Optimizing Lighting in the Workplace and Occupational Risk Prevention through Mobile Applications

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Abstract

Nowadays, there are many problems arising from the exploitation of energy resources and the production and use of energy. This research aims to analyze in which way the development of a mobile application may help on registering the lighting levels from different kind of environments, allowing to manage and assess consumption, comply with current regulations. Furthermore, the application provides information about how to optimize the use of energy and prevent occupational risks resulting from mismanagement. To do this relevant information is stored for the evaluation of the measurements through a rule engine that behaves as an expert system capable of guiding in the decision-making process.

Keywords: risk prevention, mobile devices, Android, management, optimization.

1. Introduction

Light allows people to receive the information related with the outside environment through the view, so the process of watching becomes fundamental for human activity and remains attached to the need for good lighting. Accordingly, it follows that setting appropriate lighting levels within the workplace is essential for several reasons including, allowing to see without difficulties the tasks carried out in the own workplace or elsewhere in the company (warehouse, garage, laboratory, offices, etc.), as well as transit without risk in enclosing areas, traffic routes, stairways or corridors.

Therefore, it is evident that a poor quality of light can increase the likelihood of workers making mistakes which increases the probabilities of having an accident.[7] In the same way, an unproven lighting system can cause eye strain, causing relevant damages in the people's health: problems in the eyes (dryness, itching or burning), headaches, tiredness, irritability, moodiness, etc. Consequently, an ergonomic and security analysis of the working place should take into account the proper illumination level. The correct lighting is what allows distinguishing shapes, colors and objects in movement and appreciate the relief, and furthermore, do everything easily and without fatigue, i.e. to ensure visual comfort permanently [7].

At European Union level, the Parliament and the Council drafted and published in 2002 the 2002/91/CE Directive [12] on energy efficiency in buildings, which is of mandatory application in the EU countries. Its aim consists of reducing the excessive consumption of energy up to 22% driving the adoption of measures to savings and energy recovery. In addition this directive offers pieces of advice about the replacement of certain polluting energy sources by renewable energy sources which are less aggressive with the environment [10].

It is import to note that this desire to save energy co-exists with the obligation of satisfying the quality criteria to provide lighting installations not only based on a light level accuracy, but also supported by the satisfaction of all those parameters that help to create a comfortable and safe environment in the workplace.

As a result of this directive two different standards were developed: UNE 12464-1 [10] which is related to lighting of workplaces indoor, making special emphasis on the fulfillment of two aspects: the visual comfort and the performance of colors and standard; the second standard is UNE 12464-2 [11] relative to the lighting of outdoor work places. In both regulations the lighting requirements are established regarding the activity.

Lighting requirements are determined by three basic human needs: (i) visual comfort to provide workers with the sense of well-being, contributing in an indirect way to an increase in the productivity level; (ii) visual performance allowing workers to perform their visual tasks, even in difficult circumstances and for long periods; (iii) security, reducing the risk of having an accident

Currently, there are plenty of problems arising from poor management of the lighting in working areas, either from the point of view of prevention of occupational risks, or from the point of view of management of energy resources. Therefore, this research aims to analyze in which way the development of a mobile application allows to comply with current regulations and prevent occupational risks resulting from mismanagement, allowing at the same time to manage and assess energy consumption.

Therefore, to achieve our stated goal, the connection of sensors has been developed to measure illuminance levels, among the integration of a local database in the application which stores relevant information for the evaluation, and the evaluation of the measurements through a rule engine that behaves like an expert system capable of guiding in the decision-making process.

The paper has been divided as follows: Section 2 contains the prior research made in this area. Section 3 shows the methodology followed to develop the system. Section 4 shows the experimental design of the application. Section 5 explains the resulting application, and the paper finishes with the discussion and conclusions obtained through out of the research.

2. Prior Research

Mobile applications use on occupational health and safety prevention

Occupational safety and health regulations imposed on enterprises are positively related to the presence of unsafe working conditions for firms not in compliance with standards [31]. In recent years, the increased of the use of smartphones, joint with the emergence of the mHealth, have helped to the development of mobile applications oriented to help in citizens' health [33]. Some of these applications can be used by workers to help them to avoid risk situations that could injure them.

There is no doubt that the widespread use of these applications may cover multiple areas. One of the most important problems in workspaces is the posture, primarily in offices where sitting is prolonged during hours, being this action detrimentally associated to health and wellness and shortening life expectancy [30][15]. To help in this field several applications have been built to offer office ergonomic equipment setup advice, a variety of workplace specific stretching exercises, and programmable reminders to help office workers time their breaks. One of the most important applications developed in this field is called Ergonomics [13], and won the People's Choice Award in the recent Worker Safety and Health App Challenge sponsored by OSHA.

Other important aspect to control in workplace is noise. In many workplaces, as factories, workers are exposed to a high level of noise, interfering with communication, distracts from concentrated activities, or disturbs in the sleep. These are clear but broad academic references that explains the noise causes adverse effects [19] have been found. Some studies show that the advances in mobile devices accuracy makes possible the development of applications that can be appropriately employed for occupational noise measurements [16].

Temperature also plays an important role in workers environment, where an inadequate heat dissipation or short-term acute extreme heat exposure can be the cause of a rise in core body temperature. Among the possible long-term heat effects in workplace it is possible to find cardiovascular diseases, mental health problems or even kidney diseases [28], increasing the risk of occupational injuries and accidents [32]. As it happens in previous cases, the advances in mobile phones can help workers to prevent problems related with temperature in workplaces. There are many applications oriented to monitor and inform users about the ideal temperature conditions at work [29][25].

One of the most common workers' health problems is job stress. This problem costs billions of dollars to organizations all over the world [24] and it is produced by negative aspects as long hours, time pressure or role ambiguity. Researches have proofed that work stress does not only damage workers and economically burdens organizations and societies, it also damages workers physically and psychologically [27]. Though stress at work is a relatively a new phenomenon of modern life styles, it exists in every organization. To help with this issue several applications have been developed with different methods to identifying stress and deals with copy strategies for reducing the stress felt at work [21].

Another important hazard that must to be controlled are the falls at heights. A fall can occur during the simple acts of walking or climbing a ladder to change a light fixture. According to the 2009 data from the Bureau of Labor Statistics, 605 workers were killed and an estimated 212,760 workers were seriously injured by falls to the same or lower level [14]. As it happened in previous hazards, smartphones also may help to decrease the risk thanks to the help of applications that are designed to improve extension and step ladder safety.

Health problems derived from a bad illumination

Most of the office tasks are linked to reading and writing, whether through paper or digital documents. Therefore, these activities demand high visual requirements, where the light conditions are very important to prevent discomfort and vision problems [7].

One of the main lighting problems is over-illumination which occurs due to multiple artificial lights in the ceiling and/or daylight penetrating the room. For example, in a shared-space office, the light illuminates not only the cubicle of one worker but also the rest of cubicles. Besides, the contribution of a light to the light level of the other cubicles is the cross-illumination effect of the particular light. When these effects arise, lighting control requires a regulation between the lights in order to obtain a desired light level across the room [18].

This situation of over illumination is linked to several negative health effects. Different studies attribute migraine headaches fatigue, medically defined stress, anxiety or decreases in sexual function among others to overly intense light [3][6][17][23].

Despite most of these symptoms might be caused by light that is simply too intense, the color spectrum of fluorescent lighting is other factor that must cause other problems due to the fact that this sort of lighting is significantly different from sunlight [3][5]. Fatigue is another common complaint from individuals exposed to over-illumination, especially with fluorescent media. For that reason, natural light is preferred over purely artificial light by office workers from both eastern and western cultures [20].

3. Methodology

To perform the study behind the developed mobile application it has been followed the methodology proposed by Peffers et al. 2007 [34]. The first task of the study has been to identify the problem and motivation in order to define the objectives to reach. Those objectives have been proposed as questions which they will be answered afterwards. The next step has been focused on the evaluation of the developed model through a simulation and cases of study. Finally, we have evaluated the resulting model through user's satisfaction surveys and user's feedback.

Before starting the work, a hypothesis to help to analyses the process of data acquisition has been provided, and subsequent presentation of results are offered. This hypothesis has four main points:

- H1: Does the use of mobile applications help in the illuminance measurement in work places?
- H2: Does the use of mobile applications produces energy efficiency optimization?
- H3: Does the use of a multi-agent facilitates helps user in decision making providing information about greater compliance with lighting standards set out by the EU?
- H4: Does the use of mobile applications help in the prevention of occupational risks?

Finally, the system has been built and applied to a real case to obtain the degree of implementation. For this task, an interface easy to handle that reduces the transitions between screens has been built.

4. Analysis of the System

The aim of the developed application is to allow users evaluating the light requirements needed to risk for their health. To help in this issue, has been developed a mobile application has been developed for android platforms, which incorporates an intelligent agent that allows measuring and evaluating the illuminance level of each space.

To perform this task the application will measure the illuminance of the work place to evaluate a wide range of spaces, both indoor and outdoor. Along with the measurements, the system provides additional information, giving users a new perspective that help them in the decision making process on how increase or decrease the illuminance levels. The aim is to keep the spaces with an adequate lighting level for helping workers in their eyes' comfort. This is achieved by the integration of a rule engine in the expert system developed.

Therefore, an expert system where the lighting reference level of information, stored in the device's data base, is compared with the real level, obtained through the illuminance measurement. To perform this comparison an analysis based on a rule engine has been developed. Its main objective is to inform user about the possible actions to adapt the light to the requirements of the specific scenario. To ensure that the level of reference derived from the stored values are correct, a comparison has been obtained from the European Union regulations (UNE-EN 12464-1 [10] and UNE-EN 12464-2 [11]), where the minimum illuminance is set.

Thus, the proposed system has been divided into 4 parts, as can be seen in Fig 1: mobile application; data base; light sensor and rule engine.

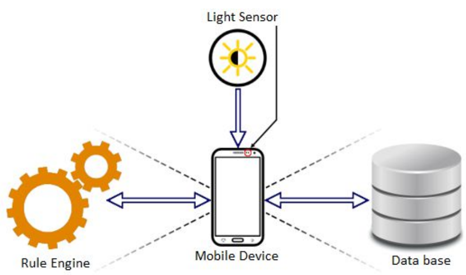


Fig. 9. Structure of system.

Mobile application

The application was developed by using the Android SDK provided by Google and Java, as the programming language, has been applied. As development environment, Android Studio has been used since the provided tools integrate seamlessly with IDE using the ADT plugin, which allows debugging code in connected devices, emulators included.

At all times the design patterns specified by Google for your system, have been applied, by using the theme "clear" (white and light colours) and maintaining consistency with the rest of the interface devices. The guidance is horizontal, due to its greater flexibility in terms of space, and the display menus showed in an intuitive way and lead to a partitioning of space in which several graphs are simultaneously appreciated.

During the development of the application, the MVC (Model View Controller) has been followed, which is useful to separate the operation of the visual layers. All the logic part is programmed in Java and visual part of an XML layer and it is modified and improved by Java.

Data Base

The application is supported by a database used to store information about user's profiles, predefined locations with their light requirements and information about registered locations and light measurements performed until the date.

The first time the application is running, the database only will have to provide the different locations and their characteristics. This information will be the base for the light analysis done by the application.

To ease the use of this tool by different users, the application provides a local user register, with the potential to personalize the information about the measurements performed by each user. Once the user is registered it is possible to store information about the locations evaluated as the apps location, lighting characteristics or historical measurements.

To develop the application's database SQLite has been used. Android has integrated a complete API that allows to manage this kind of database. The main advantages of SQLite, apart from the fact that is open source, is the use of a small size records, meets the SQL-92 standard and a server to run is not required [2].

Light Sensor

In recent years, smartphones have prevailed as sophisticated multi-function mobile phones. One of their main advantages is the incorporation of sensors that let us to monitor environmental properties as illuminance, or ambient temperature among others. These sensors are hardware-based and they are not available in all of the products. Its presence depends on the manufacturer's decision. For that reason, light measurement has been developed in two different ways in order to give to the user the option that best fit with its terminal.

Mobile's ambient light sensor

Despite ambient light sensor is a simple sensor included in most of recent smartphones, its accuracy cannot be compared with the accuracy of dedicated hardware devices [9]. However, the results obtained show that they can be useful in practical cases as in the undergraduate physics laboratory [26] where a high level of accuracy is not needed.

Some operating systems, like Android OS, allows the user to obtain the values from the light sensor through APIs which collect data in the runtime of the application. This API's will return a single value for each data event [8], whereas most motion and static sensors will return a multi-dimensional array of values.

External sensor device

To guarantee the use of the application in as much devices as possible, the option to make the light measurement through an eternal device has been developed. For this option it has been made an external device which can communicate with smartphones using Bluetooth. This technology is embedded in nearly all smartphones and its low power consumption compared with other wireless communication systems, such as Wi-Fi [22], makes this the best communication option between both devices.

Rules engine

The rules engine has a specific function and it may be labeled as the most important piece of the system regarding the application objectives as a consequence of its capability to analyze the information and ease in the decision making process. A rule engine may be viewed as a sophisticated if/then statement interpreter. Besides, the rules engine can manage a big number of rules with minimum impact on the normal execution flow of the process [4].

The main task of the rules engine is to ensure that the light values measured by the application are within the proper range. To perform this evaluation the rules engine has several inputs as the measured illuminance, maintained illuminance or the location characteristics, among the XM with the rules to perform the evaluation. Once the inputs have been analyzed, the results will show the recommended actions to guarantee the proper illuminance (Fig 2). Among the actions recommended by the application there are: reduce or increase the lighting, reduce or increase the distance from the light source, reduce or increase their power, move closer or further from the windows, user light dimmers, among others.

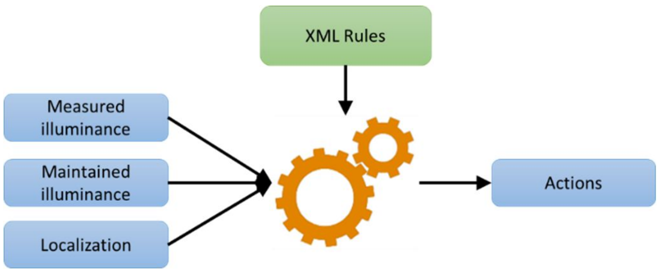


Fig. 10. Rules engine working chart.

To perform the rule engine JRuleEngine was selected due to its open license, availability of source code and practical orientation to the development of rules which may been described through an XML file. Following an example of a rule extracted from the XML file is shown. In this case it is check if the conditions of the measurement illuminance fulfill with the maximum estimated illuminance and the maintained illuminance. In case of values equal or higher than those values it will be executed the method addAdvice, passing an argument value of -1:

```
<rule name="RGoodIllum" description="Good illuminance, well done.">
      <if leftTerm="illum.getE"op="&gt;="rightTerm=" illum.getEm"/>
      <if leftTerm="illum.getEm" op="&lt;&gt;" rightTerm="0"/>
      <then arg1="-1" method=" illum.addAdvice"/>
</rule>
```

5. Results

The aim of this application is to manage the work lighting systems to guarantee eye comfort. To carry out this task, the application makes a comparison between the real illuminance level and the minimum required level required by regulations from different location profiles. As a result, the application has been divided into 5 different screens: login, main menu, new location, see location and new measurement.

Login Screen

This first screen shows when the application is started. It is an information that identifies the application and the members of the project. This screen will be shown for few seconds and then the login screen will be displayed.

Login screen allows to access to the application's information, and only authorized members can access to it. This user's register allows the use of the same application by different users making possible to personalize the information registered by each one. To control this access the credentials of the user will be checked on a local database.

The screen will show two options:

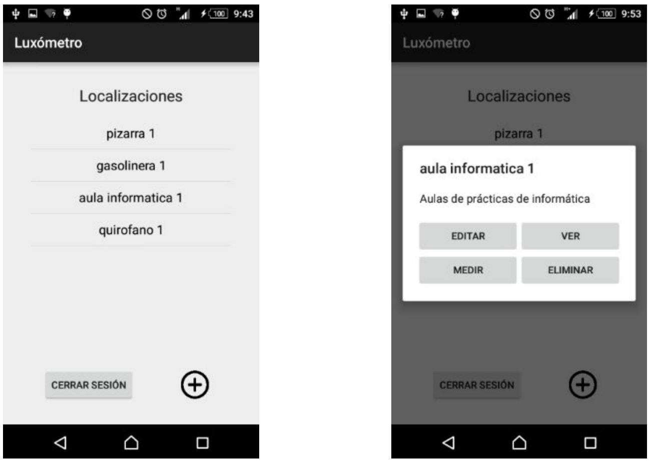
- Login of an existent user. On this option the screen displayed shows to text fields where user must to set its user name and his password. In case of correct credentials the application will show the main menu screen. On the other hand, if the credentials are not correct an alert message is shown to keep the user informed.
- Register a new user. It is possible to register a new user on the application. To make this requester a name of user, password and a confirmation of the password will be requested. Once the new user completes the registering he can access to the application.

To make easier the user access, the application allows to keep user's session logged when the application is closed. When it happens this screen is not showing when the application starts, displaying directly the main menu.

Main Menu

Once the user has been logged correctly, the application shows the main menu screen (Fig 3(a)). This screen is divided into three main blocks:

- User's locations list. All the locations registered by the user will be shown in the list. To perform an action on the location the name of the selected one should be pressed. After that, a list of four different actions is shown (Fig 3(b)):
  - o See Location. It is possible to access to the location information through this option, amongst the historic values of the light measurements done on it.
  - o Edit Location. With this option the user can see and edit the characteristics of the selected location. Besides, the information about the different measurements done in this location can be displayed, but it can never be edited.
  - o Measure Light. To perform a new light analysis of the selected location the user must select this option.
  - o Delete location. When this option is pressed, all the information related to this location (description and measurements) will be deleted.
- New location button. Whenever an user wants to perform the analysis of a location that is not in the list, it is possible to register a new one.
- Logout button. This option will be used when the user want to exit the application closing its session, or to face forward accessing of different user.



(a) Main menu screen (b) Location option

Fig. 3. Main menu screen

New location screen

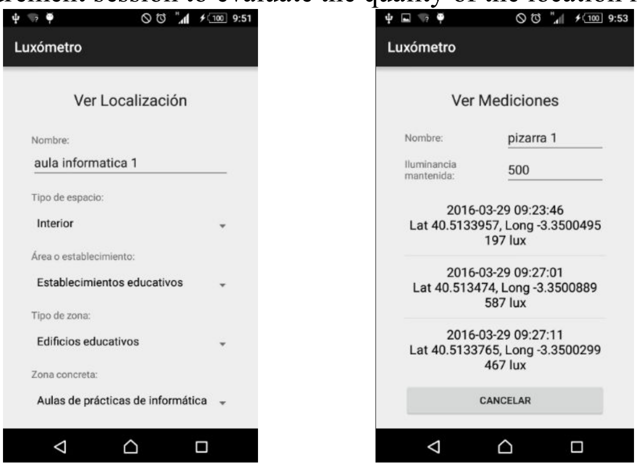
The aim of this screen is to collect all the characteristics to register a new location on the system (Fig 4). To ease the identification of it, a name of the location is required. Among this identification list, the user must introduce information about the kind of space to analyze it after. To simplify the search of the kind of space, the application has four different filters to classify each one: sort of space, area or facility, type of zone, specific zone.

Once that all the required information has been entered, it is possible to store the location and start to perform the measurements to analyze, or just store the location on the system or cancel the input.

Fig. 4. New location screen

See location screen

This screen shows information about the selected location. To display the characteristics of it (Fig 5(a)), is possible to read the historical data of the measurements performed on it (Fig 5(b)), or start a new measurement session to evaluate the quality of the location light.



(a) Location information (b) Historical measurements

Fig. 5. Locations details

Measurement screen

The aim of this screen is to perform the measurement of the illuminance level of the selected location. To keep users informed the name of the selected location is displayed.

To start the process of measurement and evaluation of the illuminance, the first task is to select the method to read the illumination from a selector, where there are two options:

- Mobile's ambient light sensor.
- Bluetooth External sensor device.

Once the lighting sensor is selected, it is possible to perform the evaluation, comparing two values, which are displayed by the application:

- Maintained luminance: it refers to the minimum illuminance required by a location's regulations.
- Current illuminance: It represents the value registered by the selected sensor.

To carry out the evaluation with the values displayed on the screen it is needed to previously store the result of the measurement. Once the button is switched on, the evaluation starts and the results will be shown in an alert dialog.

6. Discussion

Once the application has been developed, a questionnaire compounded by three blocks and 10 questions implemented and validated. All the questions have been asked by a Likert scale questionnaire 5. This allows us measuring user satisfaction, usability of the application and accessibility of information in order to contrast results and validate the hypothesis.

The results of the questionnaire are: the overall assessment of application was 4.64, where the degree of satisfaction with the application was of 4.64 and degree of efficiency provided by the application was 4.50.

Regarding the question related to the idea that if the proposed mobile application eases the measurement of work space illuminance it was punctuated as 4.71. The question on if the proposed mobile application helps in the optimization of energy efficiency was assessed as 4.64.

Concerning the group of questions about usability the questionnaire has two questions: the first about interoperability with the interface with a mark of 4.43; and second the transitions between screens and the ordered control system has been valued with a 4.71. Finally, the group of questions about information accessibility has been rated as 4.43 and the data entry and validation of the system has been rated as 4.30.

At methodological level, this work contributes to the presentation and the implementation of an engine of rules that facilitates decision-making in an efficient way telling user if it complies with the European standard, and in the case of deviation, it indicates the value of this. As a result, the developed application allows users be aware about the level of illumination of their environment and the deviation regarding the minimum and maximum illuminance levels established by the regulation UNE 12464. In case of unfulfillment of the regulation levels the application gives information and recommendation about corrective actions which may allow its compliance regarding the maximum and minimum illuminance levels. To promote their use, the developed application will be available on google play market.

Analysis of hypothesis

Furthermore, this research answers our hypothesis. As for the first hypothesis (H1), it has been observed that the use of mobile applications help in the measurement of the lighting in work spaces, allowing them to have more information in order to make a correct decision and assign resources in function of the degree of fulfillment of regulations UNE 12464-1 and UNE 12464-2. In addition, this statement is also supported by the value of 4.64 of the question proposed about if the mobile application facilitates the use and the evaluation of lighting in work spaces.

Regarding the second hypothesis (H2), the validation that the use of the mobile applications ease the optimization of energy efficiency has been observed. It allows to the user reduce energy consumption. In addition, as it is shown in the questionnaire, both cluster of issues on usability (4.43) and accessibility (4.43) the users evaluation is high allowing supporting the hypothesis.

Besides, according to the third hypothesis (H3) the validation that the use of rules engine in the mobile application allows to detect the illuminance variation in working spaces regarding the regulations has been proofed, being therefore possible to recommend measures to improve the quality of the light.

In relation to the last hypothesis (H4), the use of this tool helps in the prevention of occupational risks, was validated due to its capacity to optimize resources. Furthermore, as we can see in the result to the question on these applications motivating employees, the score of the evaluation was 4.64, so the tool motivates the work environment.

As a feedback step, and in order to validate the application, in the construction and implementation of the system it was essential to make a validation to verifying its effectiveness. To perform this task two types of validations were carried out:

1. Technical validation. Once the application was developed it was checked by a technical users in order to ensure that the application fulfill the specifications defined to its design.
2. Practical validation. This validation was made in two different ways:
   a. The first one through 20 different measurements performed by 5 different users with different locations and environments, comparing those measurements values with a professional luxometer.
   b. The second one was performed through a user satisfaction user's satisfaction with the application from the point of view of usability, handling, questions, etc.

On the other hand, the use of a rule engine has eased the development of a multi-agent that compares the values acquired by the sensors with the values of the UNE regulations, helping users to adopt the better option to improve the lighting level. Besides, the usage of the system has provided a huge amount of open data that could be evaluated with a metric tool as MELODA [1] aimed to evaluate the reuse of the data.

7. Conclusions

In this research a new tool based in the usage of lighting sensors which allows to evaluate the level of illuminance in both working spaces, outside and inside has been designed, built and evaluated. The tool allows to know the degree of compliance of UNE standards, allowing it use in the prevention of occupational risks and the optimization of energy efficiency.

The results suggest that the usage of this tool allows to obtain the value of the illuminance in a working place and the rule engine implemented provides user information through a group of recommendations for improvement, helping with decision-making tasks, allowing at the same time to decrease the number of sick leaves caused by bad lighting of the workplace.

The developed system was evaluated by professionals from two points' of view: practical and technical. The results offered some feedback and suggestions about the system. The feedback from caregivers showed that the proposed system can streamline and improve the process of risk prevention due to illumination of job.

In resume, mobile technologies allow achieving energy efficiency optimization and a better use of the resources with the aim of improving the prevention of occupational hazards.

On the other hand, this system provides risk and prevents workers to a greater mobility and an improvement on the process of evaluation of risks prevention.

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