Business Information System for the Control of Workforce Through Behaviour Monitoring Using Reactive and Terminal-based Mobile Location Technologies

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Abstract: This paper analyzes the viability of the use of employees' smartphones following the BYOD paradigm as a valid tool for companies in order to conduct presence control (primarily for remote workforce). A Mobile Information System is also proposed for Presence Control using exclusively terminal-based reactive location technologies, meeting cost minimization and universal access criteria. Qualitative and quantitative references are proposed, adequate to the location information accuracy demanded in different business remote workforce control scenarios, and taking into consideration the strictest international regulation in force relevant to the location of individuals in Emergency Systems, promoted by the North American FCC. A prototype for the proposed Information System was developed to evaluate its validity under different real world conditions, and valuable information was obtained on the accuracy and precision of location data using real devices (iOS and Android) under heterogeneous connectivity conditions and workplace premises.

1 INTRODUCTION AND DEFINITION OF THE PROBLEM

Nowadays it is commonly accepted that companies must use Information Systems that allow the collection and organization of all the information available to their disposal in order to help the success of the company's business strategy. The increasing competitiveness of the actual market forces companies to try to have a deeper understanding of the relationship of cause and effect of their actions on profitability, being necessary to have specific information that guides the process of improvement of their competitive performance (Bradley, 1998; Lahoz y Camarotto, 2012).

Performance measurements related to time, quality and productivity complement financial measurements, and allow the introduction of improvements in operational processes. Referring to the importance of time as a key factor in the performance of task completion, Ballard and Seibold, (2004) identified ten dimensions of time in the workplace. Among them, the lack of punctuality and absenteeism can be regarded as the most persistent obstacles that affect to business competitiveness (Campbell et al. 2012).

Early detection, evaluation and rapid intervention are crucial when managing tardiness and absences in the workplace, and help prevent them from becoming a serious problem for the competitiveness of companies.

Usually, to achieve such detection, Information Technologies investment is required, among other things for the acquisition and implementation of Control, Access and Presence Systems, which are often expensive, not only because of the initial costs (equipment for physical identification using card reader technology or biometric identification), but also the maintenance of the equipment and software that form the system's back-end, not to mention the possible costs for the integration with pre-existent Information Systems (Sen et al. 2009; Kauffman et al. 2011).

On the other hand, this kind of systems is proven to be ineffective when it comes to extend the control to mobile workforce, which in numerous private service sector enterprises it may represent a high percentage of the staff due to the very nature of its business. In this case what is needed is a "proof of presence" in places and times established in advance

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(Kumar & Pandya 2012).

The implementation of support for mobile workplace by the introduction of Mobile Information Systems (mobile devices and applications engineered for the mobile environment), that allow the control of said spatial and temporal dimensions of a mobile work, grants not only a competitive advantage but also labour productivity growth to companies (Yuan et al. 2010).

1.1 Opportunities

In the current economic context, it is of vital importance for a business to improve their competitiveness by rationalizing the necessary investment to achieve it. As has already been highlighted, having a Mobile Information System that permits the rational and non-intrusive control of the workforce, is one of the direct and effective means of achieving such improvement.

Two unique situations have been detected that can allow small and medium enterprises (SMEs) to have a presence control Information System for both local and remote workforce with a very reduced cost and with minimum need of infrastructure:

(A) The current maturity of mobile location technologies, using different transparent positioning mechanisms (A-GPS, GPS, WiFi and Cell-ID).

(B) The growing trend BYOD ("Bring Your Own Device") allowing employees the use of their own mobile communication devices (smartphones, tablets…etc) in the business as a complementary tool that takes a double role as a personal device for private use and as an access to the company's Information Systems.

On this basis, this paper tries to ascertain if it is feasible the implementation of an Information System for the behaviour-based control of workforce that makes a non-intrusive use of technology for getting the employees locations from their own smartphones, regardless of the make and model they have.

This paper first analyzes the viability of the use of employees' smartphones following the BYOD paradigm as a valid tool for companies in order to conduct presence control (primarily for remote workforce). Then, a Mobile Information System is proposed for Presence Control using exclusively terminal-based reactive location technologies, meeting cost minimization and universal access criteria.

Later, this paper proposes qualitative and quantitative references, adequate to the location information accuracy demanded in different business remote workforce control scenarios. And finally, this paper discuss the results of testing the accuracy and precision of location data using real devices (iOS and Android) under heterogeneous connectivity conditions and workplace premises

1.2 Granularity in the Control of Workforce

It has been noted that the use of monitoring technology can often lead to unwanted effects and behaviours (Stanton 2000), particularly, continuous monitoring with mobile location technologies increases the occurrence of such effects (Weckert 2005). In this context, it would seem reasonable to note that an Information System designed to avoid this behaviours must use non-intrusive and reactive location technologies (avoiding continuous monitoring). (Ghose et al. 2012; Kumar Madria et al. 2002).

On the other hand, to quantify the level of demand of accuracy suitable for the location of the workforce, reviewing existing international regulations on the subject, it was found that the United States Federal Communications Commission (FCC) E-911 mandate, concerning the precision of the location of calls from mobile devices to Emergency Service E911, is the most specific and strict set of regulations (Table 1). And it also provides a methodological framework for verification processes regarding compliance. At present, E-911 is the only regulation set that clearly quantifies the required location accuracy. So, for the proposed Information System, the most restrictive location accuracy values of the aforementioned regulations will be considered as a valid working quantitative reference.

2 INFORMATION SYSTEM AND PROTOTYPE

Taking into consideration all conditioning elements, it is proposed in this paper an Information System specifically oriented towards business use for the behaviour-based control of remote workforce, using smartphones under the BYOD paradigm, and putting the focus on universal access (device independence).

Additionally, a fully operational prototype of this Information System has been developed; It consists in a mobile web application along with a control panel serving as a balanced scorecard and SaaS (Software as a Service, in the cloud).

Table 1: Mobile devices location accuracy requirements from which emergency service E-911 is requested.

Location Type	**Required Accuracy**	**Regulation date of entry into force**
Mobile terminal based	50 meters for 67% of the calls and 150 meters for 80% of the calls	Already in force (since 18/1/2013)
	50 meters for 67% of the calls and 150 meters for 90% of the calls	Scheduled to enter into force on 1 January 2019

Source: Adapted from FCC (2010)

This prototype fulfills a double purpose of (i) serve as a proof of concept for an Information System for the control based on behaviour of the remote workforce using a mobile web application, and (ii) to allow an empirical analysis on the current feasibility of its use under real conditions, using the most strict obtained geographical location accuracy requirements from mobile devices to emergency services established by the FCC to be complied in 2019. (FCC 2011)

2.1 Description and Components of the Information System

The proposed Information System for the behaviour-based control of remote workforce consists of two discrete functional components:

First, a Mobile Web application that will be accessed by the workforce using their smartphone mobile devices in order to clock in when arriving at the customer's facilities or other installations deemed appropriate (Fig.2). This application also allows to send remarks concerning the clocking in that will be registered in the system in that moment.

Concerning the design, it was taken into account the various factors that affect the customer perceived usability, identified by Ho, (2012) y Lee, Lee, Moon, & Park, (2012). Technologies such as HTML5 and JQuery Mobile have been chosen due to them being the most cost-effective for companies, and also involve less costs in development as it require just one code base (only one production line) and it can be deployed in almost all mobile devices that have a browser and access to the Internet (Heitkötter et al. 2013; Zhu et al. 2013)

Secondly, a Control Panel Web Application for the control of the remote workforce, accessible from any Web browser, it allows real-time queries regarding the workforce clocking in processes, including georeferenced information in maps, as well as make individual historical analysis of such processes for each employee. This individual historical analysis is in line with behaviour analysis in the context of ubiquitous monitoring (Moran & Nakata 2009).

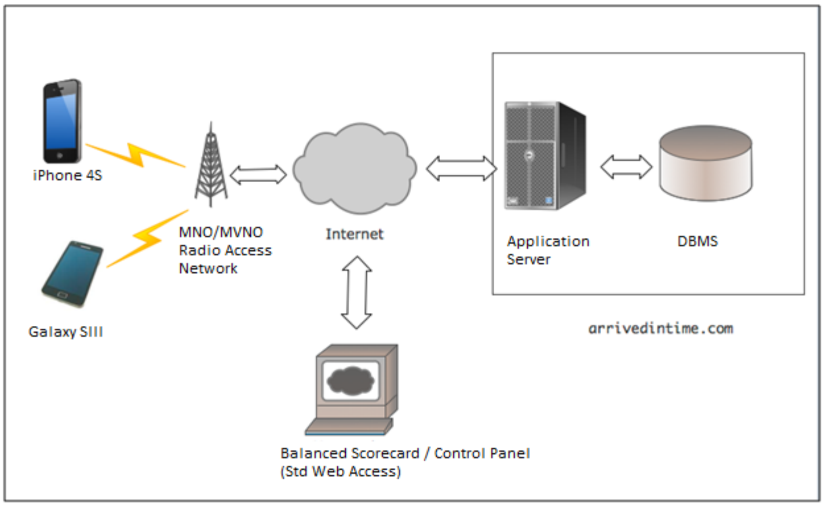

Figure 1: Information System Architecture for behaviour-based control of the workforce.

The proposed Information System has a client-server three-layered software architecture (See Figure 1). On the other hand, it should be noted that the present Information System has been modeled considering also the system proposed in the general model of location-based information system "Location Aware Mobile Services" (LAMS), tailored for terminal-based and network-assisted physical location of mobile devices.A core principle of the proposed Information System is ubiquitous access, consequently all server components can be deployed on the Internet o within a corporate intranet as services provided using HTTP (Web), in a way so that they remain accessible even if the corporation has perimetral security solutions or traffic filters (in this case, HTTP traffic is not usually restricted)

All the components used in the Server and Database layers in this Information System are open source software (LAMP platform: Linux OS, Apache Web Server, PHP, and MySQL database), in order to minimize costs involved in the deployment of the proposed Information System.

Another benefit of this approach is related to scalability; both vertical and horizontal scaling of the LAMP platform are well known issues, and there are several proven architectures that show useful when there is the need to accommodate an increasing workload.

3 LOCATION DATA ANALYSIS METHODOLOGY

An empirical analysis is to be made to determine the location accuracy obtained with mobile devices using the developed mobile web application, in order to verify the feasibility for business use as a mobile device for the behaviour-based control of the workforce and the effective application of the BYOD paradigm.

Even though the accuracy of conventional GPS receivers is well documented for various devices (such as PNDs), the study on the accuracy of devices with Assisted GPS (A-GPS), usually available in smartphones like those intended to be used in the proposed Information System, has not yet evolved as much. Due to hardware limitations, it is to be expected a worse performance concerning location precision and accuracy using smartphones than using a conventional GPS device (Zandbergen & Barbeau 2011).

To study the feasibility of the use of location data obtained from smartphones by means of a web app in the proposed Information System, sets of GPS location data under real conditions have been collected. Location data obtained is compared with a real known location ("truth point"), and with this an absolute accuracy measurement will be obtained.

3.1 Instrumentation and Data Collection

The GPS location data quality tests were done using two of the most widespread smartphone mobile terminals actually in the European market: Samsung Galaxy SIII and Apple iPhone 4S. These devices are also highly representative since they belong to two of the most prevalent smartphone groups (corresponding to the Galaxy and iPhone trademarks) with the biggest market growth, and evolving with constant improvements in their hardware specifications.

Samsung Galaxy S III uses a Broadcom BCM47511 GPS receiver chip with active suppression of sources of interference. The device used in the tests has Android v4.0.1 Operating System. Apple iPhone 4S uses a Broadcom BCM4330 GPS receiver chip and the operating system used was iOS 6. Both mobile devices registered geographical positions as decimal degrees in the WGS-1984 datum, GPS original geodetic reference system and direct equivalent to the European ETRS-89 used in most topographic or cartographic applications (IGN 2013). In both cases the tests were made with the GPS circuits activated and using network assisted mode (A-GPS), additionally WiFi based location mechanisms were active to help increase the accuracy.

The tests were carried out strictly during standard business hours, at random times between 8h and 17h, representative of workforce daily activities times in working days. Also, no value of Horizontal Dilution of Precision (HDOP) was taken into account for the completion of the observations, no planning of field mission prior to the test was conducted, thus better reflecting the use of the Information System under real conditions by the workforce.

The geographical coordinates of this point (446737m, 4114616m UTM zone 30S, European Datum 50) were obtained using a topographic grade sub-meter accuracy professional GPS receiver Topcon Hiper+ with a 10mm + 1.0ppm horizontal accuracy, properly calibrated and using Differential Global Positioning System (DGPS)

The mobile devices registered location data in WGS-84 format, in intervals of 3 minutes, generating data sets of 25 samples each. Data was gathered, in different days, 10 sets of samples, totaling 250 measurements for each study group.

Figure 1: Log-in screen requesting the user's credentials to access the Information System.

3.2 Data Analysis

To assess the accuracy of both devices used in the gathering of the data, the variability in the data will be contrasted against a previously determined real value, corresponding to the observation point (truth point).

To determine the possible normal distributions of the data sets (variable: accuracy- planimetric or horizontal error) several tests were conducted: Kolmogorov-Smirnov, de Ryan-Joiner (similar to Shapiro-Wilk) and Anderson-Darling (See Table 2)

Once again it is proved that the result is similar for the three conducted tests, which provide p-values of less than 0,05 which confirms with a 95% of reliability that for both data origins, Galaxy SIII and iPhone, the hypothesis of normality for horizontal or planimetric accuracy is rejected.

Having verified that horizontal error distributions (for accuracy) are not normal, the non-parametric Mann-Whitney U test was used in order to contrast if both data origins have the same distribution, the obtained result is a statistical value W=54544,5, this test is also statistically significant in 0,0000 ($p<0,05$) therefore the hypothesis of equal distributions of horizontal error (planimetric accuracy) for both populations is also rejected with a 95% reliability.

In the data analysis it has been shown that the average values of the precision variable and the accuracy variable differ significantly for both mobile devices.

Also it has been shown that deviations are significantly different for both data origins. Distributions are different not only in precision but also in accuracy for both populations (Android and iOS data). Both mobile devices provide data of enough quality, and the mean of their values is close to the real value, but a greater data dispersion in found for iOS devices.

Table 2: Results of the normality tests of samples of accuracy from both data origins.

Data origin device	Samsung Galaxy SIII (Android)	
Normality test	Statistical	p-value
Kolmogorov-Smirnov	0,087	<0,010
Ryan-Joiner	0,972	<0,010
Anderson-Darling	3,581	<0,005
Data origin device	**Apple iPhone 4S (iOS)**	
Normality test	Statistical	p-value
Kolmogorov-Smirnov	0,133	<0,010
Ryan-Joiner	0,946	<0,010
Anderson-Darling	8,126	<0,005

4 RESULTS

Figure 3 shows the horizontal error (in meters) of all the gathered samples. This confirms, as evidenced earlier, the variability of location data collected by the iPhone device around the well known spot (truth point) is greater than the data set collected with the Android device.

For this reason, the collected data will be analyzed quantitatively, performing the calculation of the horizontal accuracy taking the root mean square of the errors (RMSE) of each data origin, first for each component and afterwards calculating the planimetric or horizonal.value

$$RMSE_X = \sqrt{\frac{1}{n}\sum_{i=1}^{n} e^2_{xi}} \quad RMSE_Y = \sqrt{\frac{1}{n}\sum_{i=1}^{n} e^2_{yi}} \tag{1}$$

$$RMSE = \sqrt{RMSE_X^2 + RMSE_Y^2} \tag{2}$$

4.1 Accuracy Results for the Android Device

The planimetric RMSE error value obtained is 17,44m for the horizontal component (XY). This value means that for a 67% of the observations made with the Android device, the accuracy will be less at

17,44m. In this case, the value for the Samsung Galaxy SIII device is 2DRMS = 34.88m.

It might be concluded that at a 95% confidence level the accuracy obtained with the mobile web application using the GPS of the Samsung Galaxy SIII device is within a 34.88 meter radius from the real location value in an urban environment with demanding conditions for GPS signal propagation and shifting HDOP values, non planned in the tests conducted.

4.2 Accuracy Results for the iOS Device

The planimetric RMSE value obtained is 33,74m for the horizontal component (XY). This value means that for a 67% of the observations made with the iOS device, the accuracy will be less at 33,74m. In this case, the value for the iPhone 4S device using the mobile web application is 2DRMS = 67.48m.

It might be concluded, that with the samples taken in this test, that at a 95% confidence level the accuracy obtained with the mobile web application using the GPS of the iPhone 4S device is within a 67.48 meter radius from the real location value in an urban environment with demanding conditions for GPS signal propagation, and shifting HDOP values, non planned in the tests conducted.

5 VERIFICATION OF COMPLIANCE WITH FCC RULES

The FCC proposes a method for determining if a set of location errors demonstrates compliance with accuracy requirements of location data, using order statistics. The FCC's confidence intervals for accuracy standards can be selected with a 90% confidence based on the number of samples. (FCC 2000).

Generally, when

- The number of measurements is n,
- The r-th and s-th largest measurements are x_r and y_s, respectively
- x and y are the percentile points associated with probabilities p_1 y p_2, respectively, then

the probability that x is less than x_r, while simultaneously y is less than y_s, is given by the formula

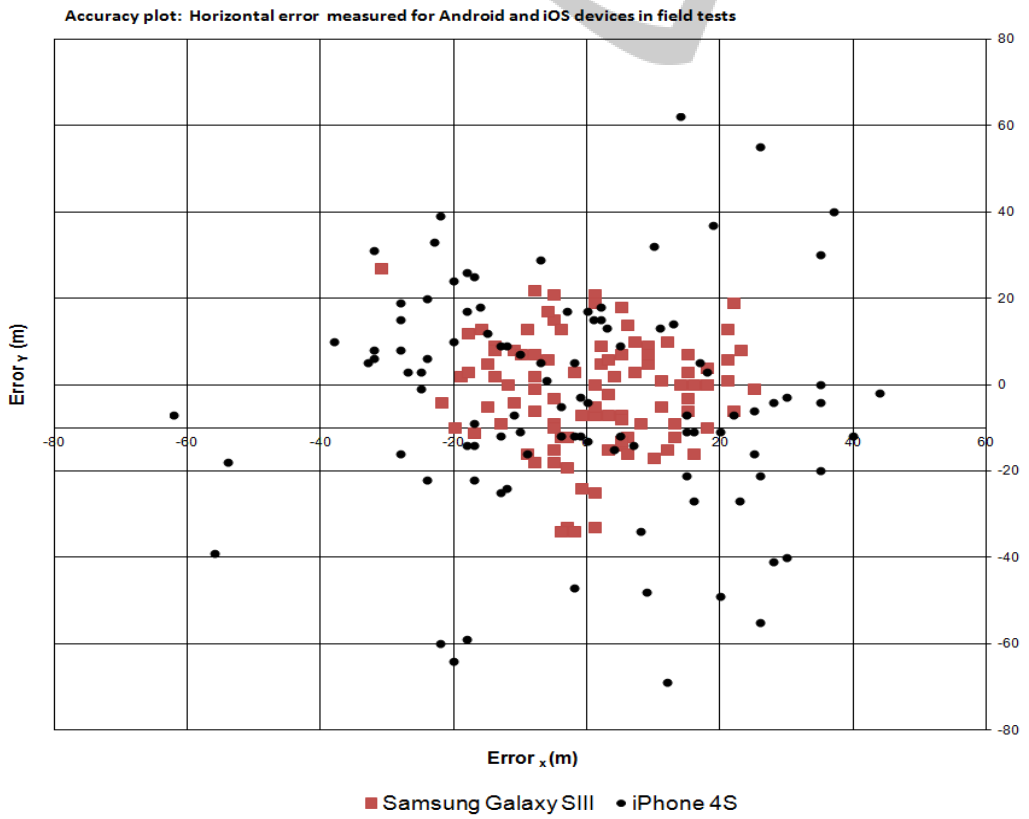

Figure 3: Horizontal error measurements for both devices.

$$confidence(x \leq x_r, y \leq y_s; n, r, s, p_1, p_2) = \sum_{i=0}^{r-1} \sum_{j=i}^{s-1} \binom{n}{i} \binom{n-i}{n-j} p_1^i (p_2 - p_1)^{j-i} (1 - p_2)^{n-j}$$

Being in this particular case p_1=0.67 y p_2=0.95

From this expression, upper bounds on the percentile points can be determined, searching pairs of values (r, s) for which the level of confidence desired of 90% is achieved (Table 3)

As stated in Table 1, the most strict accuracy requirements established by FCC to be met in 2019 are 50 meters for 67% of the samples and 150 meters for 90% of terminal based samples. If not, the data set is rejected for not meeting the proper standards. In this case, a data set of location errors obtained using the mobile web application (developed as part of the proposed Information System) under real conditions, will be tested using the methodology proposed by the FCC for the assessment of compliance of accuracy requirements. (FCC 2000)

To that end, data tables are sorted in ascending order of accuracy for each observed location error, and for each 100 samples obtained, according to Table 3 it must satisfy the following expression

[(accuracy$_{74}$ < 50m) and (accuracy$_{100}$ < 150m)]

or

[(accuracy$_{75}$ < 50m) and (accuracy$_{99}$ < 150m)]

5.1 Android Device Verification

First, the verification process will be performed with those samples obtained using the mobile web application in an Android device. The results show that:

Accuracy$_{74\text{-android}}$ =19.2 m < 50m and
Accuracy$_{100\text{-android}}$ =41.1 m < 150m

Accuracy$_{75\text{-android}}$ =19.7 m < 50m and
Accuracy$_{99\text{-android}}$ =34.2 m < 150m

Therefore, it can be stated that following FCC's proposed methodology, with samples obtained with the Android device, using the mobile web application of the proposed Information System under real world conditions, with a 90% confidence level, the compliance of the strictest requisites set by this organization is verified.

5.2 IOS Device Verification

Equally, a verification process will be performed with the samples obtained using the mobile web application in an iOS device. The results show that:
Accuracy$_{74\text{-iOS}}$ =35.2 m < 50m and
Accuracy$_{100\text{-iOS}}$ =68.2 m < 150m

Accuracy$_{75\text{-iOS}}$ =35.5 m < 50m and
Accuracy$_{99\text{-iOS}}$ =70 m < 150m

Table 3: Horizontal error value sample identification for its comparison with thresholds of 67% and 95% as required by the FCC for a 90% confidence level.

Sample size	Test sample pairs
50	(x_{40}, y_{45})
60	(x_{47}, y_{60})
70	(x_{53}, y_{70})
75	(x_{57}, y_{75})
80	(x_{60}, y_{80}) o (x_{63}, y_{79})
85	(x_{64}, y_{85}) o (x_{66}, y_{84})
90	(x_{67}, y_{90}) o (x_{68}, y_{89})
95	(x_{71}, y_{95}) o (x_{72}, y_{94})
100	(x_{74}, y_{100}) o (x_{75}, y_{99})

Source: Adapted from (FCC 2000)

Therefore, it can be stated that following FCC's proposed methodology, with samples obtained with the iOS device, using the mobile web application of the proposed Information System under real world conditions, with a 90% confidence level, the compliance of the strictest requisites set by this organization is verified.

5.3 Results Discussion

The most important conclusion of these results is that an Information System for the behaviour-based control of workforce can always identify the employee's location with an accuracy level that comfortably fulfills actual and future people location requirements of the most strict Emergency Systems, which nowadays provide the only valid quantitative reference to validate the quality of people geographical location data in this context.

This also entails the protection of the investment made by the company in the implementation of the proposed mobile based GPS Information System.

Due to the evolving nature of technological innovation, mobile GPS receivers sensitivity will increase still further, thus, obtaining more precise and accurate results than those here obtained (Cao et al. 2003; Elnahas & Adly 2000; Schiller & Voisard 2004) Also, both iOS and Android devices used in the verification process performed quite well in terms of power consumption throughout the working hours without battery recharges, and this is specially important taking into consideration the typical battery drain usually associated to the GPS receiver circuit.

6 CONCLUSIONS

This paper proposes an Information System for the behaviour-based control of workforce. It defines the architecture and functionality, always in line with business needs relative to control and taking into consideration the implementation costs. The latter is achieved by using open software technologies and adapting those technologies to give adequate support to the BYOD paradigm.

A prototype was developed and tested under real world conditions, not evaluating strictly controlled parameters of a device's accuracy -like in empirical tests-, but testing the Information System as a whole in real conditions that reflect normal business activity. Under these conditions, it has also been verified the compliance with the strict accuracy demands proposed here as a reference.

In the proposed Information System three concepts, which until now have been evaluated separately by previous studies, have been brought together: (i) IT consumerization, (ii) actual capabilities of personal mobile devices which employees can use in the workplace, and (iii) the opportunity represented by the new Mobile Web technology which provides information on the move -no matter the device being used and without any app installation hassles-, and significantly reduces costs in comparison to other technological options.

Lastly, the study establishes a new reference framework regarding qualitative and quantitative requirement levels which must be set in relation to the accuracy of mobile location systems used in business Information Systems, particularly those related to the control of the remote workforce.

The results obtained in this study confirm that at present it is viable for companies to implement an Information System for the control of remote workforce that allows the companies to gain competitiveness, at the same time reducing costs and increasing the ROI, adopting a BYOD paradigm which allows their employees to use their own smartphone mobile devices in the workplace.

As for future work, the ongoing research focuses on evolving this Information System so that (i) it can be integrated seamlessly with the different emerging indoor positioning technologies, allowing the companies to get more accurate position data of remote workforce under very adverse indoor conditions, and (ii) it can take advantage of contactless technologies, like NFC, in order to speed up the check-in process when the workforce is at local premises, and to provide location proof using the NFC tag as an extra authentication factor.

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