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Exploratory Study of a Mobile Location-based Real-time Notification System for Frontline Police Officers

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Abstract: The police organization is highly dependent on information. Frontline police officers are working on the streets and need the right information at the right time. Mobile technology can provide location-based information and could be of great assistance to them. We developed a mobile location-based real-time notification system and conducted an exploratory study in two real-life experiments. The system provides information on a point of interest (PoI) when frontline police officers are close to that PoI. Usability, recall of information, and situational awareness were measured to assess the impact of the system on police work. The results show that the system usability was adequate, recall of information varied between police officers working with the system and without, whereas little difference in situational awareness was found. Interviews suggest that awareness regarding PoI's was increased and new behaviour was triggered by the system. Future research will evaluate further developments of the system and its impact on police work.

Keywords: Mobile Computing, Notification Systems, Location-Based System, Situation Awareness, Experiment, Police
Categories: H.5.2

1 Introduction

Information is considered the lifeblood of the police; fighting and preventing crime is highly dependent on the availability of information [Garicano and Heaton 2006, Maltz, Gordon and Friedman 1991] and frontline police officers function in an information intensive environment [Sørensen and Pica 2005].

It is thus no surprise that the police widely embrace information technology [Byrne and Marx 2011, Koper, Lum and Willis 2014, Yalcinkaya 2007]. Mobile technology has the potential to significantly support frontline police officers [Sørensen and Pica 2005]. As to be expected, the police have adopted mobile technologies a long time ago, for example the introduction of two-way radios in the early 1900's [Poli 1942]. These voice-based mobile technologies have shown to be supportive to police work, see for example [Manning 1996]. Mobile technologies currently also enable data communication through information services and location-based services [Byrne and Marx 2011], next to voice communication. Prior research shows that there is not one answer to how mobile information services impact police work. It depends on the working environment [Pica and Sørensen 2004] and will evolve over time as well [Karanasios and Allen 2014].

To study the impact of new mobile location-based technology on the situational awareness of frontline police officers and their work, we developed a system that proactively provides information on PoI's to police officers in the field when they are in close proximity of it. Based on the provided information, frontline police officers can decide how to handle the PoI. We evaluated the impact of the system in an exploratory study in two real-life experiments. The experiments were performed in two regions with different characteristics for police work. The results show that the usability of our system is adequate whereas situational awareness in general was not significantly impacted by using the system. Still, awareness on specific PoI's improved and the exploratory study provided valuable insights for future work.

The remainder of this paper is structured as follows. In the next section, we give an overview of research into the use of information and of mobile technologies by police officers. In the third section, we describe the system we have developed for this research project. In the fourth section, we describe the research method we have used to evaluate our system. The results of which are presented in the fifth section. We conclude this paper in section 6 with a discussion of the results, general implications for science and practice and suggestions for further research.

2 Background

2.1 Information for police officers

Police officers rely on quick, adequate access, and exchange of accurate context-related information [Lin, Hu and Chen 2004]. High-quality information is a valuable resource to police officers for analysing and understanding a problem in order to develop problem-solving strategies [Brown 2001]. ICT can play a major role here by providing an infrastructure to store, forward, retrieve and distribute such quality information. However, there is a mismatch between the information needs of police officers and the ability of ICT to provide the information [Manning 1996, Sawyer and Tapia 2005]. Misaligned organizational culture [Allen et al. 2008] further negatively impacts the performance of ICT systems. This overall mismatch can impact the performance of teams and can ultimately save or cost lives [Jones and Hinds 2002]. Even before an event occurs, the lack of adequate information can cause anxiety due to non-availability of information in more dangerous neighbourhoods [Agrawal, Rao and Sanders 2003].

Currently, frontline police officers attend a briefing session in which important information for their shift is shared orally. However, oral communication can be understood and interpreted differently by different team members [van Knippenberg, De Dreu and Homan 2004]. Furthermore, information presented through a briefing is only partly remembered later by police officers; 60% of the information cannot be recalled by the police officers [Scholtens, Groenendaal and Helsloot 2013].

In the briefing, only a small amount of all available information is presented; a briefing has to be short and to the point. Police officers, therefore, use a multitude of systems to share information. Email, database systems and sharepoint working spaces are all examples of such systems. Most often these systems are only available inside the office. When arriving at a location, frontline police officers need to retrieve the correct information. Since it is not possible to recall all information from memory, police officers are provided with mobile services to retrieve it. This takes time, effort and attention, which restricts the amount of attention that can be directed at the situation on the street.

Instead of retrieving the correct information at the right time from memory, frontline police officers could benefit from proactive, visual information, automatically provided to them through a mobile service.

2.2 Mobile technologies for police officers

Some state that there is a mismatch between the information need of police officers and ICT to provide the information [Manning 1996, Sawyer and Tapia 2005]. However, most of the available technologies have not been developed specifically for the police and the police mainly use technologies already available on the market [Pauw, Ponsaers, Deelman, Vijver and Bruggeman 2011]. Nevertheless, technologies can be found in all aspects of police work [Custers 2012]. Information technologies are an important category in this as police work can be considered highly information intensive [Foucalt 1975].

The paper-based record systems have been replaced by computerized information systems long ago [Chen et al. 2003]. Most police forces have one or more systems available with which police officers can record their observations and retrieve relevant information. A well-known problem with these systems is that police officers experience the systems to be cumbersome and taking up too much of their precious time they would like to spend outside on other valuable activities [Koper et al. 2014].

Mobile technologies take away this disadvantage of not being on the street [Easton 2002]. At the operational level, officers on the street are increasingly equipped with mobile devices through which they can access relevant information by themselves in a timely fashion, something that has been lacking for a long time [Chen et al. 2003]. Especially these kind of technologies that provide officers with information to enable them to take action, respond, react and arrest, are favourable [Koper et al. 2014]: this allows police officers to do the same work in a more modern and autonomous way, but it does not yet offer genuinely new ways of working. [Karanasios and Allen 2014] show in their research that mobile technologies result in a reduction of the voice-based communication between police officers and the control room, a faster access to information and a decrease in the number of situations in which officers acted without information. This positively influences the safety of police officers as they are better informed. Using mobile devices, however, also

negatively influences officer's safety as they are distracted [Streefkerk, van Esch-Bussemakers and Neerincx 2008] since they are looking down at the device rather than monitoring the surrounding environment [Karanasios and Allen 2014]. With less attention being paid to the dynamic environment, this loss of attention can have an effect on reduction of situational awareness [Lum, Koper and Willis 2017].

Mobile devices also offer the possibility of deploying location-based systems for contextual information. Hotspot policing has been shown to be effective in the reduction of crime [Braga 2007] and it is thus no surprise that location-based systems are of interest for police forces. Prior studies have shown the potential of location-based systems in emergency response [Betts et al. 2005], but there is a clear lack of field studies showing the impact of such systems.

2.3 Summary

The above discussion shows that mobile technologies offer huge possibilities to provide frontline police officers with quality information in time. Such quality information is critical for facilitating and maintaining situational awareness. However, mobile technology can also have negative impacts. In the following, we describe a system to provide quality location-based information to frontline police officers. Bases on this system, the impact on a frontline police officer's situational awareness and the overall police work is evaluated.

3 Mobile location-based real-time notification system

Our system consists of four main elements: a database containing the information (component 1 in Figure 1), an app on the mobile device for the frontline police officers (component 2 in Figure 1), a team leader web-based application (component 3 in Figure 1) and a back-end server (component 4 in Figure 1) which establishes the communication between the first 3 elements. The mobile app for the frontline police officers runs on Android platform for which Samsung Galaxy S5 and Samsung S7 smartphones and Samsung Gear S2 smartwatches were used. The S5 and S7 smartphones are standard equipment for the Dutch police personnel.

The database platform (1) used in our system is NoSQL-based and runs on `MongoDB`. The app for the mobile device (2) is implemented as a web-app, using a cross platform technology (`Cordova`). The back-end (4) is implemented using `nodejs` platform. The team leader app is implemented as a web-app which communicates with the backend webserver over a secured channel (`https`). All communication between the app for the frontline police officers to the backend, and between the team leader app and the backend, relies on secured web-sockets.

Figure 1: System diagram showing the database system (1), the mobile app for the frontline police officers (2), the user interface for the team leader (3) and the system (back-end) server (4)

3.1 Database

The database contains information about two kinds of events; a point of interest (PoI) is an ongoing situation that requires police attention, such as nuisances of drunken persons. This in contrast to special PoI's which are ad-hoc incidents such as a car accident or a missing child that requires immediate action from the police. Each PoI is stored in terms of the street/address, the decimal degrees (latitude and longitude geographic coordinates), a description of the location, a description of the case, the action to be taken, the police code of the problem used in their internal system, the begin and end time and date of the problematic situation, and a photo of the problematic situation (see Table 1). Similar data can be stored for the special PoI's. When we talk about PoI's in this paper we mean ongoing situations as well as ad-hoc incidents.

The system prototype includes a log-module which stores all the events related to the system interaction for all the users. The system logs the following events: 1) creating a new PoI, 2) updating a PoI, 3) deleting a PoI, 4) marking a PoI as "done" (by a frontline police officer) and 5) current location (latitude and longitude) and orientation for all the frontline police officers.

Address	<Street name and number>
Coordinates	<GPS location>
Location description	Next to railway bridge
Case information	Illegal fishing and waste dumping
Action	Check & summon
Code	M11
Time	12:00 – 22:00
Date	1 July – 30 August
Photo	<Picture showing the PoI>

Table 1: Example information of a PoI

3.2 Frontline police officer app

The frontline police officer app provides police officers with information on PoI's at a specific location. PoI's from the database are pushed to frontline police officers' mobile devices based on two filters.

The primary filter type is location–based and identifies a frontline police officer's area of interest. This area of interest has a circular shape and is always centred at the current position of the frontline police officer. The size for the area of interest is a parameter that can be changed manually by the user (being accessible in the mobile app's configuration panel), being in the range from 5 meters to 10000 meters. The mobile app constantly adjusts the area of interest so that the user is in the centre, meaning the circular-shaped area of interest moves with the frontline police officer. This filter is active all the time and enforces the delivery of notifications to the frontline police officer with regard to PoI's which fall in the users' circularly-shaped area of interest.

The second type of filter is based on the code of the PoI, which indicates what kind of PoI it is, i.e. a youth-related incident or vagabond related incident. By using the app's configuration panel, the frontline police officer can choose to receive notifications about certain type of PoI's.

Notifications about incidents that require immediate attention (special PoI's) are always directly pushed to the frontline police officers, i.e. independent from the filters configured by the frontline police officers. Compared to the current way of working, in which such incidents are communicated orally through the mobile communication device to all frontline police officers listening to the audio channel, this allows the team leader to directly contact frontline police officers in a specific region around the incident. By communicating via the app frontline police officers are able to read back the information at their own speed and processing capacity. In addition, it enables the team leading officer to selectively address police officers in the field, instead of broadcasting the information to everyone.

Three types of views are enabled in the mobile app for the frontline police officers, namely the list view, the map view, and the mixed view. The List view displays a scrollable list of PoI's in line with the applied filters. The PoI list is continuously updated to be sorted from small to long distance based on the distance to the frontline police officer. The Map view shows the location of the frontline police officer (aka the actual position of the mobile device), the position of the PoI's

available in the area of interest, as well as the other frontline police officers in the team (using distinct numbered coloured discs). The mixed view combines the former views and shows the list on the top part of the screen and the map on the lower part of the screen (see Figure 2).

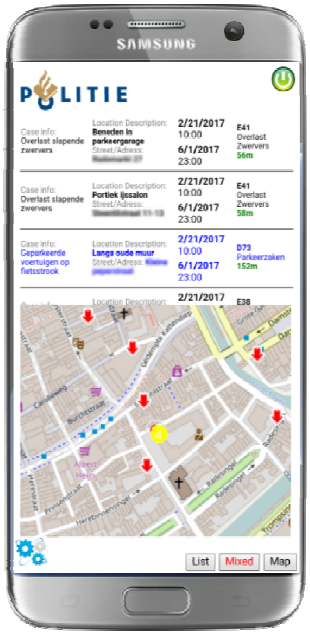

Figure 2: Screenshot of mobile device <list + map>

Once a frontline police officer selects a PoI, detailed information is shown (see Figure 3). A frontline police officer can see where the PoI to be investigated is on the map, together with other information. After investigating a PoI, a frontline police officer can press the "done" button in the bottom-left corner of the page. . The PoI will disappear from the PoI's list of all frontline police officers. In such a situation, the PoI is not removed from the system entirely, but is only marked as "done" in the database.

In addition to the S5 or S7 police smartphones, the system integrates smartwatches (Samsung Gear S2). A frontline police officer wearing such a smartwatch simultaneously receives a notification (by vibration and short text) on the smartwatch and on the smartphone. With the support for smartwatch vibration in place, a frontline police officer can easily notice newly received notifications even when not looking directly at the smartphone's screen.

One more feature of the mobile app is the "stealth mode". When in this mode, the mobile app does not receive notifications, it only reports back to the server the current geographic coordinates, orientation of the user, and the filter preferences. This mode is activated on the mobile devices of the officers who work according the standard procedure and take part in comparative tests as a control group.

Figure 3: Screenshot of mobile device <detailed info>

3.3 Team leader app

The team leader app provides the team leading officer with information on the PoI's and the current location of all frontline police officers. It runs on a regular monitor, laptop screen or on a smartboard as a web-based application. It has two main components:

1. Map visualizer (see Figure 4)
2. PoI editor (see Figure 5)

The first component, the map visualizer, provides a representation of the georeferenced PoI's directly on the map using arrows (see Figure 4). It also shows representations for all frontline police officers using numbered coloured discs. On the map, the regular PoI's are displayed in red, the PoI's marked as "done" are displayed in black, and the PoI's marked as "special" are displayed in blue. Furthermore, the system can show the individual orientation and the area-of-interest for each frontline police officer. The area-of-interest is represented as a circle centred at the current location of the mobile user and having a radius according to the setting in the user's mobile device.

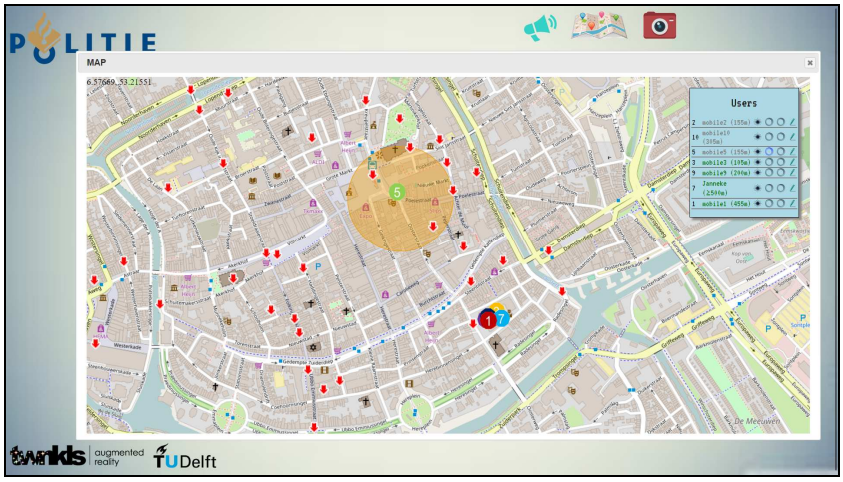

Figure 4: Map visualizer

The PoI editor allows the team leader to add, delete and update any PoI. In addition, PoI's that have the status 'done' can be reactivated directly in the database. The reactivation process can be immediate or can be done automatically after a specific amount of time elapsed (e.g. after 10 hours). From the PoI editor, the team leader can mark any PoI (regular or "done") as "special".

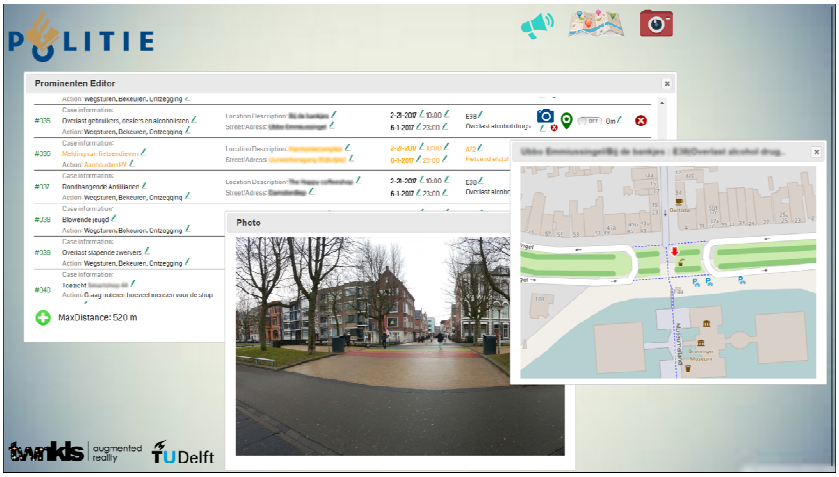

Figure 5: PoI editor

4 Method

To test our mobile location-based real-time notification system, we have conducted an exploratory study consisting of two real-life experiments in two different police regions. We have selected different police regions to see how the working environment influences the use of the system. The first police region can be characterized as urban, whereas the second police region has a more rural character with industry and nature as part of the region, next to an urban area (see Table 2).

	Region one	**Region two**
FTE	112	193
Square km	2	99
Population	16.500	118.800
Houses	8.550	54.850

Table 2: Characteristics of regions (2016)

In total, 39 police officers participated in this study during a normal working shift (see Table 3). 31 Males and 8 females participated, their mean age was 35 years (stdev = 9) with on average 12 years (stdev = 10) of police experience. The frontline police officers were on one of the following shifts: emergency response (15%), surveillance (70%) or community policing (15%). Most frontline police officers went by car (54%) and too a much lesser extent by foot (25%), bike (18%) or scooter (3%).

The experiment in region one took place in April 2017, the evaluation in region two took place in July 2017. Each frontline police officer participating started with the team briefing as usual. After the briefing, they received an introduction of ten minutes into the functionalities of the app on the mobile device and they were asked to do their work as normal, but with the app running in the background. They were instructed to respond to notifications whenever they think it is appropriate. Before the experiment started they were asked to fill in an informed consent form and a demographic questionnaire about their personal characteristics such as gender and age. Approximately thirty minutes later, they went out on the street to do their work as a frontline police officer. After working for approximately two hours they returned to the office for a debriefing interview and to fill in questionnaires on their experiences using the app.

For control purposes, we also asked several frontline police officers to participate without using the app. In region one, 6 frontline police officers participated in this control group and in region two, 10 frontline police officers. Like the frontline officers using the app, they returned after approximately two hours to fill in questionnaires on their experiences.

We used different measurement instruments:

1. System usability scale (SUS)
2. Questionnaire on situation awareness (3D SART)
3. Recall questionnaire
4. Unstructured interview for debriefing

		Region one	Region two
Gender	male	88%	74%
	female	12%	26%
Age	avg. years	36	34
	stdev.	9	9
Experience	avg. years	11	14
	stdev.	9	11
In region	avg. years	6	7
	stdev.	7	5
Shift	emergency	0%	26%
	surveillance	88%	57%
	community policing	12%	17%
Mobility	foot	63%	0%
	bike	31%	9%
	scooter	0%	4%
	car	6%	87%

Table 3: Characteristics of respondents

The SUS is a questionnaire consisting of 10 items with a 5-point scale ranging from strongly agree to strongly disagree [Brooke 1996]. Based on the answers an overall usability score is calculated. Score above 68 are considered above average and indicate a good usability. The SUS questionnaire was only completed by the frontline officers using the app.

For situation awareness the short version of the Situation Awareness Rating Technique (SART) [Taylor 1990] was used, namely the 3D SART. 3D SART groups the 10 dimensions into 3 groups; demands on attentional resources, supply of attentional resources, and understanding of the situation. Demands on attentional resources comprises the constructs instability, complexity, and variability. Supply of attentional resources comprises arousal, concentration, division of attention, and spare capacity. Understanding the situation comprises information quantity, information quality, and familiarity. The questionnaire consists of 10 7-point questions filled in after the experiment. Both, frontline officers using and not using the app, completed the 3D SART questionnaire.

The recall questionnaire consisted of a map and five questions to measure how much information about the PoI's the frontline police officers could recall. Both, frontline officers using and not using the app, were invited to complete the questionnaire and indicate on the map where they had been during their shift and to answer the following questions per location:

1) What was the situation?
2) What was the requested action?
3) What action was taken?
4) If you deviated from the requested action, why did you deviate?
5) Which (extra) information would you have liked to have?

The interviews were unstructured and conducted for debriefing the frontline officers using the app. They focussed on the experiences of the officers while using the app. Questions targeted the general usability of the app and suggestions for improving the app, but also asked for reflections on the impact of the app compared to the traditional way of working without the app.

In region one, we implemented the app on the police issued mobile devices of the frontline police officers. During the experiment, we noted that the existing police system on the mobile device was interfering with our app: once the police system was used, the connection between our app and server was lost. Frontline police officers had to manually close down the police system and restart the app to reconnect again. To overcome this in region two, we worked with separate mobile devices. Frontline police officers usually work in pairs of two, so one officer used the mobile device with the police system and the other officer used the mobile device with our app. This small disadvantage was considered to outweigh the problems with reconnecting.

5 Results

First the quantitative results from the questionnaires are discussed and secondly the qualitative results from the de-briefings are presented.

5.1 Questionnaires

The average overall system usability score is 71 on a scale of 100. For region one, it is 68 on average and for region two 75. The difference between region one and region two can be explained by the fact that in region one the existing police system on the mobile phone was interfering with our app; in region two we solved this problem by using a separate phone for our app. The overall system usability scale is considered to be sufficient.

The situation awareness of frontline police officers with app is more or less equal to the situation awareness of frontline police officers without app, see Table 4. Whereas information demand and understanding are quite similar, the largest difference can be observed in the supply of information; how much attention police officers could give their work. Without app, they could give slightly more attention to their work than with app.

	Without app	With app
Demand	5.2	5.0
Supply	5.8	5.4
Understanding	5.2	5.2
SART	5.8	5.6

Table 4: Situation awareness

From the recall questionnaire, we deduced that frontline police officers without app paid more attention to emergency response calls and less attention to ongoing PoI's than frontline police officers with app. 60% of the locations and activities reported by frontline police officers without app concerned emergency response calls to which they were directed by the central dispatch department. In contrast, only 5% of the activities reported by frontline police officers with app concerned emergency response calls which were dispatched through the mobile phone.

5.2 Interviews

Unstructured interviews were conducted during the debriefing of the frontline police officers using the app. Depending on the amount of feedback, the debriefing lasted five to 15 minutes. The feedback received can be categorized in general feedback on the app and its effect on the way of working, requested additional functionality and feedback on the smartphone as well as smartwatch.

Generally, the app was perceived as valuable for frontline police work and the interaction with the app was considered simple and pragmatic. The officers specifically highlighted the added value of the app and the information when being new to the area. Police officers, e.g., stated [translated from Dutch]:

- "Your curiosity is triggered: once you receive a notification you want to know what is going on."
- "I know most of the places, but through the vibration your attention is explicitly drawn to the hotspot. Without the app I would have passed by without explicitly looking."
- "It helps. Usually I walk around and know about a few hotspots. Now I am also aware of other hotspots."

Some officers considered the app as useful in the car, as the co-driver can look at the app and point to PoI's. Once a PoI is approached, they can slow down the car, take a quick look, maybe get out of the car and, in case no action is required, continue with their normal patrol. These officers indicated that they went to several new places, which they would have driven past otherwise. Other officers, though, considered the app in the car as distracting from standard surveillance tasks, as they were continuously busy checking the information on the phone. They suggested to install the app on a fixed tablet in front of the co-driver to enable less distracting access to the provided information.

Furthermore, several officers reflected on the provided information. Though the information was considered useful, especially when being new to the area, all officers highlighted the need to continuously update the information and make sure that the information is relevant. Otherwise, they expect a low acceptance of the app for daily use.

With regard to the functionality of the app, the officers provided a lot of feedback. Though the most frequent feedback was in relation to the notifications, the provided information and navigation support. As the officers could select and change the notification range on their own, some increased the range so far that they received notifications for all PoI's at once. In this case, it became difficult to identify from the list which of the PoI's is closest by. One officer suggested to not only sort the PoI's with regard to distance, but also use colors to indicate the time passed since notification. A good working notification range, though, appears to be personal preference, as seen in the large variation of responses. Some officers on bike indicated that more than 55m is not suitable for receiving notifications, whereas others recommended a notification range of 200m.

When receiving a notification on a close PoI, officers would like to have a possibility to easily ignore the notification and also prevent further notifications from the PoI for a certain amount of time. When acting upon a notification, officers would like to not only indicate that they have acted upon the notification, but also provide additional text describing their actions.

With regard to the information, officers indicated that they not only would like to see general information of the active PoI's, but also access and view the 'historic' information. The latter specifically to understand when, by whom and how a PoI was handled. They further suggested to not only include PoI's with a specific location, but also indicate areas of interest, e.g. to check whether it is allowed to drink alcohol in the area or whether specific persons are not allowed to be in the area.

Almost all officers commented on the provided map and navigation support. They suggested that the map should rotate in the direction of movement and that the map should move with the own location to better support localization and navigation. Also, some suggested to provide special notifications on the smartwatch when approaching a PoI, e.g. 200m to go, 100m to go, etc. Finally, they suggested to include a link to navigation support such as, e.g. Google Maps.

With regard to the used hardware, the officers indicated that the smartphones got quite warm during usage and that the battery should last longer when the app is used on a daily basis. Furthermore, they indicated that the GPS positioning was sometimes not precise, especially when in the car. The smartwatch was generally appreciated, especially by officers on bike. The major reason for this was that it was considered difficult to notice the phone notifications when not holding the phone in your hand. Here, the officers suggested to include simple interaction possibilities with the system from the smartwatch, e.g. to indicate that a PoI was handled or that notification should be turned off for a specific amount of time.

Table 5 summarizes the major outcomes. The remarks of the participants were in general feedback on the app and its effect on the way of working, requested additional functionality and feedback on the smartphone as well as smartwatch.

Category	Example
General	Good system, simple and pragmatic Awareness on PoI's is increased Curiosity is triggered Unknown PoI's are handled Make sure information is relevant
Functionality	Map rotation corresponding to own movement Navigation support Allow describing text on performed activities Allow to access more information on PoI's Support area notifications
Hardware	GPS is not precise enough Battery life of smartphone too short Smartwatch useful to receive notifications

Table 5: Main outcomes of unstructured interviews

6 Discussion and conclusion

In order to explore the impact of new mobile location-based technologies on frontline police officers, a mobile location-based real-time notification system was developed and an exploratory study with two real-life experiments was conducted. Overall the participants gave positive feedback about the system, which was also shown in the results of system usability (above average score of 71).

Situation awareness seems similar for frontline officers with and without the app. We would have expected that the frontline officers with the app have increased situational awareness. Possible explanations for the lack of difference can be found in the three underlying components. First, the demand on attentional resources heavily depends on the shift and is probably only minimally influenced by the app. Second, the questions about the supply of attentional resources show that frontline police officers without app were more alert and ready to take action than frontline police officers with app. The average arousal score without app was 6.3, while the average score with app was 5.5. A possible explanation could be that frontline police officers relied on the app to point out PoI's, and thereby, assuming a more passive role instead of an active role [Parasuraman and Mouloua 1996]. Third, the understanding of the situation: it appears that in both situations, with and without app, frontline police officers experience the same level of understanding. We would have expected the level of understanding for frontline police officers with app to be higher, since they receive more information on situations. Yet, this is not visible in the research results. A possible explanation would be that frontline police officers with and without app pay attention to different situations. Frontline police officers with the app attend the PoI's one by one, whereas police officers without app only pay attention to ongoing PoI's if they are aware of them. Besides, most of the time they pay attention to ad-hoc incidents on which they receive information through their mobile communication device.

The unstructured interviews showed that the app impacted the frontline police officers' behaviour. Two observations were made: PoI's were investigated more thoroughly and more PoI's were visited. The notifications drew the frontline police officers' attention to the PoI's, instead of passing by without explicitly investigating the PoI. A possible explanation could be that curiosity is triggered by the notifications. In addition, more PoI's received attention, because frontline police officers received a notification at the right time and did not have to know all the PoI's by heart. Because the frontline police officers with and without app encountered highly different situations during their shift, the recall questionnaire could not confirm these findings. The unstructured interviews also showed that the information quality about the PoI's is important for the value of the system. The participants vocalized that more information, more precise information, new information, and continuously updated information is important to maintain a relevant system. When the information quality degrades the use of the system will also lessen.

A number of limitations should be considered in relation to the findings. Since this was an exploratory study on how the app impacts frontline police officers, only a limited number of participants participated in this study for a limited time. In order to perform statistical analyses to discover the effect on situational awareness more participants and a longer observation period are needed. The same holds for the fact that some officers participated in both 'conditions' while others only participated in one 'condition'. Furthermore, it seemed difficult for participants to reflect on how the app impacted their behaviour and performance. Instead, they mostly commented about the functionality of the app. A more structured interview might overcome this limitation. Lastly, there were some technical issues during the experiment in region one, which were solved by using an additional smartphone in region two.

In conclusion, our mobile location-based real-time notification system adds value to daily work of frontline police officers. The study produced insights into the impact of the system on awareness and behaviour, as well as suggestions for further development.

Based on the experiences and feedback of the participants, the next version of our mobile location-based real-time notification system will consider the following aspects:

- Location determination must be highly accurate and reliable
- Navigation support
- Possibility to add comments and pictures to a PoI while on the street
- Possibility to add a new PoI via the frontline police officer app

In future research, we will evaluate the system with the extended functionality and consider different means of visualising the information. In earlier projects [Lukosch, Lukosch, Datcu and Cidota 2015a; Lukosch, Lukosch, Datcu and Cidota 2015b], we visualised and shared information among police officers using augmented reality, i.e. by superimposing virtual information on the real world [Azuma 1997]. Based on these experiences, we plan to extend our system such that PoI information is shown in augmented reality. We will then evaluate in how far augmented reality supports the provision of location-based information for police officers. Furthermore, we will involve more participants in the study in order to perform statistical analyses. In order to study the long-term impact of the app, we further plan to evaluate the use of the app over several consecutive days. Here, we are especially interested in the

processes around creating PoI's and keeping the information on PoI's relevant for frontline police officers. Lastly, we will analyse the log data from the system to explore performance and behaviour of the frontline officers.

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