Measuring Urban Activities: A Review for Methods for Evidence Informed Urban Planning and Design

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Successful urban planning and design projects require planners to make assumptions about users and use cases for urban spaces. Therefore, urban planners need to capture activities that happen in the urban spaces. Traditionally, planners relied on surveys and observation to capture urban activities. However, with technological advances, urban planners can access spatiotemporal data covering longer periods of time and space. In this paper, we review the data sources that can be used to measure urban activities under four sections: traditional methods, data from static sensors, data from mobile sensors, and big data. Although the data sources discussed have great potential for recording urban activity, there are challanges such as privacy issues, sampling limitations, lack of knowledge of the context and the need for technical infrastructure. In order to benefit from these data sources successfully, more efforts are needed such as improving the data accuracy, combining different methods to infer the context, making different collaborations to create technical infrastructure or purchasing the data readily.

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Kentsel Aktivitenin Ölçülmesi: Kanıta Dayalı Kentsel Planlama Yöntemleri Hakkında İnceleme

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Kentsel planlama ve tasarımların başarılı olmaları için planlamacıların kamusal alanları kullananlar ve kullanım durumları hakkında varsayımlarda bulunmasını gerektirir. Bu nedenle, şehir planlamacılarının kentsel alanlarda meydana gelen etkinlikleri kaydetmeleri ve ölçmeleri gerekir. Geleneksel olarak, planlamacılar kentsel etkinlikleri yakalamak için anketler ve gözlemler kullanıyorlardı. Bununla beraber, teknolojik gelişmelerle birlikte, şehir planlamacıları daha uzun zaman ve daha geniş mekânları kapsayan mekânsal-zamansal verilere erişebilmeye başladılar. Bu incelemede kentsel aktivitenin kaydedilebilmesi için kullanılabilecek veri kaynakları dört başlıkta toplanmıştır: geleneksel kaynaklar, sabit sensörlerden toplanan veri kaynakları, hareketli sensörler tarafından toplanan veri kaynakları ve büyük veri kaynakları. Tartışılan veri kaynakları, kentsel aktivitenin kaydedilmesi için büyük potansiyel taşımasına rağmen gizlilik sorunları, örneklem kısıtlaması, bağlamın bilinmemesi ve teknik altyapı ihtiyacı gibi zorlukları barındırmaktadır. Bu veri kaynaklarından başarılı bir şekilde yararlanabilmek için verinin doğruluğunu iyileştirilmesi, bağlamı çıkarımsamak için değişik yöntemleri birleştirilmesi, teknik altyapı oluşturabilmek için değişik iş birlikleri yapılması ya da verinin hazır olarak satın alınması gibi daha fazla çabaya ihtiyaç vardır.

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1. INTRODUCTION

Urban planning and design are complex processes and are highly dependent on information that come from many different sources such as experience, professional knowledge, new data collection, and interactions with other decision-makers (Krizek, Forysth, & Slotterback, 2009). When urban planners and designers make design decisions, they need to use this information and knowledge and complement it with "assumptions about users and use cases" (Tunçer and &, 2017). To create these assumptions, planners need to measure the activities of residents in existing urban spaces to have insights from the existing situation or draw new visions for new planning projects. Although measurements of urban residents engaging in activities enable planners to have quantitative and qualitative data regarding urban areas, this does not guarantee a successful planning outcome, since design is a complicated process linked to a variety of factors. Data supports the planner by grounding the assumptions about the use cases. For instance, for pedestrian-friendly design, the observation of pedestrian movements provides invaluable evidence for urban planners and designers. Before there were methods to collect and measure urban behaviour, urban design and planning depended on the expertise and anecdotal knowledge and lacked actual data of residents' usage of the urban spaces. For example, Jane Jacobs depended on her anecdotes along with some interviews and third-party sources in *The Death and Life of Great American Cities,* which lead to some critics accusing her of being unscientific (Jacobs, 1961; Marshall, 2012). Although Jane Jacobs knew that the variables affecting streets are "many, but they are not helter-skelter; they are interrelated into an organic whole", and valued empirical data, she did not have the necessary data or tools to collect this data to prove these variables and relied on her observations instead.

Traditionally, urban planners used surveys, trip diaries, and counting for understanding urban behavioural patterns of the residents. These techniques require researchers to engage with the residents while they are in the urban space. Therefore, these techniques require more human-resources, time, and cost. Because of this, data from these studies are limited in scale, and they are not updated frequently.

Urban planners and designers incorporated tools that can be used for recording movements of urban residents as a method for collecting evidence as these tools progressed. One of the first use of recording devices in urban planning research was William Whyte's observation of public plazas by using video cameras, in collecting evidence of human activity. He recorded many images from public plazas to see how people behave in certain situations such as sitting on a bench or sitting in the shade. Although his method was manual, as all the recordings needed to be watched by his assistants and recorded on a sheet with location information, made it possible for him to gather precise positions and actions of individuals, and the duration in which these actions took place (Whyte, 1980).

Technological advances allowed urban planners to employ new sensors for collecting evidence from the everyday life of urban residents. These sensors allow researchers to measure and record activities precisely. Besides, researchers can access data from applications and equipment of residents which they use daily. The volume of this data allows urban planners to work with unprecedented scale and longitudinal data which covers periods that are longer than that were possible in the past. These improvements in accessing data from residents allow the democratization of urban governance.

The focus of this study is reviewing data sources for measuring spatiotemporal patterns of urban activities. Although the urban activities can refer to a diverse set of actions, we focused on the movements of urban residents. Aggregating movements of residents is required for studying crucial topics in urban planning and design such as walkability, transportation, and leisure activities. In this context, we gathered data sources for measuring spatiotemporal urban activity, their strengths, and weaknesses. The emphasis of this review is to list contemporary approaches that are made possible with the advancement of technology. The rest of the paper is organized as follows: Section 2 includes the discussion of the methods for measuring urban activities with their applications and potentials and shortcomings of the methods. In Section 2, we discuss the challenges of using these methods and ways of overcoming the challenges. Finally, Section 4 concludes the study and discusses future possibilities.

2. DATA SOURCES FOR MEASURING URBAN ACTIVITY

We gathered data sources for measuring urban activity in four clusters: traditional sources, data sources from static sensors, data sources from mobile sensors, and big data (Figure 1). In this chapter, we are going to discuss these sources with their potentials and shortcomings.

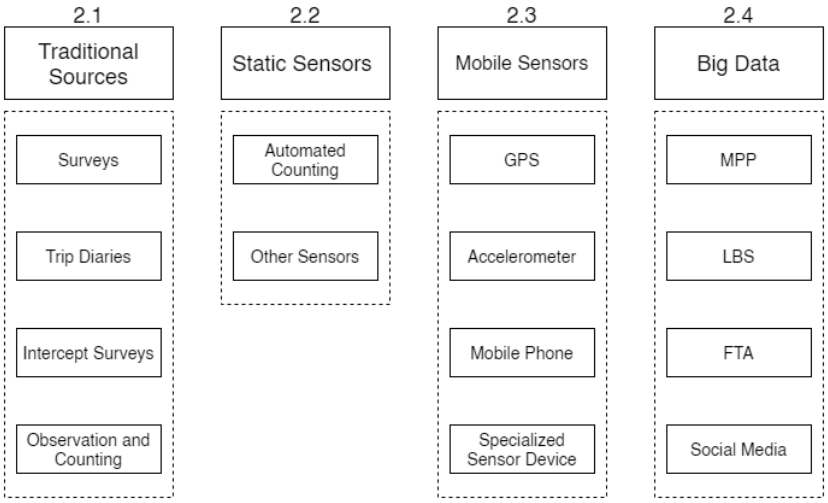

Figure 1: Overview of the data sources for measuring urban activity.

2.1 Traditional Sources

Traditional data sources do not require technologically advanced tools; most of the time it is possible to record the data with just a pen and paper (Table 1). Data is collected either person-to-person, meaning a researcher asks questions to participants, or a researcher observes residents' behaviour while the residents are using a specific area.

Methods	Surveys	Trip Diaries	Intercept Surveys	Observation and Counting
Possible Data	Flexible	Route, Duration, Intent, Mode	Location, Intent, Mode	Count, Mode
Locational Precision	Low	Low	Precise	Low
Number of Participants	Low	Low	Low	Low
Longitudinal	Possible	Yes	No	No
Temporal Precision	Low	Low	High	Usually low
Effort	High	High	Depends on scale	Depends on scale

Table 1: Overview of traditional sources.

2.1.1 Surveys

Traditionally, surveys were used extensively as they were the most straightforward data collection technique. One example use of survey comes from a study done by Handy (1996). He used a mail-out, mail-

back survey technique in which he mailed surveys to approximately 1000 people, and %25 replied. As a result of the survey, he concluded that some environmental factors play more important roles in the case of utilitarian walking rather than walking for leisure. The strength of surveys comes from the flexibility of questions that can be crafted to collect evidence for specific behaviours. Also, in surveys, it is possible to gather demographic data such as income levels, education, and gender. The downsides of surveys are their limited scope, dependence on respondents' ability to remember or willingness to answer the questions honestly, and the amount of labour required in collecting and analysing responses (Turner et al., 2017). Besides, surveys generally inform urban planners about the situation occurring in a cross-section in time, which is when the survey took place. It is hard to make a longitudinal study with surveys, which would require commitment over time from the respondents.

2.1.2 Trip Diaries

Another traditional way of observing the movements of people is using trip diaries (Stopher & Greaves, 2007). In this case, participants record their trip in a diary along with the intent of the trip, time, mode, and an approximation of the route. This method relies heavily on the motivation of the participant and his/her ability to recall the trips. Similar to the surveys, trip diaries are time-consuming and expensive to conduct. Also, generally, participants do not include short trips as they think it is less important; therefore, short walks are often underrepresented (Wolf, Oliveira, & Thompson, 2003; Stopher, Fitzgerald & Xu, 2007). Example usage of trip diaries in Cervero and Kockelman's seminal work where they used trip diaries in 50 neighbourhoods and found an association between travel demand and 3D's (Diversity, Demand, Design) (Cervero & Kockelman, 1997).

2.1.3 Intercept Surveys

Intercept surveys are surveys that are conducted while the respondent is performing the activity that is being studied. In the case of leisure walk intercept surveys, respondents are approached by a researcher in the streets and asked questions about the activity they are engaging in. Compared to surveys, intercept surveys are generally limited to the area that is studied in, and they focus more on the activity (Richardson,

Ampt, & Meyburg, 1995). Evenson, Herring, & Huston (2005) studied the effect of building a multi-use trail in a neighbourhood in increasing the physical activity levels of the residents by using intercept surveys.

2.1.4 Observation and Counting

Surveys and trip diaries use samples of a population that might not show the whole picture. Also, they work for wider areas such as neighbourhoods rather than one street. If more specific information about the usage of a particular street or a public space is needed, then counting can be used (Transportation Research, Engineering National Academies of Sciences, & Medicine Board, 2014). Counting can be manual, in which case collectors record peoples' movements. These collectors need to get instructions and pre-training from the researcher to have a successful data collection (Schneider, Arnold, & Ragland, 2009).

William Whyte used cameras in capturing people's behaviours in urban plazas (1980). Similarly, Montigny, Ling, & Zacharias (2012) used web cameras situated throughout nine cities and captured 6255 frames in seven months. They extracted the number of people from the images along with sunlight levels, and they complemented their data with weather data coming from weather stations.

2.2 Static Sensors

Through time, traditional methods evolved with the advancement of many different sensors that can capture data of people using urban spaces (Table 2). This group is differentiated from the previous group as the former requires manual collection whereas in this group the data is collected automatically. With the help of automation, it is possible to include many more participants in this group.

Methods	Automated Counting	Other Sensors		
		Kinect	Wi-Fi	Bluetooth
Possible Data	Count	Trajectory	Count, Location	Count
Locational Precision	Precise	Very Precise 4cm	Low	High 10m
Number of Participants	Medium	Low	Medium	Low
Longitudinal	No	No	Yes	Yes
Temporal Precision	Low	Low	High	High
Effort	Low	High	Low	Low

Table 2: Overview of data sources originating from static sensors.

2.2.1 Automated Counting

Previous counting techniques needed manual counting of the number of people in a particular place, but with the help of sensors such as pneumatic tubes, inductive loop detectors, and infrared sensors, it was possible to automate this process (Lee & Sener, 2017). It was also possible to use computer vision techniques to count the number of people from the images recorded by cameras directed at particular streets. The Placemeter online platform used this technique to count pedestrian numbers on the streets of New York. Sands used pedestrian numbers from the Placemeter platform and compared them with complaints submitted to an online portal (Sands, 2015), to test if Jane Jacobs' concept of "eyes on the street" theory holds.

2.2.2 Other Sensors

With the advancement of technology, there are a wide variety of sensors that can be used by urban planners today. Sensors are used when there is a need for more accurate and detailed data on the movements of people in urban settings and their interactions with other people. In one example, Seer, Brändle, & Ratti (2014) used three Kinects which are cameras that have three-dimensional depth maps, to capture people's trajectories and how they respond when they meet other people along their paths. The accuracy they could capture was extremely high at around 4 cm but the scale they could cover was quite small; they could only cover an area that is 12 m^2.

As the internet became an indispensable part of everyday life, people are drawn to internet sources in their use of public spaces, especially when needed for a particular purpose. Using this as a premise, many researchers tested Wi-Fi access to record people's flow to these spaces (Hampton, Livio, & Sessions Goulet, 2010). Danalet et al. (2016) collected Wi-Fi traces of students within the EPFL campus to capture the students' movements to get food from the canteen.

Much like Wi-Fi, the Bluetooth feature that is available in many electronic devices can be utilized to gather traces of people's movements. Yoshimura et al., in two different studies, collected Bluetooth traces of people. In the first study, they used it in a commercial center during the discount period and gathered data

regarding people's mobility to shops (Yoshimura et al., 2017). In the second study, they analyzed people's movements in the Louvre Museum (Yoshimura et al., 2012). Shlayan, Kurkcu, & Ozbay (2016) used Bluetooth traces in public transportation terminals to evaluate the performance of public transportation.

2.3 Mobile Sensors

As sensors that can record all the traces of people's movements became cheaper and more widely available, it became possible to get participants to carry these around and hence record their movements. In all these methods, participants are supplied with some form of sensors by surveyors (Table 3). Since it still requires participants to volunteer for the task, the number of participants was generally limited, and in some cases, the participant number further decreased with the surveyors' capability to supply more sensors. Because of this limitation on the number of sensors, studies following this technique are often restricted to a limited area. Before and after using this technique, surveyors often collect demographic data and ask questions about the movements to the participants. Therefore, this method constitutes an improvement to surveys.

Methods	GPS	Specialized Sensor	Accelerometer
Possible Data	Route, Duration	Route, Duration, Mode, Intent	Trajectory, Duration
Locational Precision	Precise 20m	Custom	Low
Number of Participants	Medium	Medium	Medium
Longitudinal	Yes	Yes	Yes
Temporal Precision	High	High	High
Effort	Medium	High	Medium

Table 3: Overview of data sources originating from mobile sensors.

2.3.1 Global Positioning System (GPS)

GPS is a sensor that can be used to track the movements of residents in urban settings. It is cost-effective, commonly used, and can be tracked anywhere on Earth when the person is outdoors. The only challenge comes from the need to receive the signal, meaning having no obstruction between the satellite and the sensor, which is not always possible in dense urban environments or indoors.

Stefan van der Spek has done a series of observational studies of pedestrian movement in three historic city centres in Europe: Norwich, Rouen, and Koblenz using GPS. The study is named Spatial Metro, and

its goal was to "observe pedestrian behaviour and to investigate pedestrian movement and experience in city centres" (Spek, 2008). The author distributed GPS devices to people visiting the city centre and recollected them at the end of the day. Throughout the day, the users walked in the city centre, and the sensors on the device collected the participants' traces of movements. Before the participants finalized the study, surveyors asked participants to fill a questionnaire and their purpose during their movements. The researchers determined four main themes; origins of the users' movement, purposes of the users' visits, their familiarity with the space, and the duration they took during their visit. For every theme, the researcher then plotted the traces of the movements of the participants of the study for each city.

Spek concludes that it was useful to visualize each theme to gain insights into the walking behaviour of different visitor types to each city. He also suggests that even though this method did not aim to evaluate or address some urban design issues, it is possible to use this methodology for this purpose in the future.

2.3.2 Accelerometer

Accelerometers record movements in the physical environment in terms of three dimensions. In walkability research, they are used to increase the precision of trip diaries, as it is possible to collect accurate distance of the walks (Tudor-Locke, 2002). However, unlike GPS, accelerometers do not record geographical data, therefore researchers cannot localize the routes that participants take during the activities.

2.3.3 Specialized Sensor Device

On some rare occasions, it is possible to create a device that is uniquely created to collect traces of people's movements. In the "National Science Experiment", researchers created a sensing device that is capable of recording "temperature, relative humidity, light level, sound pressure level, atmospheric pressure, 9-degree of freedom motion data" (Monnot et al., 2016). It also has a Wi-Fi receiver to transfer recorded data and to locate its geographical location. By using these devices, researchers were able to collect the start and endpoints of students' trips, the intent of the trips, and whether their trips are efficient compared to the possible shortest route. Although creating a

research-specific bundle allows researchers to collect data specific to the study, it requires the most resources in terms of both volunteers and money. Its advantage is that it can be used by population groups like young or elderly where it might not be able to use other sensors.

2.3.4 Smartphone as a Mobile Sensor

Today majority of the population use smartphones, which means a person carries many sensors together with his/her phone wherever he/she travels. Since people are constantly carrying a wide range of sensors, the previous problem of the need of supplying participants with specialized sensors has been solved. This section considers only the methods where participants know that they are part of a research. The methods that collect data generated from mobile phones without people actively knowing or being involved in this process are presented in the next section, big data.

Many researchers used smartphones to collect data from the everyday activities of participants. In the BeWell Project, researchers created an application that collects data from GPS, accelerometer, and microphone of the phone to track activities that impact well-being such as physical activities and social activities (Lane et al., 2011). Jun Yang (2009) used accelerometer sensors within smartphones to classify and record six physical activities: sitting, standing, walking, running, driving, and bicycling. In this study, he managed to keep track of these six activities for one month as a physical activity diary. These two examples were before the quantified-self movement; today many users are actively recording their physical activities with applications that are dedicated to this purpose.

Lastly, Bluestates was an artwork that used the Bluetooth function of mobile phones to record interactions with other people that have the same function in their phones (Pesce & Tonkin, 2006). Who interacts with who, in what order, and how long, becomes an artwork exhibited on an online website. This artwork aimed to show traces of personal interaction in a social environment.

The most positive aspect of using smartphones in research is that participants will not need extra equipment, assuming all the participants will already have a smartphone. Compared to using specialized sensors in research, smartphones will not have an additional

cost for hardware. However, both methods need specialized software that is created for the research and volunteers to use them. These two downside factors are mitigated in big data.

2.4 Big Data

In this section, we gathered data sources that originate from everyday data traces of millions or even billions of people. We include techniques that collect data from both individuals that did not necessarily volunteer for the study, but the data is rather a by-product of their online activity and volunteered crowd-sourced data (Table 4).

Methods	MPP	LBS	FTA	Social Media
Possible Data	Rough Route	Intent	Route, Intent, Duration	Intent
Locational Precision	Low 50m - few km	Low	Medium	Medium
Number of Participants	Big data	Big data	Big data	Big data
Longitudinal	Yes	Yes	Yes	Yes
Temporal Precision	High	High	High	High
Effort	Low	Low	Low	Low

Table 4: Overview of big data sources.

The most crucial aspect of this group is the scale of the evidence. The prevalence of using smartphones or other devices that has sensors and that tracks everyday movements of individuals.

2.5.1 Mobile Phone Positioning (MPP)

Mobile phones work by communicating signals to the nearest cell tower. During this exchange of signals, cellular carriers keep track of the individuals' connection to a specific cell tower in time (Chen 2016). When individuals travel throughout the day, their mobile phones, and by examining this change, it is possible to trace the movement of individuals (Huntsinger & Donnelly 2014). However, cellular carriers only store data from which cell tower the users are getting a connection. Users can be at any place within the cell. The sizes of cells change according to the population density, generally the denser it gets, the more cell towers there are. In big cities, cells generally have a spatial resolution as low as 50 m, whereas in rural areas it can be in the range of few kilometres or even more.

Kang et al. (2013) used mobile phone signals to locate the movements of residents in a city with an accuracy of around 50 meters. From the mobile signals, the authors deduce the character of neighbourhoods. Similarly, Ahas derived a pattern of movements of tourists visiting

Estonia by tracing their mobile phone activity (2007). Lastly, Gonzalez, Hidalgo, & Barabasi (2008) collected and analysed mobile phone usage traces of one hundred thousand people, over asix-month period. Tracking the patterns of people, they concluded that, although human behaviour is complex, it is possible to find some patterns in the everyday movement of people.

2.5.2 Location Based Services (LBS)

The prevalence of smartphones enabled many applications with different purposes to be used by people. Some of these applications record the physical locations of people by using a variety of sensors within smartphones. These applications such as TripAdvisor, Foursquare, Yelp, and Google Places keep track of amenities around users. Compared to movement recording applications, LBSs keep track of where people go, how long they stay, and in what frequency (Lee & Sener 2017), therefore these applications are better at recording the intention behind these trips.

Noulas et al. (2012) collected and analysed 35 million check-ins made by around one million Foursquare users all over the world for five months. Similar to Gonzalez, Hidalgo, & Barabasi (2008), they found it is possible to predict people's behaviour by observing their past movement traces.

2.5.3 Fitness Tracking Applications (FTAs)

FTAs collect registered users' physical activities such as walking, running, and cycling. FTAs work on many different devices: smartphones, smartwatches, and fitness tracking devices. In most cases, these devices feature GPS sensors, which help to record accurate geographical locations. Depending on the device, FTAs also feature many more sensors such as heart rate monitor, temperature sensor, and altimeter. FTAs record users' physical activities only when they explicitly wish to, therefore only the activities that users want to record are recorded as opposed to everyday movement data in MPP. However, recent FTAs started to feature a smart physical activity recognition feature where FTAs automatically recognize the physical activity these users are engaging in and record these activities (Fitbit, 2018).

Many different companies have an FTA such as Endomondo, Strava, and Fitbit and they all come with different features. In some of the

applications, it is possible to share the activities, which then can be collected by researchers. Šileryte (2015) collected and analysed physical activities that are recorded in 48 days in Endomondo. She managed to create a visualization of the physical activity movements of people in three cities. Similarly, Vanky et al. (2017) collected data from an FTA and checked different patterns of engagement of physical activity in different weather conditions. Lastly, Balaban (2019) gathered FTA data in Singapore and concluded city planning in Singapore provides spaces for leisure activity (Figure 2).

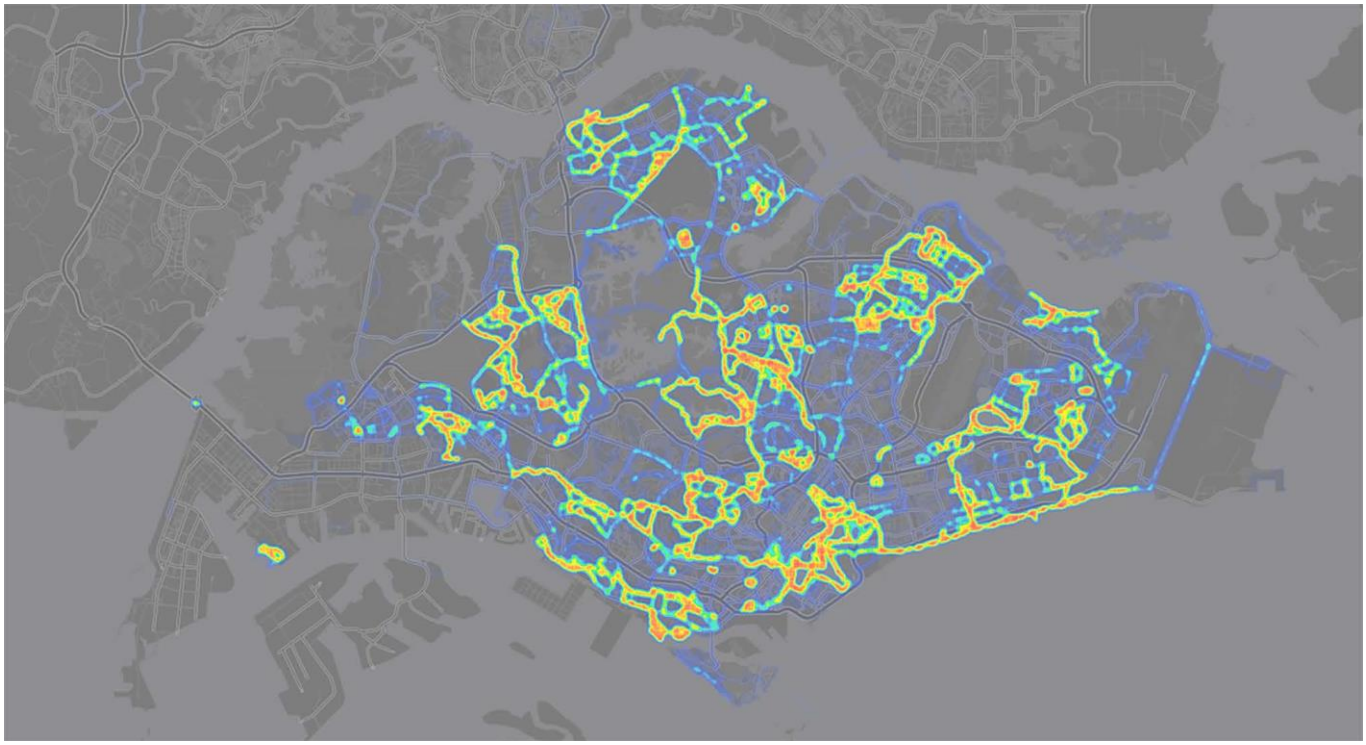

Figure 2: Heatmap generated from Endemondo data for weekday leisure activities occurring in a year in Singapore (Balaban, 2019)

2.5.4 Social Media

Concomitant to increased use of social media, urban planners can observe the utilization of urban spaces by residents. With the help of social media, urban planners can collect traces of the places that are discussed more. In a study, Tomarchio (2016) collected social media posts regarding art places in Singapore and plotted them in a GIS system, to find out if the collected data traces reflect the actual planned art spaces by the government. Being in the big data group, social media has the advantage of the ability to collect a significant amount of data. However, the location data obtained from social media is not precise and the collection of the data required a more complicated method.

Lastly, social media is not suitable for collecting the traces of movements of people.

3. DISCUSSION

In this section, we will discuss the challenges of using various data sources for measuring urban activities and ways of overcoming the challenges.

3.1 Data validity

One of the biggest challenges for measuring urban activity is to validate the representativeness of the data collected for the overall population. In all listed methods, a sample of urban residents is used. In traditional methods, researchers select the sample of users by applying statistical methods to create a valid sample. However, not all of the selected users return answers for the survey, which inherently introduces a sampling bias. In methods that use active usage of sensors or mobile applications, users are generally from a certain population group. For example, users of FTAs are generally physically active people, young to middle age, and predominantly male. Data that is sourced from FTAs will introduce sampling bias in the studies. Similarly, even in big data methods where billions of activities are recorded, only the users that actively use mobile phones or applications are represented.

To overcome the misrepresentation of urban residents, combining different methods can be a strategy. Data originating from mobile applications can be verified by field counts or intercept surveys. As the usage of mobile phones and applications increases and the data originating from these becomes more available, urban planners will be able to aggregate data covering the whole population of urban residents.

3.2 Privacy

As the collection and use of data originating from multiple sources become a common source for research, privacy became an important issue. In most of the applications that personal data is released, users generally have control over information that is shared with other users. In studies where data like MPP is used, data is often shared in an

aggregated form where it is not possible to extract individual data of the users. Although there are controls to avoid releasing sensitive information, there were cases where soldiers using fitness applications shared locations of secret army bases unknowingly. After events like these occurred governments started taking safety precautions that protect the privacy of users.

3.3 Context vs Accuracy

In the methods for measuring urban activities lies an inherent dilemma. In the methods there is active participation of users, researchers can engage with the participants and realize the context of urban activity. However, in these methods, the scale of data is much smaller than the passive data collection techniques. Conversely, in passive data collection methods, although it is possible to collect more data, it is not possible to reveal the context of the activities. To overcome this problem, it is possible to fuse different data sets. In some cases, there are mobile applications where the users can input the context of their activity. For example, in FTAs users select their activity. However, in some cases, users forget to select the appropriate activity, which results in erroneous data. There are improvements in the automatic recognition of activities of the users, which might supply a better context to the researchers.

3.4 Technology

Traditionally, urban planners could collect data regarding urban activities without the need for complicated technologies. However, to increase the breadth of the data, they relied on technological advances. Starting with Whyte's usage of video cameras to record the urban behaviour of residents, they used state-of-the-art sensing technologies. Today, collecting, cleaning, and analysing data originating from mobile technologies require expertise and access to resources. It also takes time to set up the means to collect this data. However, there are establishments selling data sets collected from different applications. For example, Strava Metro supplied a data set for Virginia for $300.000 which includes 2.5 million activities by 110.000 users (Ohlms et al., 2018). By accessing this data set urban planners can immediately work on drawing conclusions about how the residents access certain areas in

the city. However, the cost of this data set is restricting for most researchers (Figure 3).

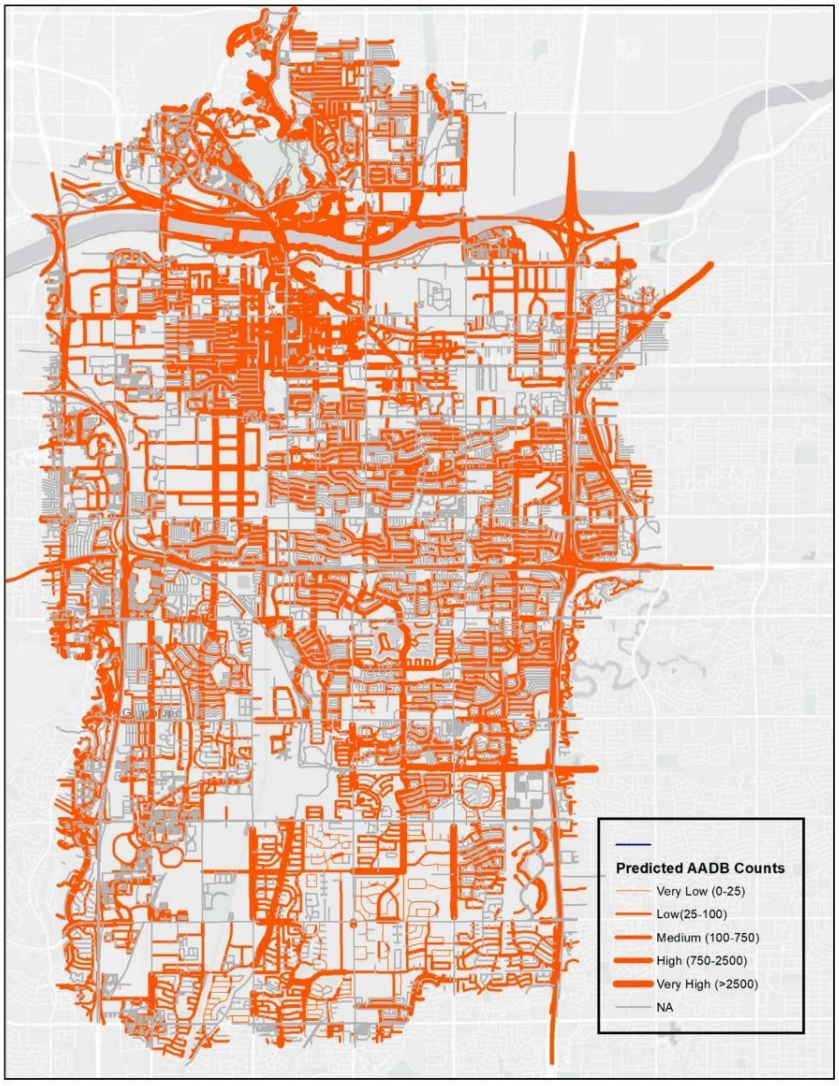

Figure 3: Ridership map of Tempe, Arizona using data from Strava Metro (Nelson and Wilson, 2021)

4. CONCLUSION

This paper reviewed the available data sources for measuring urban activities, covering from traditional approaches to most recent methods that can be useful for city planners and the scientific community. For each data source, we discussed the scale and use cases along with several examples. The overview is complemented with a set of challenges posed by their nature and characteristics that are precluding its ready use in applied urban research.

Ultimately, with plenty of data sources available, it may be possibleto bring answers to the perpetual questions of urban science such as walkability and transportation planning. The potential of much granular data gives a perspective that can bring out insights that has remained elusive.

The paper presents the availability, shortcomings, and strengths of different data sources in measuring urban activities, rather than claiming discovery or exhaustiveness. Cities are getting increasingly difficult to study as the residents are more mobile than in the past, and researchers need to incorporate different data sources in search of new insights. Although the constant collection of many different personal data with different devices seems distressing in apersonal freedom context, with strong regulations and blind aggregation, it might lead to democratization in the design and governance of the cities. However, to realize this, there is a need for applications or devices that record precise spatiotemporal movements of residents augmented with the contextual information of activities and collected with the consent and willingness of the residents. This data should be stored with strong regulations respecting personal rights and collected in transparency so that the users are aware that they are being monitored and choose to opt-out easily if they are not willing to participate.

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