How to Measure Campus Interactions

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ABSTRACT

Background and aim – To better facilitate on campus-interactions between business and university employees, campus directors first need to know where these interactions, which can lead to knowledge sharing an valorisation, take place. This paper investigates if location-based measurement systems are a viable option to measure where one-to-one interactions between business and university employees take place on a campus.

Methods / Methodology – Using desk research (literature search) the five measurement methods (GPS, Wi-Fi tracking, RFID badges, surveys, and observations) are compared.

Results – Measurement methods were compared in using six criteria: accuracy, data loss, false positives, implementation costs, personalia collection, and privacy. Location-based measurement methods cannot (yet) be effectively employed to measure campus interactions, due to insufficient accuracy and the need for very high participation rates. Location-based measurement methods in smaller, contained spaces can be very effective.

Originality – This study includes the effects of scale on the viability of location-based measurement methods for interaction. It gives an overview of the current state of measurement accuracy and applicability.

Practical or social implications – Our results support campus directors in applying methods allowing them to learn where campus interactions take place.

Type of paper – Research paper.

KEYWORDS

Campus, interaction, global positioning system, Wi-Fi tracking, badges, survey, observation.

INTRODUCTION

As part of their valorisation efforts, many universities are actively attracting companies to their campuses to create a meeting place where the different campus users, such as faculty, business employees, and students, can interact (Buck Consultants International, 2014; TU Delft, 2014; Vrije Universiteit Amsterdam, 2014). As described by Jansz, van Dijk, & Mobach (2019), a chain of events is assumed, where (un)planned meetings lead to interaction, cooperation, knowledge sharing, and eventually to innovation and valorisation.

As facility directors' main concern is to supply the appropriate spaces and services to support the primary process (NEN, 2018), in this case valorisation, it is of interest to them to be able to evaluate current (un)planned meeting locations. This will allow them to find what factors make these spaces and services successful and could therefore be applied in future campus designs. However, to be able to elevate these meeting places, these factors first have to be identified.

As the goal is to facilitate interaction between the different campus users of company and university employees, a measuring system should include both these user groups and preferably be able to differentiate the two. Furthermore, to ensure the meeting contributes to the goal of valorisation, it

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should take place between two (or more) campus users. Moreover, the users would not otherwise have found each other (i.e., unplanned meetings) and have sufficiently new knowledge to share to make the meeting productive (i.e., complementarity). As an unplanned interaction can only occur when both participants are in close proximity, to reveal such meeting places a location-based measurement system seems a viable option. This paper aims to investigate whether location-based measurement systems are indeed a viable option to measure where interactions take place on a campus. Digital meetings are excluded, as these can be performed without being present on a campus. We will compare these methods through literature research, with a focus on practical implementation by FDs on campuses and who want to learn which locations currently facilitate interaction between different campus users (faculty and business).

METHODS

Currently, more and more options for location-based measurements are being developed. This study will compare the most used or most easy to implement options on Dutch campuses. Available methods were retrieved, selected, and compared by performing a desk research based on relevant literature. These are: GPS, Wi-Fi tracking, RFID badges, surveys, and observations.

RESULTS

GPS

The global positioning system (GPS) is a satellite-based global navigation system that provides a precise location at any point on the Earth's surface (Krenn, Titze, Oja, Jones, & Ogilvie, 2011, p. 2). Nowadays, many smartphones have the ability to use GPS to create location data. To be able to use this data an app would have to be developed that collects the data and sends it on. It can then be combined with an (open source) map to create an overview of where people's wearable devices are on campus.

Wi-Fi tracking

When a Wi-Fi enabled device sends out a search signal to connect to a Wi-Fi router, this signal can be recorded by a tag, which sends it on to a beacon. This beacon collects the signals from several tags located in the space, calculating the location of the search signal. As described by Ray (2018), Wi-Fi tracking can be a good option if you have a newly-installed and fairly dense Wi-Fi coverage that supports this real time location system (RTLS). Moreover, you need to have the budget to install the necessary tags.

Badges

Sociometric radio-frequency identification (RFID) badges that can be experimentally applied to collect data within bounded settings, such as within organizations, schools, or at conferences (Elmer, Chaitanya, Purwar, & Stadtfeld, 2019)a number of human sensor technologies have been proposed to incorporate direct observations in behavioral studies of face-to-face interactions. One of the most promising emerging technologies is the application of active Radio Frequency Identification (RFID. These badges can record if participants are facing each other. RFID badges are typically worn on the chest by participants (possibly hidden under a name tag) and measure if another study participant's badge is in close proximity (within 1.6 m) and in an angle that indicates that these two people are actually facing each other (approximately 65 degrees angle). Other options are microphones to detect alternate speaking and Bluetooth beacons to register location in a space (Bernstein & Turban, 2018). As the architectural layout of the space can affect this location calculation the space has to be tested in advance (Elmer et al., 2019)a number of human sensor technologies have been proposed to incorporate direct observations in behavioral studies of face-to-face interactions. One of the most promising emerging technologies is the application of active Radio Frequency Identification (RFID. In addition, the information from the badges has to be collected through either 'reading' them after the participants return the badges or beacons connecting to the badges. Consequently, in space-related studies RFID methods are mostly used in closed settings (e.g., a single room).

Survey

Asking participants to fill out a questionnaire is a standard research method and will be included as the 'industry standard' comparison method for the location-based methods. The survey will have to include a map-based application that allows participants to indicate where they meet other campus users. This

will rely more on the participants recollection of past interactions instead of real time self-reports and/or direct observations and may therefore include a higher risk of bias.

Observations

Finally, direct observations on location can be used to track interactions on campus. Based on an observation protocol, researchers cover a particular space (generally a single room) and visually observe the people in that space. If possible, participants of an interaction may also be asked to fill in an additional survey after the interaction was observed.

Each of these five measurement methods has different measurement units and defines an interaction differently. GPS and Wi-Fi tracking measure physical location only. An interaction could then be defined as a certain proximity for a certain duration of time. For instance, interaction is a situation where distance and duration of participants' meetings are respectively maximal 2 meters and minimal 2 minutes. For badges Bernstein & Turban (2018) defined this as badges facing each other, recording alternate speaking, and within a distance of 10 meters.

SELECTION CRITERIA

As discussed above, the following five methods have been compared: GPS, Wi-Fi tracking, badges, survey, and observations. Based on a literature six selection criteria were deduced and applied: accuracy, data loss, false positives, implementation costs, personalia collection, and privacy.

Table 1 Comparison of measurement methods.

Measurement unit **Selection criterion**	**GPS** Physical distance & duration (2 meters / 2 min)	**Wi-Fi tracking** Physical distance & duration (2 meters / 2 min)	**RFID Badges** Badges facing each other, alternate speaking, within 10 meters	**Survey** Self-indicated meeting location	**Observations** Researcher location registration
Accuracy	Horizontal: 7-13 meters. Vertical: problematic	3-5 meters when connected to 3 beacons. insufficient outdoor coverage	Depends on architectural layout, can cover one room.	NA	NA
Data loss	The longer the measurement the higher the data loss	When moving from one beacon to the next continuous data is lost (cannot track a person)	Badge battery life	Partial responses	Cannot observes several meetings at once
False positives	Co-working may register, vertical differentiation is lost	Co-working may register, Double counting phones and laptops same user	Hawthorne effect	One meeting may be indicated by all participants (double counting)	Hawthorne effect
Implementation costs	High. app development, promotion	High. Beacons range from $40-$90 each, many are needed to cover entire campus	Medium, depending on number of badges and beacons	Low, depending on cost for map implementation survey tools are low cost	Medium, high time commitment, low development costs.
Personalia collection (incl. base location)	When installing the app	Not possible	When registering the badge	Included in survey	Deduction or survey after observation
Privacy	When downloading app	Not possible, push notification?	When registering badge	When completing survey	When entering room? Signage?

Measurement accuracy

The five different methods each have a different level of accuracy. Average horizontal position accuracy for Smartphone GPS is accurate between 7-13 meters (Merry & Bettinger, 2019), However, vertical positioning is still a challenge and the urban structures on a campus may greatly influence accuracy (Krenn et al., 2011). Wi-Fi tracking is generally accurate up to 3-5 meters but only when connected at least three access points (Ray, 2018). As badges are applied in a specific area (a certain room specifically

equipped for the study) accuracy is dependent on the measurement of badges facing each other and alternate speaking, as well as distance. A study by Bernstein and Turban (2018) used a sociometric badge with an infrared (IR) sensor (direction), microphone (speaking), accelerometer (body movement), and a Bluetooth sensor (spatial location). An interaction was recorded when two or more badges were facing each other, detected alternating speaking, and were within 10 m of each other. A sensitivity analysis showed the results to be robust at shorter distances as well (Bernstein & Turban, 2018). The accuracy of these features can be affected by the architectural layout and should therefore be tested in each specific setting (Elmer et al., 2019)a number of human sensor technologies have been proposed to incorporate direct observations in behavioral studies of face-to-face interactions. One of the most promising emerging technologies is the application of active Radio Frequency Identification (RFID. For surveys the accuracy of the interaction location is dependent on the participant, who has to accurately remember, locate, and indicate the location. For observations the same applies, but for the researcher, who has to collect this data while performing the observations. Due to these accuracy differences GPS can be used for measurements on the campus scale (outdoors), Wi-fi tracking on the buildings scale (indoors), and badges and observations on the scale of a single room. Surveys can be applied on any scale, depending on the specific survey questions and chosen distribution of the survey.

Data loss

Especially when a study runs for a longer period of time, data loss becomes an issue. Recording devices may run out of battery life, loose connection, etc. For GPS, Krenn et al. (2011) stated that data loss increases substantially after four days. For Wi-Fi tracking, being able to maintain a connection with at least three access points throughout the campus is a tall order, as tags will have to be installed everywhere. It is therefore to be expected that data loss or reduced accuracy, will occur when participant move between buildings or through low coverage areas. For badges the battery life may pose an issue, although in a closed application (e.g., a fixed setting of a maximum one-day event) this should not be a problem. As participants will receive and hand in their badges when entering and leaving the space, loss of badges should also be manageable. For surveys, data loss may occur in the form of partial responses, while observations are limited by the number of observers, who can only observe one meeting at the time.

False positives

When using only location measurements to capture interactions there is a risk of including people who are co-working with desks that are close together, yet who are not interacting with each other. This would lead to false positives, creating a higher number of measured interactions then are actually occurring. This compromises content validity. For GPS, vertical measurement is still challenging. This adds a risk that people on different floors are registered as interacting when they are on the same horizontal location. Wi-Fi tracking may double-count participants when both phone and laptop are Wi-Fi enabled. For surveys, multiple participants of the same interaction may fill in the survey, making it hard to identify how many meetings were actually captured. There is also a risk of selection bias, where the selection of participants asked to fill out the survey, or the self-selection of those who decide to do so, creates a bias in the results (NCI, 2020). Similarly, there may be an observation bias when researchers are not properly trained. Finally, the knowledge of participants that they are being observed may change their behaviour (Hawthorne effect, Franke & Kaul, 1978), leading to a higher amount of interactions then would normally have taken place. As participant know that this is the expected behaviour and try to conform. Moreover, this may affect all methods, as privacy law requires that participants are informed before the start of data collection.

Implementation costs

Each method will have its own associated cost, which may be higher or lower based on the needed hardware and software. For GPS, an app will have to be developed that can track GPS location and share this with the researcher in a private and secure way. It will also need to include appropriate questions to collect personalia and permissions. Finally, the app will have to be hosted and promoted. This makes it an expensive method. For Wi-Fi tracking, tags need to be distributed (costing approximately 40-80 euros each) resulting in high cost when covering a single building or even the whole campus. For badges, costs range depending on the functionality of the badges and the area to be covered, making it a medium high cost method for room sized applications. Surveys are a lower cost option, especially when the

needed software is already available, e.g., through university connections. If not, an application able to record locations in the survey may have to be developed. For observations, costs are largely dependent on the time investment needed by the researchers. As each researcher can only observe one interaction at a time, many researchers may be necessary to cover a building or campus.

Personalia collection

For location data the complementarity of participants requires background information of participants. Information about the home location of participants and the differentiation between university / business employees would be necessary. Moreover, the possibility to ask single-meeting related questions, e.g., through push notifications or additional questions, would improve the data with respect to complementarity and planned vs unplanned meetings.

Privacy

Privacy laws have become stricter. For example, Dutch privacy law now states that permission has to be acquired from each participant individually before data collection has started (Wet AVG, 2018). As GPS will require the participant to download an app, this app can include a request for permission. The same works for badges (during registration) and a survey (first survey question) However, this is more complicated for Wi-Fi tracking as participants are recorded as anonymized points and there is no direct contact with the participant to ask additional questions. It is possible to ask for permission during observations, but this would influence the flow of the interaction and may affect the results.

DISCUSSION

When comparing the accuracy of the different location-based methods with different definitions of an interaction, the accuracy of GPS and Wi-Fi tracking is currently insufficient (respectively 7-13 meters and 3-5 meters). Both are not sufficiently accurate to comply to the 2-meters criterion. Especially, taking into account limitations of accuracy for GPS (indoor, vertical) and for Wi-Fi tracking (outdoor).

Furthermore, location-based methods (GPS, Wi-Fi tracking, badges) requires both parties to participate in the data collection to be able to measure interaction. This is limited by compliance. If only one party is sharing his/her location, we cannot measure the proximity to another campus user and the interaction will not be recorded.

It is difficult to make an estimation of how many interactions can be expected during a certain time period, especially when looking at unplanned interactions. However, these unplanned interactions are the reason why universities wish to stimulate companies to (re)locate on campus. The assumption is that unplanned meetings between business and university employees will result in knowledge sharing, valorisation, and innovation (Jansz et al., 2019). For instance, let us assume that each business employee on campus has one useful, knowledge sharing, unplanned meeting per year with a university employee. Moreover, let us assume that a campus has 3,000 business employees and 18,000 university employees. Ideally, we could then measure 66 interactions per week and 3,000 interactions per year. However, it is not likely that all employees will participate in the study. Table 2 shows how many meetings could be measured at certain participation rates of both company and university employees, ranging from full participation to a more realistic assumption of 100 company and 180 university employees (4% and 1%, respectively). However, this would only lead to app. 1 interaction a year (0,02 a week). This would require data collection to last for a very long period of time to be effective, enlarging the risk of data loss and further reducing participation levels.

Table 2 Measurable interactions at a certain percentage of participants.

# employees		**% participating**		**# interactions**	
Company	*University*	*Company*	*University*	*A year*	*A week*
3,000	18,000	100%	100%	3,000	66.7
30	18,000	1%	100%	30	0.7
30	180	1%	1%	0.3	0.0

The fact that location-based interaction measurement requires at least two participants to be part of the study makes it unsuitable for large populations, such as a campus. Application in smaller populations or populations where a (very) high participation rate can be guaranteed, such as the use of badges in a single room during an event, would be more appropriate.

CONCLUSIONS

GPS and Wi-Fi tracing are currently not suitable for the measurement of campus interactions. Its accuracy is not yet high enough to define an interaction (maximal 2 meters) from measurement data. In addition, application of any location-based measurement method that requires both interaction partners to participate in the study cannot be applied on a campus scale. Unless high participation rates can be guaranteed, which is very unlikely in most cases. This is due to the very low number of interactions per set of recording devices, potential data loss, and low participation rate (when only a small percentage of the total population is participating). Not to mention the cost, complexity, and potential data loss on a campus scale! In contrast, location-based measurement methods in smaller, contained spaces can be very effective, for instance, RFID badges in a single room during an event.

When looking at a specific space or room, both badges and observations may be appropriate. In this case badges would have the advantage of being able to record multiple interactions at once, while researchers can only record one observation at a time. However, additional context of the interactions that could be included in observations is lost when using badges. Hence, it is concluded that the most efficient and cost-effective method to use on a campus scale is still a survey. This allows researchers to include questions about specific interactions. At this stage it seems the best option for studying campus interactions: proven technology, relatively low-tech, reliable, valid, and relatively cheap. However, potential drawbacks of this method may be participants' poor memorization of (past) interactions, limited spatial awareness (poor accuracy of reported map locations), possible risk of double counting, and selection bias (it may be hard to find participants from all over the campus).

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Deltapremie

The 'Deltapremie' or Delta Prize is a new leading research prize in the Netherlands focusing on practice-oriented research by professors. The prize is developed for professors who have managed to repeatedly make a special difference with the social impact of their research over the years. It shows where practice and research can come together in an innovative way. Practice-oriented research has acquired a solid place in Dutch society. Almost 700 professors and more than 3,000 teacher-researchers are currently involved. The starting point of the research is always to find solutions for practice-based problems, also by partnering with practice. In this way, practice-oriented research provides applicable solutions to societal challenges.

An independent selection committee selected the winners. The committee consisted of six experts from Erasmus University Rotterdam, Innofest, Delft University of Technology, Netherlands Study Centre for Technology Trends, and the Association of Netherlands Municipalities. In the report the selection committee tributes Mark Mobach and his research group for the impact that they have on the crossroads of various domains from public transport to mental health. Mobach: "We see the prize as enormous encouragement to continue our research into space and organisation in healthcare, education, offices, and cities together with our partners. We extend our research to areas where there are perhaps fewer financial possibilities, such as research with the arts and frailty."

Research focus area

With his research group, Prof. Mobach wants to contribute to the best buildings for people and organisations. He does so by devising better space and services in a multidisciplinary setting together with students, lecturer-researchers, Ph.D.-students, and postdocs. Better spaces and services for education, offices, and even cities that stimulate healthy behaviour, better healthcare buildings that reduce stress, but also prisons and stations that better meet the needs of society.