study of Parking Sensors in a City Environment

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***Abstract*— Wireless sensor networks (WSNs) have a variety of purposes. They are mainly used for monitoring environmental factors, like CO2 concentrations, temperature and humidity. Other applications of sensor networks focus on detecting traffic parameters, e.g. passenger flows, damaged roads and traffic lights. This paper extends the current research with an economic feasibility of a real case, deploying a wireless parking sensor network in a city environment. After modeling the service adoption, the costs and revenues of the project are estimated. The static Net Present Value (NPV) case is already highly profitable. However, like most network projects, WSNs offer many flexibility options. A business case is extended with a Real Option Analysis (ROA), in order to quantify the value of the learning possibilities. We show that the built-in flexibility in the original project raises the attractiveness of the project.**

***Index Terms*— business case, real option analysis, wireless sensor networks**

I. Introduction

Wireless sensor networks (WSNs) have multiple applications. They offer possibilities for monitoring all kind of parameters, going from detecting environmental aspects, traffic flow and network control.

Techno-economic studies on WSNs are limited. An extensive study on the current state of research in WSNs can be found in [1]. However, most studies, such as [2], [3], [4], are limited to technical solutions for energy consumption savings and monitoring, rather than the economic viability of the total system. This paper extends the current research with a complete economic analysis of the potential rollout of such a WSN, in order to monitor parking spaces in a city environment. Based on the methodology of Verbrugge et al. [5], it indicates how to build an extended economic evaluation for a specific case. Opting for an initial phased deployment opens up several future options for the management. The first phase offers learning possibilities, and the speed of the second phase is based on the results of the initial rollout. The value of these options is captured with using a Real Option Analysis (ROA) [6].

In Section II, we discuss the scope of the project. Section III continues with the network modeling and in Section IV the costs and revenues are described in detail. In Section V, the economic evaluation is performed. A static Net Present Value (NPV) analysis is performed and extended with a sensitivity and real option analysis. Conclusions and remarks are given in Section VI.

II. Parking Space Monitoring in a City Environment

A. Methodology

The general methodology for an economic evaluation consists of a four step process [5]. In the first step, the scope of the project is defined. All necessary data is collected about the targeted area, the market situation and the technologies. This data is used to cover business modeling, technical design and user adoption. In the second step, all data from the previous planning step serves as input for the cost and revenue structures. The next step is the economic evaluation. Using the static NPV analysis, a first estimate of the economic feasibility is made. The last step extends this evaluation. The sensitivity of the results to the input data is evaluated. Another method is the ROA, which captures the flexibility of the initial project.

B. Project Overview

This paper studies the feasibility of the potential deployment of a WSN to monitor the activity at individual parking spaces. The methodology above is applied to the real business case. The case covers a 6 year time period, starting in 2010. The advantages of the system are legion. The main goal of the system is aiding parking guards with the detection of illegally parked cars. Numbers indicate that only 5% of the illegal cars get fined [7]. With a more effective system, the chance of getting caught should rise, thereby raising revenues both from fines and ticket payments. A direct result of a higher chance of getting caught is a decline of traffic and parking in the center. People will park their car on the free parking spaces just outside the city center.

Other possible functions of the system are data collection and automated parking payment. The data collected from the sensors could be used to guide traffic to zones where parking spaces are still available. Electronic road signs could offer this data to interested people. A last more advanced function of the system could be guiding drivers to empty parking spaces via GPS modules.

C. Rollout Area

For our business case, we choose the city centre of Ghent (Belgium) as rollout area. This area of ca. 20 km^2 is well suited, due to the high concentration of traffic. The paid parking area in Ghent is divided in two zones. The centre zone (Zone A) is the most expensive and paying is required from 9am to 12pm. The parking tariff in the second zone (Zone B) is cheaper than in the centre zone, and payment is only necessary between 9am and 7pm. The year report of the parking company of Ghent provides useful numbers in order to define the rollout area, see Table I [8]. For the chance of getting caught, we use the numbers cited in [7]. For Zone A, since this is the most crowded and most expensive zone, the chance of being caught is considered higher. In the city of Ghent, several parking payment systems co-exist. The most used option is the parking ticket for short periods. If you want to park a whole day, a day ticket is also offered at the parking payment terminals. Next to the parking tickets, the city also offers special cards to users. Inhabitants, but also doctors and other care providers can obtain a special card. These cards are offered free of charge, but only one per household. Extra cards can be obtained for a yearly fee of €100.

TABLE I
DATA FOR THE GHENT ROLLOUT AREA IN 2008

Parameter	Total	Zone A	Zone B
Outdoor parking spaces	18,412	4,124	14,288
Monthly citation	13,418		
Fine amount		€25	€25
Outside parking revenues	€6,974,859		
Cost day ticket		€10	€3
Max. cost short period ticket		€6	€2.5

D. Adoption

Recent research showed that only a small fraction of illegally parked cars gets fined. People notice this small chance of getting caught, and adapt their behavior to these circumstances. When the chance of being caught rises, two effects take place. The first effect is that more people will pay for their parking spot. The other effect is choosing alternate ways of traffic, e.g. travelling to the city centre by public transport. These two effects can be mathematically modeled. These models will be used in Section IV to derive the revenues from the new system.

Fraction Getting Caught vs. Fraction of Motorists Paying

To model the relation between chance *x* of getting caught and the fraction *F(x)* of paying motorists, a Fisher-Pry curve is used [9]. This function typically models the adoption of a technology based on an underlying driver. In a Fisher-Pry model, the inflection point *a* is the point where the speed of adoption switches from increasing to decreasing. The slope impact factor *b* is the pace of the adoption.

$$F(x) = m * \frac{1}{1+e^{-b(x-a)}} \quad \textbf{(1)}$$

With:

$m = 100\%$	(maximum market potential)
$a = x_0 + \frac{\ln\left(\frac{1-F_0}{F_0}\right)}{b}$	(inflection point)
$b = 8$	(slope impact factor)

In this model, the underlying driver is the chance of getting caught. Increasing this chance will result in a changing amount of people paying for their parking ticket. The 'market potential' m, is the maximum of the curve. We reasonably suppose that when there is a 100% of being fined when you did not pay a parking ticket, everyone will buy a ticket. The maximum of the curve is thus 100%. The model of F(x) can be found in (1) and is depicted in Fig. 1. Two other parameters need to be estimated, *a* and *b* [10]. We choose the inflection point *a* so that the curve passes through the current situation in Ghent. Parameters x_0 and $F_0 = F(x=x_0)$ describe the current situation. The current fraction of motorists paying is F_0, while the current chance of getting fined is x_0. Parameter *a* is derived from (1). Since the new parking control method will be announced to all users, we choose for a high slope factor. Notice in Fig. 1 that even when there is no chance of being caught, there are still people paying for their ticket.

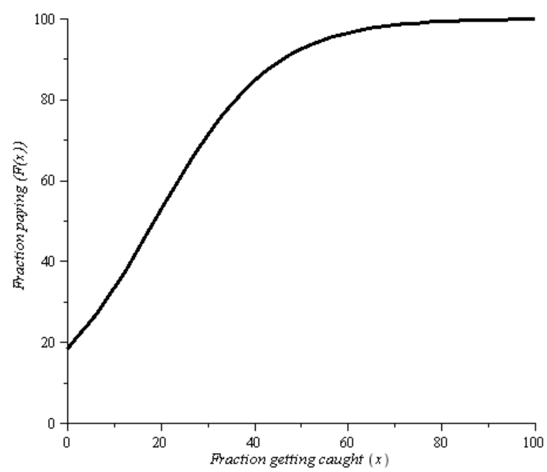

Fig. 1. F(x): Relation between fraction getting caught and fraction paying

People Choosing Alternative Ways of Traffic

Due to the higher chance of getting caught, some people will avoid coming to the city centre with their car. This is modeled with a Gompertz function [11]. This mathematical model has been found to be very well suited to predict customer adoption. The curve is fit to known values, both from the existing situation in Ghent, and from projects in other cities. For an unchanged chance of getting caught, the alternative traffic should be 0%. The maximum alternative traffic *m* is assumed to be 14% [12]. Introducing a charge to enter the city center in London reflected in a 14% decrease in traffic in the center. We believe a 100% chance of getting caught, is comparable with this situation. The current situation is implemented in this model by including the current chance x_0 of getting caught. A declining fraction getting caught results in negative alternative traffic, or more traffic coming to the city centre. The model of A(x) can be found in (2) and is depicted in Fig. 2. The first term in the equation is the original Gompertz model, while the second term is used to scale the function so a declining chance of getting caught results in a negative amount of alternative traffic. It is chosen in such a way that when the chance of being caught does not change, the alternative traffic will be zero.

$$A(x) = m * [e^{-e^{-b(x-x_0)}} - \frac{(1-x)}{(1-x_0)} e^{-1}] \quad \textbf{(2)}$$

With: $\mathrm{m} = 0.14$ (maximum market potential)

$a = x_0$ (inflection point)

$b = 4$ (adoption pace)

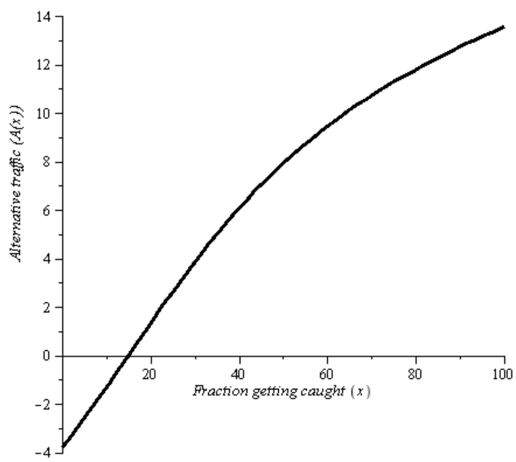

Fig. 2. A(x): Relation between chance of getting caught and alternative traffic

Parking Ticket Sales

People do not immediately adapt their behavior to the changed risk of getting caught. The amount of paying cars will gradually but quickly adapt to the new situation. This is estimated with a custom function, modeling growth T(t) over a time period *t*. The mathematical model is shown in (3) and is depicted in Fig. 3. Notice that this function is an extended Gompertz function [11], again very well suited to model customer adoption. For a rising maximum market potential $\mathrm{M_x}$ the function is an original Gompertz curve. When the market potential does not change, due to a non-changing chance of getting caught, adoption will not change. In the case where the maximum market potential drops below the current potential, a declining adoption is modeled.

$$\mathrm{T(t)} = \begin{cases} \mathrm{M_x} * \mathrm{e}^{-\mathrm{e}^{-\mathrm{b(t-a)}}} & ,\text{if } \mathrm{M_x} > \mathrm{M_0} \\ \mathrm{M_x} & ,\text{if } \mathrm{M_x} = \mathrm{M_0} \\ \mathrm{M_x} * \mathrm{e}^{\mathrm{e}^{-\mathrm{b(t-a)}}} & ,\text{if } \mathrm{M_x} < \mathrm{M_0} \end{cases} \quad \textbf{(3)}$$

With: $\mathrm{M_x} = \mathrm{Totalcars} * [1 - \mathrm{A(x)}] * \mathrm{F(x)}$

$$\mathrm{a} = \frac{\ln\left[\left|\ln\left(\frac{\mathrm{M_0}}{\mathrm{M_x}}\right)\right|\right]}{\mathrm{b}}$$

$\mathrm{b} = 0.9$

The total amount of paying cars is represented by M(x) = $\mathrm{M_x}$. The inflection point and the slope impacting factor are *a* and *b*, respectively. The current situation is implemented in the choice of *a*, with T(t=0) = M(x=x0) = $\mathrm{M_0}$. People tend to adapt quickly to this sort of changes, so we choose a relatively high slope impact factor *b*.

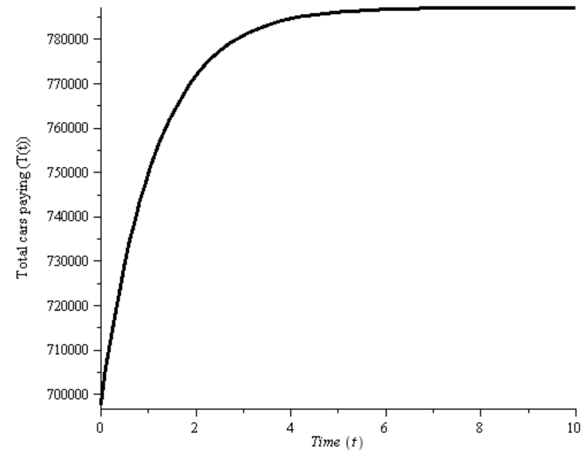

Fig. 3. T(t): Evolution of paying cars over time illustrated for Zone A, with (M0,Mx) = (697,486 ; 787,111)

III. Modeling the Network

This section deals with the network dimensioning, and gives a short description of the considered technologies. The dimensioning will serve as input for the cost modeling in Section IV.

A. Network Dimensioning

The sensor network will consist of clusters of parking spaces around parking payment terminals. The sensor nodes (SN) are attached to the ground for each individual parking space. With the average car length being 5m, adding a fair margin for parking spaces, the SN should not be more than 7m away from each other. With such a small distance between nodes, connectivity between nodes is assured. The SNs will communicate with cluster nodes (CN) or cluster heads over a multi-hop network. CNs are attached to the parking payment terminals, at a height of 1.5 m. These nodes can be wired to the power supply of the terminal. Since the SNs work on battery power, the technology for the connection between the SNs and the CN requires low energy consumption. Line-of-Sight (LOS) should also be taken into account. However, for communication between SNs, a direct LOS will in most cases be available.

CNs and parking guard client devices will be connected to a base station (BS) over a multi-hop mesh network, separate from the technology used by the SNs. To ensure reliability, it is advised that one BS serves max. 1000 SNs [13]. The BS antennas are placed on accessible buildings or poles, at a height of 5 to 6 m. In a dense populated area like the city of Ghent, with multiple government and university buildings, this will not be a problem. On the other hand, direct LOS will not always be the case. Energy saving is not the primary issue for the connection between the CNs and the BS, but a longer range and a mesh routing protocol for providing multi-hop communication between different CNs are necessary.

Data from the BSs is transmitted to the central database (DB) via leased lines. To reach the client devices of the parking guards, the info is sent back to the BS, and then sent to the parking guards. All these restrictions, i.e. energy consumption, line of sight and range, will determine the choice of technology and protocol for the different links. A high level overview of the network topology is shown in Fig. 4, together with the used technologies that are described in the next subsection.

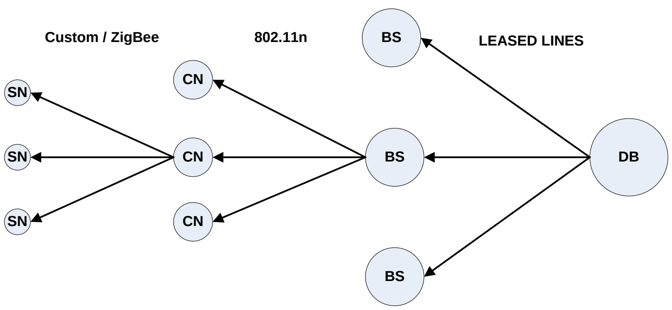

Fig. 4. Network Topology

The info retrieved from the year report of the parking company [8] provides us with useful information about the amount of nodes to be deployed. 18,412 parking spaces will be equipped with a SN, and CNs are deployed on the existing 980 parking payment terminals. This way, for every parking payment terminal, there are about 20 parking spaces, which are on average 25m away from the terminal with a direct LOS. We deliberately choose not to add more SN to one single CN, since reliability is our greatest concern in this project. When connectivity of any component is not assured, the new parking system misses its goals of real time monitoring of paying cars. CNs have higher hard- and software requirements, which is reflected in the price per node. By equipping every payment terminal with a CN, we can also collect information from these terminals about the amount of cars paying. For 18,412 SNs, we assume that 20 BSs will be needed [13]. For a parking area of ca. 20 km2 in the city of Ghent, this means that every BS will cover an area of ca. 1 km2.

TABLE II
NETWORK REQUIREMENTS

Type	Amount
Sensor nodes (SNs)	18,412
Cluster nodes (CNs)	980
Base stations (BS)	20

B. Technology

For the short-range communication between the SNs and the CN, the ZigBee protocol based on the IEEE 802.15.4 standard is well suited as it is a low-cost and low-power consuming solution. For the longer-range multi-hop mesh network connecting the CNs to the BS, the latest WiFi standard IEEE 802.11n is chosen.

ZigBee (802.15.4)

ZigBee, based on the IEE 802.15.4 standard [14] is the specification of a low-cost, low-power wireless communications solution, meant to be integrated as the main building block of ubiquitous networks. Zigbee is developed to be reliable and easy to deploy at a low cost, even when a large number of nodes need to be. For SNs that are not attached to a power supply, and are all within short distance of other nodes, ZigBee is the most designated protocol. In this model, ZigBee will be used for communication between the SNs and the CNs. Since ZigBee has been specifically designed to require much less power than WiFi, the low energy consumption requirement is met by this standard. ZigBee includes an ad-hoc networking hierarchy, and nodes can be startpoint, endpoint or intermediary point. What is even more important, the ZigBee standard allows nodes to continuously reevaluate signal strengths. In the case a SN is low on energy power network traffic will be rerouted so network connectivity is guaranteed. These two characteristics allow an easy deployment and a low cost maintenance of the network, together with a high reliability. It is clear that the ZigBee protocol suits the needs for the network well, and therefore is chosen as the communication technology for the sensor nodes [15].

WiFi (802.11n)

WiFi is a certification label for wireless local area network (WLAN) devices that comply with the international IEEE 802.11 standards and sub-standards [16]. The latest standard is 802.11n, which offers higher possible ranges than the previous standards. WiFi can be used to setup a multi-hop mesh network to send the data from CNs to the BS. We work within the license-free 2.4 GHz frequency band, and we choose for 20 MHz channel bandwidth, sacrificing larger data rates for reduced interference. This way, we achieve higher reliability in the city environment. Reduced interference and longer ranges are requirements for the links between the CNs and the BSs. The 802.11n standard offers a max range of approximately 250m. Considering this project, we have 49 CNs per BS, or one CN covers an area of 0.02 km2. This corresponds with a circle with a radius of 80m. Every CN is thus well in range of his BS, even when multi-hop is not taken into account [17].

IV. MODELING THE COSTS AND REVENUES

In order to conduct a good economic evaluation, a detailed cost and revenue overview must be made. This section gives a detailed description of the costs, consisting of Capital Expenditures (CapEx) and Operational Expenditures (OpEx), and revenues of the project. Costs are modeled with different level of detail. In this model, fractional, driver based and dedicated cost modeling is used. More info on the different cost models can be found in [5]. The business case will be compared with the current situation in Ghent, so only incremental costs and revenues will be taken into account.

These incremental revenues are calculated as follows. The year report of the parking company Ghent offers us a detailed cost and revenue breakdown. These figures are yearly raised with an inflation rate of 2%. Cost erosion is also taken into account. For the new system, costs and revenue estimations are made, based on the adoption models presented before. In the last step, the difference between projected future costs and revenues of the new system and those of the new system is calculated, offering us the incremental cash flows (CFs) of the project.

A. Capital Expenditures

The following section gives an overview of the Capital Expenditures (CapEx) of the project. CapEx accounts for the largest cost in the first year of deployment, together with the installation cost of the initial network. By definition, these expenses can all be activated and depreciated. This way, a tax advantage is created by the CapEx. In the next years of the project, these costs are non-recurrent.

Hard- and Software

The largest part of the initial CapEx is the hard- and software cost. The first aspect is the initial investment in sensor nodes, cluster nodes and base stations and the central database, which are listed in Table 3.

This project requires a complex network and as discussed in section III.B, the ZigBee protocol combined with WiFi for medium range communication suits our needs best. Using numbers provided by GreenPeak [13] we calculated specific hard- and software design costs, listed in Table III. Concerning the hardware, these costs include the design of a Printed Circuit Board (PCB) with sensor, power circuit and transceiver, and the design of the gateway to transmit data from the CN to the BS. In addition, this cost includes the certification of the hardware. The software development also covers different aspects. Adding security to the communication protocol is a major requirement, and will require custom programming. The cost for nodes and base stations is calculated using dedicated network based modeling. From the estimated amount of necessary elements, the total cost is calculated.

TABLE III
COSTS FOR HARD- AND SOFTWARE [13], [18]

Element	Cost
Sensor node	€ 7
Cluster node	€ 10
Base station	€ 2,000
Central database	€ 3,000
Design hardware	€ 50,000
Design software	€ 100,000

Other CapEx Costs

Other CapEx costs include vans for technicians and parking guards, handheld devices, computers and a telephone central. This equipment, with an initial cost of € 279,500 can all be depreciated over a lifetime of three years. Costs have been deducted from average prices for vans and average costs of handheld devices, computers and telephone centrals.

B. Operational Expenditures

The Operational Expenditures (OpEx) are incurred by a business when it performs its normal business activity. OpEx include maintenance, personnel and administration costs.

Installation Cost

Sensor nodes will be placed on every parking space. Since sensors are relatively cheap, we opt to attach them to the asphalt with a special adhesive. This way, deployment of the sensors is quicker compared to drilling holes for attachment of the SNs, and replacement of broken sensors will be easier. The cluster nodes will be installed on top of existing parking payment terminals. This makes it possible to attach these sensors to the power supply of the terminal, longing the expected lifetime of these nodes.

The operational cost of first time installation of the network consists of the wages for technicians, and the material cost. Numbers can be found in Table IV.

Maintenance Cost

The most important process is monitoring the state of the sensors. Causes of failing sensors are bad weather conditions, vandalism or accidents and low battery power. In case of a damaged component, the sensor is immediately replaced. Since they operate outdoor, sensors are placed in a waterproof shell. Combined with the low price for both sensor nodes and cluster nodes, replacement is cheaper than repairing the damaged component. Recharging of the nodes is thus disregarded, as it is not cost effective. This system also allows preventive replacement, thereby minimizing the risk of failing sensors. We assume that every sensor will be replaced every 3 years, so a replacement ratio of 33% seems fair. Maintenance of BSs is calculated using fractional cost modeling. We estimate a yearly maintenance cost of 20% of the initial investment.

TABLE IV
INSTALLATION AND MAINTENANCE COSTS [19]

Hourly wage technician	€ 30
Sensors installed per hour	3
Material cost	€ 1.8
Amount of sensors to replace yearly	33%
Leased Lines	€ 3,500/BS/year
Base station maintenance	20% of initial investment

Administration and Customer Relationship management (CRM)

When fined, administration consists of linking the car license plate to an address, and forwarding the fine. Expenses made for this process are mainly costs for stamps, envelops and paper. Combining these three expenses gives a cost of € 0.60 per fine. All special cards will need replacement. The new cards will be equipped with a RFID tag, so sensors can pick up the parked car of the resident. This way, the registered cars are picked up as paying cars. Special cards are in the current model already replaced yearly, so no extra cost is taken into account.

Personnel Cost

The last OpEx cost concerns the personnel cost. The parking company of Ghent currently hires 12 parking officers from a private security firm. In the new system, the amount of guards will change yearly. The number of guards hired will depend on the amount of tickets one guard can write per hour, the amount of illegally parked cars and the postulated chance of getting caught. The cost for the parking company is based on the wages for the private firm, added by a fair profit margin. This is an example of driver based cost modeling.

Both the administration and helpdesk department also need personnel. Their wages are based on the average wages paid in Belgium for this kind of employees. Adding the social security cost for the employer, this comes to a cost of € 34,000 per employee. [20] The cost breakdown can be found in Fig. 5. Personnel costs are responsible for the highest expenditures.

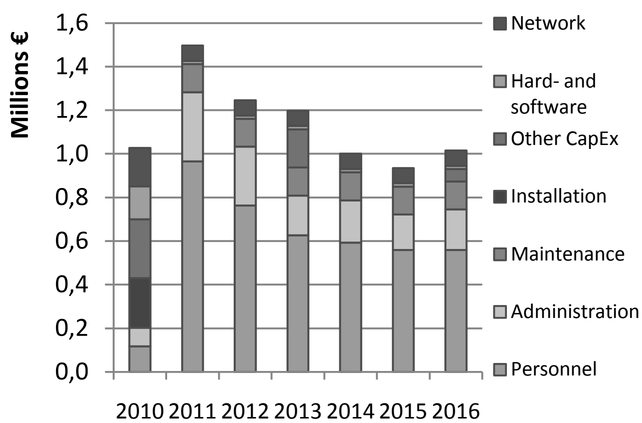

Fig. 5. Costs of the parking system in the city center of Ghent

C. *Revenues*

When first deploying the WSN, revenues will come from fines and parking tickets. To calculate the total revenues, a closer look at the current system is needed. In order to estimate the total revenues, income will be modeled per zone. With the input data found in Table 5 and the adoption model described in Section II.C, the amount of future parked cars is calculated. Due to the new system, the chance of being caught is estimated to rise to 20% for both zones. From these forecasts, total revenues from fines and tickets can be estimated. A smaller fraction of the total revenues consists of income out special cards. An overview of the total revenues for Zone A and B can be found in Fig. 6.

TABLE V
DATA PER ZONE

	Zone A	Zone B
Parking spots	4,142	14,288
Average Payment	€ 4.0	€ 1.25
Revenue from tickets	€ 2,789,943	€ 4,148,915
Legal cars	697,486	3,347,933
Current chance of getting caught	15%	5%
Illegal cars	429,376	1,932,193
Total cars	1,126,862	5,280,124

In 2010, no revenue will be generated by the new system, so the incremental revenues for 2010 will logically be zero. From 2011 on, we see a decline in revenues from fines, while the income from parking tickets rises. Revenues generated by special cards and subscriptions remain negligible. Currently, revenues generated by street parking are about € 10 million (2008) [8]. Introducing the new system would raise revenues substantially. Next to the monetary benefits from tickets and fines, other non-monetary benefits exist. The system allows a better detection of illegal cars. More offenders get cited, which reduces illegal parking in the city, and lowers the amount of traffic in the city centre, due to people choosing alternate ways of traffic. We choose not to include these extra advantages in our calculation. This way, the comparison with the current situation is not biased.

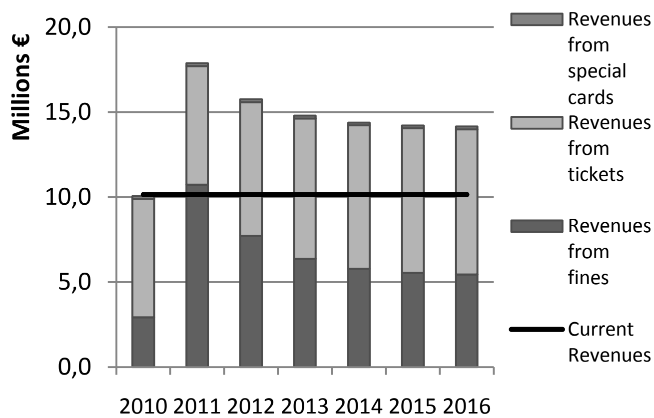

Fig. 6. Revenues of the parking system in the city center of Ghent

V. ECONOMIC EVALUATION

A. *Static NPV Analysis*

In this section, the static Net Present Value (NPV) analysis is performed for the two-phase rollout. The NPV evaluation is based on incremental cash flows (CFs). From the CFs calculated for the project, the CFs generated with the current system are deducted, to give a better view of the profitability of the project. In the static scenario, the WSN is rolled out in Zone A in 2010. No revenues are generated that year, while most expenses are made then. From 2011 on, income from both tickets and fines is generated. In the third year (2013) after the functioning of the system in Zone A, extension of the WSN is started to Zone B. This results in revenues from Zone B from year 2014. An important remark is to take into account the time value of money. One hundred euro earned today is worth more than €100 earned next year. Therefore, the last step is discounting the cash flows, using the weighted average cost of capital (WACC) of 10% as discount factor. The cumulative discounted cash flows are equal to the NPV. When a project has positive NPV outcome, it is advised to execute the initial investment. This project, incremental to the current situation, has an NPV of almost € 7.4 million, which can be seen on Fig. 8 in the normal rollout scenario.

B. *Sensitivity Analysis*

Several assumptions in this model come with uncertainty. For example, what is the amount of sensors that will need to be replaced every year? Will the chance of being caught effectively rise to 20%? And more importantly, what is the impact of the chosen adoption model parameters on the final result. In this section we will perform a sensitivity analysis, estimating the impact of these factors on the NPV result. A Monte Carlo simulation is frequently chosen as a method to measure sensitivity. We run the model, changing the input factors we expect to have a great impact on the final result. From these simulations, a sensitivity chart is obtained, offering insights in the input factors. For this model, a Monte Carlo simulation was run (using Crystal Ball), changing the predicted chance of getting caught, the percentage of sensors failing and the average payment at the parking payment terminal together with the input factors of the adoption models for 100.000 simulations. We assume these values all follow a normal distribution. After the sensitivity analysis, the NPV remains positive with a mean of € 7,163,552, indicating that the project is still economically feasible. The sensitivity chart is shown in Fig. 7. The estimated future chance of getting caught contributes the most to the variance with more than 97%. The uncertainty about this factor is hard to reduce, since it will always be an estimate about the impact of the new system. It also shows that the chosen adoption parameters do not influence the results much. The average ticket costs have much less impact on the total variance of the NPV result. The adoption parameters have also been tested, but their impact was negligible.

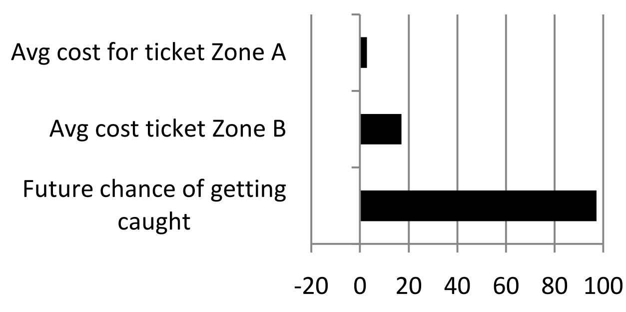

Fig. 7. Sensitivity chart (impact of parameter on NPV variance)

C. *Real Option Analysis*

Due to the nature of the static rollout scenario, the management has several options to cope with the uncertainties. They could speed up or slow down the rollout in Zone B, or even not perform phase 2 at all, depending on the results during the first years. When the project has not generated the desired payoff, and the NPV does not climb to an acceptable level, the management will slow down or even abandon the project. On the other hand, when expectations are exceeded, a faster rollout to Zone B can be performed. It is obvious that the project offers several options for the management to alter the static project. However, a static NPV analysis cannot include this flexibility in its calculations. The economic theory formulated an extended evaluation technique to include the value of this flexibility in the calculation. A Real Option Analysis [5] approach captures the value of these options, and implements managerial flexibility in the model, in contrast with the static NPV analysis. In this paper the simulation approach was taken. Three scenarios are defined, a slow, normal and fast rollout scenario. The evolution of the static NPV of three scenarios is shown in Fig. 8. In the slow rollout scenario, management waits until year 2014 to expand the parking sensor network to Zone B. On the contrary, the fast rollout already includes the expansion in year 2012.

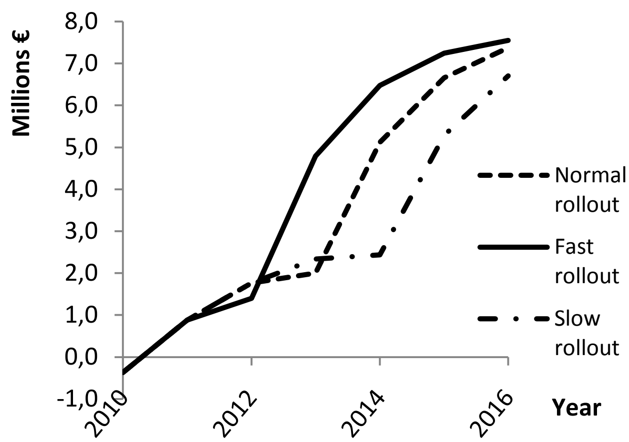

Fig. 8. NPV evolution of different static scenarios

The management flexibility is included as follows. In year 2012, the management can make the following choice. Depending on the outcome of the different scenarios, they choose the most economically interesting from the normal rollout scenario and fast rollout scenario. In year 3 they can choose between the normal and slow rollout scenario. Depending on the fluctuations in the input parameters which are currently unknown, a different choice will be made, but it will always be the most profitable one. Again running 100,000 Monte Carlo simulations, the value of the project with the speed up and slow down options is derived. The same input factors as in the sensitivity analysis are modeled with uncertainty. It is important to notice that options never have a negative value. When the speed up option is less interesting than the normal scenario, the faster rollout will be disregarded, thus having a value of €0. The decision tree is shown in Fig. 9.

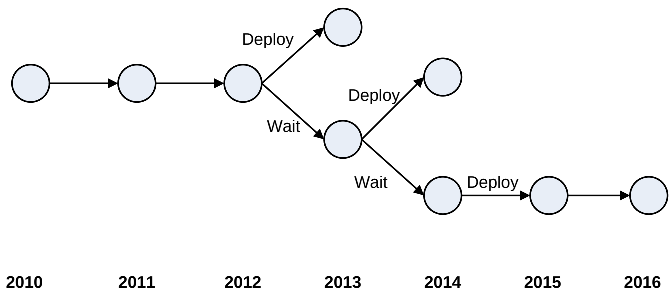

Fig. 9. Decision tree

Fig. 10 displays the impact of these options on the NPV calculations. The same simulation as in the sensitivity analysis is run, but now the values of the options to speed up and to wait are included. The static project already has a relatively high NPV, resulting in a smaller impact of the options. Still, introducing this option raises the average NPV with € 155,000. When the value of each option is calculated separately, we find a value of € 154,200 for the speed up option, and € 800 for the option to wait. The low value found for the wait option is a result of the high value of rolling out in Zone B, where more revenues can be generated. Therefore waiting to roll out will only be interesting in worst case scenarios.

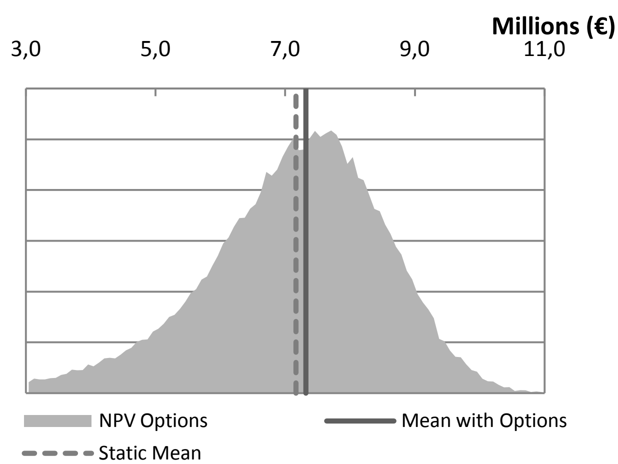

Fig. 10. NPV distribution with options. Comparison of static mean and mean with options

VI. Conclusion

In this paper, an in-depth study of the economic feasibility of a wireless network of parking sensors is performed. In the first step, input data is collected to model the network infrastructure, the service adoption and the operational processes. With both costs and revenues modeled, a static NPV analysis is conducted. The results show that the static case is already highly profitable. However, network rollouts offer various flexibility options, which cannot be captured with a static NPV analysis. Therefore, this analysis is extended with both a sensitivity analysis and a real option analysis, in order to allow decision makers to make a well funded decision whether to deploy such a system or not. The case described in this paper clearly shows that network rollout projects offer flexibility options, which can be captured using a Real Option Analysis. All results point towards the same conclusion. Deploying a WSN for parking spot monitoring is highly profitable. The project generates high revenues from the start. Doubts about the assumptions can be made, but after running a sensitivity analysis, results show that the NPV remains positive, even under the worst conditions. Municipalities could thus profit from the deployment of such a network in their city. Next to the high profitability, the non-monetary benefits are factors that raise the attractiveness of the investment.

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