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Technical requirements for organising successful mobility campaigns in citizen observatories

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Abstract

Traditional travel surveys are usually organised in a top-down manner, when data collection is commissioned by transport authorities. Recently, however, there has been an increasing tendency towards bottom-up initiatives when citizens and stakeholders initiate and implement data collection campaigns in citizen observatories. Citizen observatories are usually based on participatory sensing i.e. data collection by volunteers using smart mobile devices. The ubiquity of smartphones and hardware developments make it a potentially useful instrument to have travel behaviour registered. However, deploying a new citizen observatory remains technically difficult and labour-intensive. Today, citizen observatories have to be developed from scratch, which acts as a significant barrier to their deployment. Recently, an open, reusable and reconfigurable citizen observatory platform has been proposed. Through such a platform, ICT-agnostic stakeholders are able to initiate new citizen observatories in various domains.

In this paper we have developed a general technical framework for a platform that can allow stakeholders to create citizen observatories, with the aim of collecting data on travel behaviour. The framework is based on the already available functionalities of travel survey applications, elaborating on the potential limitations and enhancements of a citizen observatory platform compared to travel survey apps. In the first part of this paper, we have compared the functionalities of smartphone-based travel surveys and citizen observatories, which exposed the main areas of concern of citizen observatories compared to traditional travel surveys. In the next section we developed a framework for the technical requirements to organise a citizen observatory for mobility. The three most important stages in this framework are the collection of raw data, the processing of this data into valuable behavioural and environmental information (e.g. trips, travel modes, air pollution) and the feedback of this data to all stakeholders. Validation of the collected information should be applied in each stage of data collection and it is important to ensure user acceptance during the entire lifespan of the campaign. We highlighted points for attention that should be considered when developing a citizen observatory for mobility. Especially defining the required accuracy, representativeness and reliability in a specific campaign are key questions in the context of an acceptable rate of battery drain. The technical requirements developed in this paper reflect a 'best-case scenario' that will later be analysed through in-depth interviews and specific use cases to test the framework.

Keywords: Citizen observatories, participatory sensing, technical requirements, travel surveys, data collection

1. Introduction

The ubiquity of smartphone-devices and hardware developments in terms of memory, battery capacity and sensors have created a novel data collection tool for transport planning. Sensors integrated in the device provide a continuous stream of information with respect to location and activity parameters, while the ubiquity of smartphones make it a potentially useful instrument to register travel behaviour. Travel surveys have traditionally been organised in a top-down manner when data collection is commissioned by transport authorities and carried out by consultants using dedicated data collection software. Recently, however, there has been an increasing tendency towards bottom-up initiatives when citizens, stakeholders and their organisations initiate and implement data collection campaigns in citizen observatories (H-Y Liu, Grossberndt, & Kobernus, 2017). Citizen observatories are sets of ICT-tools to collect, analyse and visualise sensor data, with the aim of improving the quality of life of citizens. They are series of observations made by citizens in a structured manner, which is collected, reported and commented upon. In a citizen observatory, a citizen's direct surroundings or environment are under observation. A citizen observatory tries to raise awareness for a specific issue, initiate dialogue between stakeholders and allow for citizens to exchange data. They are usually based on participatory sensing i.e. data collection by volunteers, which allows people-centric contextual monitoring using smart mobile devices (Kobernus et al., 2015).

First-generation citizen observatories have been proven to have an important role in the evolution towards a sustainable society but deploying a new citizen observatory remains technically difficult and labour-intensive. Today, citizen observatories have to be developed from scratch or use dedicated software that has to be developed for a specific campaign, which acts as a significant barrier to their deployment. They are thus beyond the reach of most societal stakeholders (Hai-Ying Liu, Kobernus, Broday, & Bartonova, 2014). Recently, an open, reusable and reconfigurable citizen observatory platform has been proposed (D'Hondt, Zaman, Philips, Boix, & De Meuter, 2014; Zaman et al., 2014). Through such a platform, ICT-agnostic stakeholders themselves can initiate new citizen observatories in various domains. Web services and mobile apps are generated automatically based on the stakeholders' needs and the parameters defined by them. Data collection uses the sensors in smartphones to register behaviour (e.g. trips, travel modes) and environmental variables (e.g. noise, air pollution).

The observatory is based on the notion of a campaign. A campaign is defined by a stakeholder (e.g., the cyclist's association) through spatial and temporal constraints on the data that need to be collected (e.g. which routes do cyclists take in the city centre during morning peak hours?). Subsequently, the campaign is enacted through the stakeholder's citizen observatory, which also monitors campaign progress in terms of incoming data and orchestrates activities in case progress is not as expected. Finally, the campaign is analysed by producing the requested output (maps, reports) to both the campaign organiser and the participants (D'Hondt et al., 2014).

While multiple citizen observatories have been initiated in the domain of environmental monitoring, the concept has not to date been applied in data collection in transport. Such an observatory would enable citizens and civil organisations to organise bottom-up data collection campaigns focusing on local problems (e.g. parking pressure, traffic congestion, traffic safety) and providing data to support decision making.

The aim of this paper is to draw up the technical requirements for a citizen observatory that aims to collect data on travel behaviour, enabling non-experienced stakeholders to develop their own data collection campaign. On the one hand, we draw upon previous experience with smartphone-based travel surveys from the literature as the proposed citizen observatory should be able to provide the functionalities of such survey systems. On the other hand, additional elements of citizen observatories usually not present in smartphone-based surveys such as two-way communication, motivation and feedback are also key elements of citizen observatory campaigns, therefore specific requirements concerning these will also be explored.

In the next section we compare the functionalities of smartphone-based travel surveys and citizen observatories. Then we lay out the technical requirements for citizen observatories for mobility in terms of data collection, processing, feedback, validation, user interaction, acceptance, and motivation.

2. Comparison of functionalities of smartphone-based travel surveys and citizen observatories

While GPS-based travel surveys have been used since the 1990s, in recent years we have seen a proliferation of smartphone-based travel survey applications. They use the internal sensors of the devices to register travel behaviour and interact with the users through surveys or user prompts (see for example Pereira et al., 2013; Raveau et al., 2016). Based on the generic definition of a citizen observatory (H-Y Liu, Kobernus, Broday, & Bartonova, 2014), smartphone-based travel surveys and citizen observatory data collection campaigns for mobility have many differences. Table 1 compares a number of features of smartphone-based travel surveys and citizen observatories for mobility. From the table it becomes clear that citizen observatories are complex and require thorough guidelines for sampling, motivation strategies and campaign management.

One of the key differences between smartphone-based travel surveys set up by experts and researchers and citizen observatories is that the organizer of the data collection campaign may not have expertise in setting up, managing and analysing data collection campaigns and specifically travel surveys. Since the citizen observatory platform that we propose aims to provide a self-explanatory interface and the ability to set up data collection campaigns without employing consultants or external experts, this puts limitations on the extent of the data collection, the guidance required and the methods employed for sample recruitment, data conversion and analysis.

The proposed citizen observatory for mobility is similar to travel surveys using smartphones as the ultimate goal is to register the behaviour, perceptions or environment of a sample of users. Travel surveys, however, may address larger-scale issues (e.g. travel patterns in a city or metropolitan area) and reflect the data needs of public or planning authorities. Citizen observatories, on the contrary, enable citizens to initiate data collection that reflect on local issues (e.g. in a neighbourhood) therefore their scale and generalizability may also be limited.

An issue that is critical to the validity of any type of travel survey is the representativeness of the data collected. Travel surveys rely on random samples with elaborate sampling strategies and a contribution of an expert for the recruitment. It seems unrealistic to expect that in a bottom-up campaign a representative sample can be achieved through random sampling due to the lack of expertise and resources to recruit a random sample. Therefore, citizen observatories will mostly rely on convenience samples.

Similarly, while travel surveys may rely on existing panels of respondents and paid or rewarded participants, bottom-up campaigns usually rely on volunteer data collectors and there may be no possibility to offer financial rewards due to limited funding. This also links to the motivation of the respondents which may primarily be extrinsic for travel surveys (because of the rewards offered) but it is mainly intrinsic in citizen observatories (volunteering). While travel surveys do not necessarily need integrated communication functions (e.g. to share results on social media), for citizen observatory campaigns this is an essential element and part of the motivation.

Smartphone-based travel surveys usually offer limited feedback to the respondents (possibility of seeing one's travel routes, distance and time travelled). In citizen observatories, two-way communication is key (H-Y Liu et al., 2014). Therefore, it is important that not only individual results but also aggregated results are shown to the campaign participants in an attractive format (map, graph, chart, dashboard).

Travel survey apps provide data to calculate comprehensive travel behaviour indicators such as daily trip rates, average trip duration, which are mostly only useful for researchers or policy makers. Citizen observatories, however, also need a set of indicators that are easily understandable and interesting to participants (such as daily travel distance, average speed) and may increase their motivation (CO2 emitted, calories burnt, health impact etc.).

The management of data collection is carried out by experienced project managers or researchers in case of travel surveys. In citizen observatories, campaigns may be organised by laypeople with no previous knowledge of mobility issues or organising a campaign. Therefore, campaign management tools are needed that make it easy to recruit and invite participants, maintain motivation (e.g. send out reminders) and monitor progress (dashboard). The expertise of the data collection managers also defines the types of data analysis carried out. In case of travel surveys many of the indicators, maps or graphs are created by experienced transport planners manually based on the raw data. In a citizen observatory, most of the indicators, maps and graphs should be produced in an automatic or semi-automatic way due to the lack of expertise of working with raw data. For the same reasons, observatory users may need extensive guidance on how to use the software platform as opposed to managers of smartphone-based travel surveys who would already have this experience.

Table 1. Comparison of smartphone-based travel surveys and citizen observatories

	Smartphone-based travel surveys	**Citizen observatory**
Organiser of the data collection	Consultant or researcher	Societal stakeholder (e.g. NGO, citizens)
Focus of data collection	General travel behaviour, stated/revealed preference, large or small scale	Travel behaviour focused on a specific problem (e.g. travel patterns in a neighbourhood) or target group (e.g. school children), small scale
Sample selection	Random/convenience	Convenience, guidance required
Recruitment of respondents	Panels, paid respondents	Volunteers, campaigns with gamification
Motivation of respondents	Extrinsic (paid or expecting reward)	Intrinsic (volunteers)
Communication functions (e.g. social media)	Not necessary	Essential
Feedback to respondent	Limited & only after analysis of data	Extensive (visualisations, reports, dashboards, leaderboards) & quick (real time or same-day)
Indicator types	Comprehensive mobility indicators (daily trip rates, average trip duration, modal split)	Easy-to-communicate indicators (modal split, CO_2 emission, health impact)
Data collection devices	Large array of smartphones, GPS loggers	Large array of smartphones
Expertise of campaign organiser	Extensive	Limited
Campaign management	Comprehensive by experienced project managers	Limited, low level of expertise
Data analysis	Semi-automatic and manual	Semi-automatic and automatic
Guidance needed for software and management	Limited	Comprehensive

3. Main functionalities of citizen observatories for mobility

Figure 1 presents the most important stages of a citizen observatory campaign: the collection of raw data, the processing of this data into valuable information such as detection of trips and travel mode, and the feedback of this data to the user. Validation of the collected information is necessary and should be applied in each stage of data collection to ensure that the data is valid. During the entire lifespan of the campaign, it is important to ensure two-way communication with the data collection to increase user acceptance and motivation. These stages will be used in the following part to synthesize technical requirements and limitations for observatories for each stage.

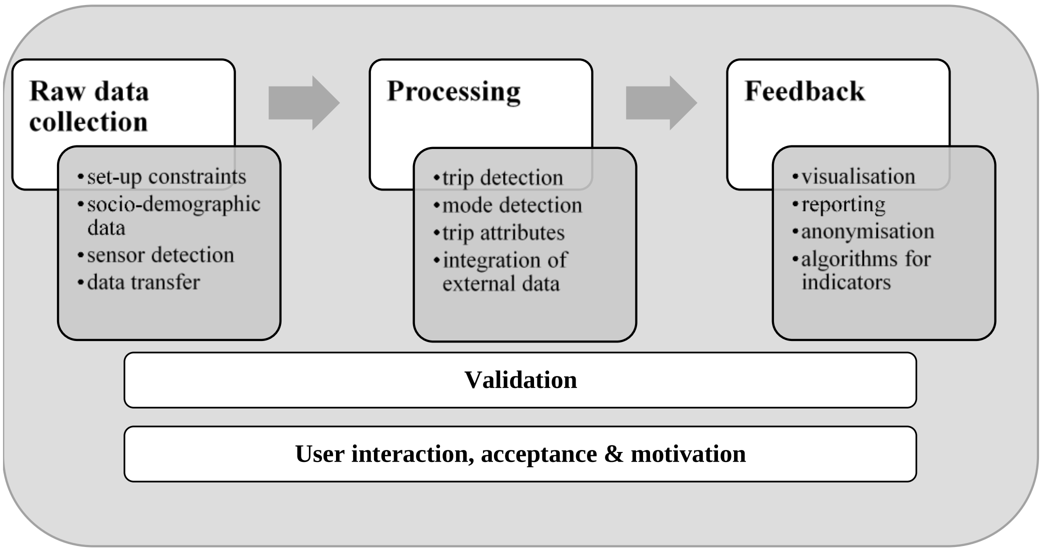

Figure 1. Framework for the technical requirements to organise a data collection campaign in the mobility domain

3.1. Data collection

3.1.1. Set-up constraints

Smartphone-based travel surveys cannot target the entire population and therefore they can never be 100% representative (Nitsche et al. 2012). However, the representativeness of the collected data, and therefore the sampling strategy, is crucial for the validity of the outcome of the citizen observatory. To overcome this limitation, the coordinator of the campaign needs to take three constraints into consideration before deploying a campaign:

- Locational constraints i.e. the geographical zone of the data collection (e.g. municipalities in Flanders, city districts, school environment, commute to industrial zones, low-emission zones)
- Time constraints i.e. the time period when the data collection should be carried out (e.g. during an event, before and after the implementation of a low-emission zone, car free days, for the next two weeks, during peak hours)
- Population constraints i.e. the specific groups of the population from/about which the data will be collected (e.g. residents of a city district, recreational cyclists, car drivers, working population)

Clear guidelines in terms of the capabilities of the observatory platform and the proper way of organising campaigns to ensure representativeness should be provided towards the campaign organiser. In this stage of the research, little is known about how to determine the ideal sampling size. This largely depends on the campaign objective, set-up constraints and desired outputs.

3.1.2. Socio-demographic data collection

Smartphone based surveys aim to provide a similar level of representativeness to traditional paper and pencil or phone-based surveys. Technology is used in different ways, by different population segments, which makes it increasingly difficult to identify a sampling frame representing the population (Bhat, 2015). Bhat (2015), See et al. (2017) and A. Prelipcean, Gidófalvi, & Susilo (2016) emphasize the need for substantial additional research on the representativeness issue when collecting data through different portable data collection mechanisms such as smartphones. Bhat (2015) focused on issues of representativeness when collecting travel diaries solely by portable devices. Smartphone based data collection requires respondents to download an application from the Apple App store or Google Play store, which may cause selection bias in the data collection since the older generation can find downloading an intimidating task because they are less technology savvy then the younger smartphone users (Bhat, 2015). Voluntary Geographic Information (VGI) is entirely provided by volunteers and has a heterogenous nature i.e. is often biased. For example, urban areas generally have more data available than rural areas or the collected data is influenced by the interest of the volunteers (See et al., 2017). The data gathered in smartphone-based citizen observatories is also provided by volunteers, which automatically requires caution for bias. Therefore, it is even more important in citizen observatories to pay attention to the characteristics of the sample. The volunteers should be representative of different sociodemographic groups (e.g. age, gender, cultural background, etc.) to avoid imbalances and biases in the observations. Based on the set-up constraints, periodic and spatial representativeness also needs to be taken into consideration. Depending on the type of the campaign and the campaign objectives, the campaign organisers need to consider additional aspects of representativeness in terms of transport modes, trip purpose and additional trip information. The more complex the needs of the campaign are, the more respondents need to be gathered to ameliorate representativeness in its different aspects. In citizen observatories, this becomes increasingly difficult. Therefore, in order for citizens to participate in citizen observatory initiatives, activities with low barriers and with incentives need to be created. Every volunteer needs to be respected, their expectations need to be managed and the plans and actions need to be presented in a transparent manner (See et al., 2017). To improve representativeness, different motivation techniques can be considered to attract different population segments (Rutten, Minkman, & van der Sanden, 2017). While it is unrealistic to expect that most citizen observatory campaigns will be able to collect data based on a representative sample, efforts should be made to ensure that at least some sample characteristics are close to the distribution in the real population (e.g. only gender or age) (Richardson, Ampt, & Meyburg, 1995).

3.1.3. Sensor detection: smartphone sensors and performance

While it provides the most accurate locational information, the main limitation of the GPS sensor is that it is a burden on the smartphone's battery life. If the GPS sensor is on, a fully charged smartphone battery will in most cases not last longer than 3 hours (Bhat, 2015). Therefore, auxiliary sensors other sensors less affected by battery drain are often used. Accelerometer sensors are mainly used for battery savings purposes (A. Prelipcean et al., 2016). Additional sensors that can also be used to improve the accuracy of location detection such as the cellular network cell ID, although the accuracy of the cellular network identification for speed and location is limited compared to other data collection methods. And finally, Wi-Fi signals are complementary to other sensors to determine specific locations with limited accuracy (Greaves et al., 2015).

Data accuracy, the speed of getting exact GPS location and battery depletion time depends on many elements. The high number of smartphone models and different versions of the operating systems pose challenges to the deployment of smartphone applications for data collection.

Ideally, a citizen observatory platform should support data collection using a combination of the above sensors to ensure accurate data on location. To decide which combination of sensors will be used, the campaign organiser needs to make a decision about balance between data accuracy, quantity, characteristics and the battery depletion.

3.1.4. Data transfer

Data registered on the smartphone can be transferred to the server for further processing. To reduce the burden of asking for manual input from users, more contextual data needs to be provided other than GPS locations. Additional spatiotemporal data, however, needs higher amount of transferred data (Safi et al., 2015), which leads to faster battery depletion. The collected data can be transferred via the cellular network, but this comes with a direct financial cost. When transferring data via a Wi-Fi network, the financial cost is potentially removed (at least if the Wi-Fi connection is free of charge), but the data will probably not always be sent in real-time, depending on the availability of an open and accessible Wi-Fi network.

Ideally, in the citizen observatory platform, a possibility to select between data transfer options (through cellular networks and Wi-Fi) should be offered to the campaign organiser depending on the needs of the campaign (e.g. is real-time data transfer needed or not).

3.2. Processing

Raw data needs to be processed to extract meaningful information from the positioning locations of the user for trip generation, identification of travel mode and other trip attributes.

3.2.1. Requirements for trip and tripleg identification

Complex multimodal tours involve several transport modes with different speeds and idle periods (e.g. waiting). Prior to any processing at the trip level, it is common to detect trips and to segment these trips into triplegs (Prelipcean, 2016). Triplegs can be identified with an accuracy close to a 100% (Tsui & Shalaby, 2006; Shin et al., 2015). At the same time the trade-off between the accuracy of trip and mode detection remains an issue. The higher the accuracy that required is, the faster the battery drain would be. Since a reusable citizen observatory aims to cater for different data collection needs in terms of duration of data collection, required accuracy for mode and trip detection, ideally the setup interface of the observatory should offer the possibility to indicate the preference of the campaign organiser in terms of accuracy required versus acceptable battery drain.

3.2.2. Requirements for transport mode detection

Information about the transport mode is crucial if we want to analyse multimodal trips. The literature reports that walking is the easiest mode to detect (Adrian C. Prelipcean, Gidofalvi, & Susilo, 2016). According to a test by Harding (2017) of 17 commercially available or open source travel survey and location logging smartphone apps, the accuracy of mode identification lies between 38% and 56%, which is much lower than what A. C. Prelipcean, Gidofalvi, & Susilo (2015) found for dedicated GPS loggers, where the accuracy was between 70-95%. This indicates that automatic mode detection using a diverse range of smartphones may still be a crucial limiting issue for travel surveys. To overcome the current limitations of automatic transport mode identification, transport mode identified by the software can be validated by the participant through prompted recall interaction (Cottrill et al., 2013). This, however, means additional burden on the respondents, of which the campaign organisers must be made aware of. To reduce burden, different strategies can be considered (e.g. the participant can validate trips at the end of the day, through prompted recall interaction, or after the data transfer on the feedback website).

The campaign organisers should consider which transport modes are of their primary interest and select an appropriate campaign design to meet their needs. The transport mode identifications that the platform aims to support are walking, which can be achieved with an accuracy up to 100%, cycling, car and public transport, with the potential to extend the structure with the additional insights (e.g. distinguishing between public transport options as bus, tram, train, metro etc.)

3.2.3. Identification of trip attributes

Travel is a derived demand i.e. most trips have a purpose at the destination other than just the enjoyment of travelling. Therefore, transport planning requires information about activities at the origin and destination of trips. To derive trip purpose, the useful insight could be the destination of the trip. Dill and Broach (in A. C. Prelipcean et al., 2015) defined travel destination by using stated and revealed data, with an overall accuracy of 46%, which seems quite low for any practical purpose. Third party POI databases (such as Yelp in Feldman, Sugaya, Sung, & Rus, 2013) can enrich the information available on maps by providing detailed information about opening times, potential activities at the location etc. Machine learning techniques have the potential to be implemented for the identification of frequently visited places, although results on this are still at a very low level of success to be applicable for practical purposes (Cottrill et al., 2013).

Due to these technical limitations, to reduce the need for data cleaning and frequent prompted recall interaction episodes, automatic detection of trip purpose is not recommended for the observatory unless the travel purposes and destinations that are of interest for a campaign are limited to easily identifiable ones (trips to home, work, school).

Other important trip attributes include travel companions or vehicle occupancy (how many and who), type of vehicle used (e.g. if the household has multiple vehicles), travel cost (Greene, Flake, Hathaway, & Geilich, 2016), and satisfaction with the trip (Raveau et al., 2016). This additional information, however, requires direct user input for which optional in-app prompts should be included.

3.2.4. Integration of external data

It is one of the main characteristics of citizen observatories that they can integrate different data sources (Kobernus et al., 2015b). External data sources have the potential to complement trip information with the contextual insights. Such data sources may include weather information, since the weather influences mobility in general (e.g. accident rate, mode choice); traffic congestion based on floating car or camera data provided by GPS navigation applications or transport authorities.

3.3. Feedback

3.3.1. Visualisation and reporting

One of the aims of a citizen observatory is to go beyond passive data collection and actively involve and motivate data collectors. Therefore, a two-way communication with data collectors is very important (H-Y Liu et al., 2014). Feedback to both campaign participants and campaign organisers and eventually third-party users of the data (e.g. policy makers) distinguishes a citizen observatory from a simple travel survey. A survey of policy makers (potential users of tracking data) has shown that policy makers require easy-to-interpret data visualisation of travel routes, origins and destinations, modal split, heat maps and isochronal maps showing cycling and walking intensities (Bossuyt, Christiaens, Deham, Franchois, & Vleugels, 2016).

For easy understanding of the data feedback, the appropriate format of the presentation of the data is important. Based on the review of current practice participatory sensing applications, the following types of visualisations and reporting functions are desirable of the citizen observatory platform:

- Dashboards
- Rankings of individual or group performance (leaderboards)
- Periodic reports of the most important aggregated indicators
- Customizable analytics tool to display data on charts, graphs and cartograms

These tools are accessible either through the smartphone app and/or a dedicated website with a personal account for the users; on an administrator website for advanced analytics, data export and campaign management functions for campaign organisers; and on a public website where aggregated indicators by period or time interval or user type are being presented to the broad public (Figure 3).

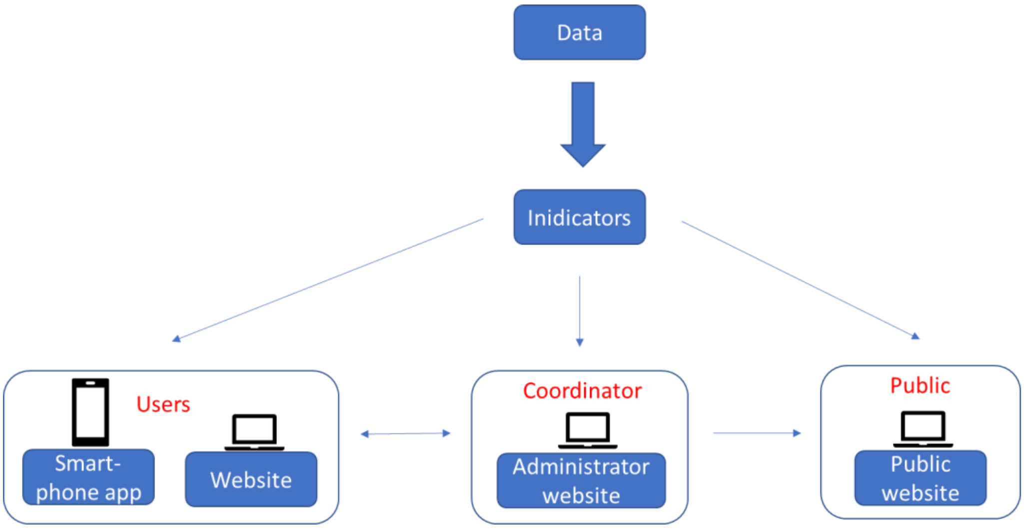

Figure 3. Accessibility of visualisation and reporting tools

3.3.2. Indicators

In order to create visualisations and reports is to calculate indicators. The following indicators are proposed for feedback to users and policy makers (Keseru, Wuytens, & Macharis, 2018).

- Travel time by mode
- Arrival and departure times
- Location of trip origins and destinations
- Travel distance by mode
- Travel route
- Average speed by mode
- CO_2 emission
- Health impact (e.g. calories burnt)
- Average travel cost
- External cost (for policy making)

The appropriate calculation of the indicators is an important issue. There is limited research available on the algorithms for the indicator calculation. An exception is the paper of Semanjski, Bellens, Gautama, & Witlox (2016), which provides guidelines to calculate burned calories and CO2 and particulate matter (PM) emissions based on travelled distance and mode.

3.3.3. Privacy

Privacy is a central issue of smartphone-based data collection (Lindqvist et al., 2011; Nitsche et al., 2012). Barbeau et al. (2013) concluded that a smartphone-based travel surveying application should consider giving the end-user the ability to disable tracking characteristics of his smartphone at any given time. Participants collecting data (i.e. passively collected, such as GPS, GSM or Wi-Fi) in the platform should also be able to voluntarily participate in the data collection and be made aware on the relevant privacy policies associated with the campaigns.

3.4. Validation

Validation of the participatory data can occur at any point when data is collected and/or processed. To eliminate user burden, the process of validation should be simplified as much as possible. Validation of ambiguous data or data which cannot be collected automatically, requires direct user input. When developing a smartphone-based travel survey, the trade-off between user burden and data accuracy needs to be considered.

The reviewed literature provided three main options of data validation. The first option is to ask for real-time validation any time it is needed, through **prompted recall interaction** (Cottrill et al., 2013). In order to provide correct indicators and visualisations, validation should preferably occur before giving feedback to the campaign participants. Real-time validation occurs directly upon trip detection and requires less context (C. Harding, 2017). Therefore, there is less confusion with the application user and less effort needed to recall trip attributes. The downside of real-time validation is that prompts throughout the day may become annoying and user burden could increase. Secondly, **diary validation** is possible, which takes place at the end of a fixed period (e.g. once a day). Compared to real-time validation, the chance that a prompt is missed or snoozed is lower with diary validation. When opting for diary validation, the design must be more carefully considered since there is a greater chance for confusion. A diary validation option is preferably customizable in proximity and time (e.g. morning or evening, upon return home)

(Harding, 2017). The last option is to give the application user the possibility to validate data **retrospectively**, e.g. on the feedback website after the output has already been generated. In the literature, some use cases provided validation of the data only in the feedback phase (Jariyasunant et al., 2012, Pereira et al., 2013).

In terms of the accuracy of the processed data it is important to identify how the data will be used. Transport modelling, for example, requires a high level of accuracy while the estimation of health benefits or CO_2 emissions can rely on less accurate data. The time and periodicity of validation requiring user input depends on the level of accuracy that is needed. The three options mentioned earlier, namely direct, diary and retrospective validation, each have their own benefits and limitations. Therefore, these options should be considered in the citizen observatory platform, with an emphasis on real-time validation with a retrospective option where multiple edits are allowed. A trade-off between the accuracy of data and user burden should be made by the campaign organiser.

3.5. User interaction, acceptance and motivation

In terms of user interaction, the data collection application should run in the background without obstructing normal operation of the phone (Ball et al., 2014), but still its interface should easily be accessible if desired. The indicator to measure this is the number of manual interactions with the software per day. This indicator seems as potentially interesting for the campaign organiser.

The apps deployed for data collection should be straightforward to use. Since there will be no opportunity to carry out usability tests before launching each campaign, the citizen observatory needs to provide interface modules that are straightforward to use even when combined with each other in a single application. The indicator for the usability of the software is the proportion of users finishing the data collection campaign without additional support requests (Hamid Safi, Assemi, Mesbah, Ferreira, & Hickman, 2015). However, a limitation of this approach lies in the number of passive users who might be completely demotivated and inactive, while being accounted as satisfied and successful in using the application.

Interaction with the user should involve both maps and textual information since some users prefer either or the other. When identifying locations on a map (e.g. for origins and destinations) it is important that the zoom level provides enough context to identify locations (Cottrill et al., 2013). It is preferred that the interaction with the data collector occurs through the smartphone interface rather than a separate web interface, if smartphone interface seems applicable for the requested interaction (Safi et al., 2015). An exit survey can provide information about the survey experience and any additional information about extraordinary behaviour during the survey period (e.g. illness).

Another great challenge of participatory sensing is the recruitment, motivation and retention of participants especially for longer campaigns or regular data provision. According to Bossuyt et al. (2016), 40% of the respondents of the user surveys of the Routecoach, Bicycle Counting and Cycling365 applications did not continue data collection after the main campaign was finished.

If the applications can offer auxiliary functionalities to the users, they could be more inclined to use the applications without the incentive of a main campaign (e.g. applications that give participants personalized information about travel routes). Gamification is often used to attract participants to the applications. The most used gamification incentive is the establishment of a community where users can compare results (e.g. travel distance, use of sustainable travel modes, frequency of data reporting, etc.) with other participants across the city, country or even world. The Belgian Bicycle Counting campaign awards prizes to the most active users, while Go-Safe tries to create an actual competition between participants. As a limitation, the lack of transparency of the calculation of the points and the difficulty of getting into the 'top list' was mentioned by the users of the Belgian Bicycle Counting App (Bossuyt et al., 2016). Public advocacy can be another incentive for citizens to take part in data collection campaigns as citizen observatory campaigns can create a communication link between citizens and public authorities.

4. Conclusions

This paper has presented a general technical framework for a citizen observatory for mobility. It is based on the already available functionalities of travel survey applications elaborating on the potential limitations and enhancements of a citizen observatory platform compared to travel survey apps.

Several important points for attention have been highlighted that should be considered when developing a citizen observatory for mobility. Defining and evaluating the required accuracy, representativeness and reliability in a context-sensitive campaign are key questions one needs to ask when developing a campaign, especially in the context of an acceptable rate of battery drain. It is still unclear how campaign organisers can be assisted to decide for the best combination of accuracy and battery depletion for their specific case. Citizen observatories seem to work best with narrow set-up constraints, straightforward research questions and easier-to-reach objectives. Accuracy and representativeness need to be weighed against each other, as manual validation to increase the accuracy can decrease engagement and therefore sampling and response bias.

Another issue that has emerged is the automatisation of campaign management, data cleaning and processing as well as the calculation of indicators that is desirable for the observatory being managed by persons with little or no expertise. Automatization of these processes, however, raises issues of reliability and accuracy as the varying reliability of mode detection has shown. Finally, campaign organisers may require comprehensive guidance for each step of setting up a campaign in order to ensure reliability, accuracy and representativeness. More research is needed to come up with ready-made solutions for the identified obstacles and constraints, as well as for evaluating them. This paper can serve as the basis for setting up more concrete guidelines for non-experienced stakeholders by offering them the main possibilities and constraints which should be focused on when developing a citizen observatory in the mobility domain. Because of the complexity and wide variety of mobility campaigns and their objectives, the general framework tends to remain very broad and needs to be narrowed down to more concrete examples for it to be more usable.

These technical requirements reflect an ideal 'best-case scenario' that will be further analysed and evaluated in the next phases of the research. Specific feedback from stakeholders will be requested through in-depth interviews to create detailed user scenarios that will help to further clarify the technical requirements and focus the available development resources. Then three use cases will be set up to test the citizen observatory framework and its technological background. The use cases will specifically investigate how the citizen observatory can collect data by:

- collecting passive data through a vehicle count campaign on major roads in Ghent;
- facilitating a monomodal data collection campaign by tracking student cyclists in Ghent;
- exploring *multimodal travel behaviour* though tracking the travel behaviour of schoolchildren (6-10 yrs.) and their parents through the parents' smartphones.

By monitoring the use cases we aim to answer the following questions:

- How accurate and reliable is the data collected through citizen observatories compared to the ground truth and travel survey applications?
- Can stakeholders with little or no experience in transport surveys set up their own campaigns and collect useful data?
- How can citizen observatories contribute to policy making though indicators, visualisation and reporting functionalities?

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