Tracking Cyclists and Walkers: Will it Change Planning and Policy Processes?

João Bernardino, Mafalda Lopes
TIS - Consultants in Transport, Innovation and Systems S.A.
Lisbon, Portugal
e-mail: joao.bernardino@tis.pt, mafalda.lopes@tis.pt

Predrag Živanović, Slaven Tica, Branko Milovanović, Stanko Bajčetić
University of Belgrade – Faculty of Transport and Traffic Engineering
Belgrade, Serbia
e-mail: p.zivanovic@sf.bg.ac.rs, slaven.tica@sf.bg.ac.rs, b.milovanovic@sf.bg.ac.rs, s.bajcetic@sf.bg.ac.rs

Giacomo Lozzi
POLIS - Promotion of operational links with integrated services, Association internationale
Bruxelles 1050, Belgium
e-mail: glozzi@polisnetwork.eu

***Abstract*—Tracking cyclists and walkers may open a new window of opportunities for urban planning and policy. Data analytics about where, when, how, why, how far, how fast and from and to where people walk or cycle, will be available cheaply and quickly. It is our hypothesis that this will cause a change in transport planning and decision making processes. How, and to what extent, will this happen? Through what actors? With what kind of information? For what types of action? Who will want it and why? Will it generate a positive outcome? We approach some of these questions by elaborating on the technical potential of tracking data towards cycling and walking planning and policy analysis, interpreting the results of a stakeholder consultation and observing the approaches and outcomes of some cases of application. We conclude that tracking data analysis is likely to become a relevant part of cycling and walking planning and policy processes in the near future, not only for the efficiency gains in technical analysis, but also crucially in the communication between actors.**

Keywords-tracking; walking; cycling; GPS; mobility tracking; transport planning, transport policy.

I. Introduction

The ubiquitous presence of smart mobile phones accompanying individuals, and its technological development, is facilitating the tracking of those individuals, with multiple applications. An opportunity is created by the fact that tracking data allows to characterize the movements of individuals in ways that may be used in mobility planning and policy processes. In the scope of motorized traffic, tracking data is already being applied in citizen information [34] and traffic model calibration [35][36]. When it comes to cycling and walking, applications in the scope of infrastructure and communication planning and policy are yet less mature, although there are already a few cases to record, either analysing data through common geographic information system (GIS) tools or even already with dedicated user interfaces (BikePrint tool [37]). These experiences are mostly part of research projects, and even though several cities have already applied tracking data, there has been no time to mature them into systematized local planning processes. It is thus not yet clear what the actual influence of tracking data might become in the future.

To contribute to such assessment, we provide a review about the positioning of tracking information in relation to current cycling and walking planning and policy practices, identifying what it adds to existing information, interpreting the results of a stakeholder consultation and reviewing some already existing applications. We finally elaborate on how tracking data could influence and change cycling and walking planning and policy processes in the future, considering also the issue of the quality of data obtained.

The stakeholder consultation included two surveys and a workshop. The first survey targeted mobility planners and approached 92 respondents from 25 European countries. The second survey was targeted at user representatives and collected 63 responses from 15 countries. The workshop targeted planners, researchers and user representatives and involved 27 participants from 12 European countries (details are provided in [27]). The samples were based partly on calls within the network of European cities POLIS [38] and partly based on calls by the entities taking part in the TRACE project [39], under which these activities were executed. The samples in question may be characterized by a higher than average interest of the participants in innovative urban mobility initiatives and a specific focus on cycling and/or walking issues. The samples were fairly representative in terms of countries, except for the user representatives survey, which has an overbalance of two countries (Portugal – 33% of respondents; Italy – 15%).

Section II of this document starts by reviewing what is the role data and planning support systems play in urban mobility processes. Section III describes the traditional methods on data collection for monitoring travel behaviour. Section IV digs into what tracking data could add to these processes, both from the perspective of the comparison with the data provided by traditional methods and from the perspective of stakeholders. Section V introduces some cases of application. Finally, based on the observations of the

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previous sections, section VI elaborates about the ways how tracking data might influence cycling and walking planning and policy processes, including the identification of its limitations and challenges.

II. DATA AND PLANNING SUPPORT SYSTEMS IN URBAN MOBILITY PLANNING PROCESSES

Reference [1] notes the influence of data in planning and policy processes in the following way: "data can help establish baselines, identify trends, predict problems, assess options, set performance targets, and evaluate a particular jurisdiction or organization. Which indicators are selected can significantly influence analysis results. A particular policy may rank high when evaluated using one set of indicators, but low when ranked by another."

In this scope, it is firstly interesting to obtain a measure of the extent to which data is being applied in the field of active mobility. The planners' survey asked which types of information were being used for cycling and walking planning in the respondents' sites. About 26% of the said that no type of network related quantitative data is considered locally for cycling. The number increases to 76% in the case of walking, showing that the use of data is much higher for cycling than walking. Qualitative information has a significantly wider use across cities than quantitative information (Fig. 1). On the other hand, asked about which types of barriers they found to be the most relevant to achieve existing priorities, respectively 51% and 62% identified the lack of data as one of the issues.

For our aim, the relevant question is why data is being (or not) used. And building on it, how could the new tracking data add to planning and policy processes. In this section we provide a review on the application of data in urban mobility and specifically cycling and walking policy.

Data is used in distinct ways depending on the context and inherent needs of the relevant actors. The work [2] points that "transport data needs may be assessed on the project basis, the business basis or the system basis. The purpose, content and extent of data needs are different for these three bases".

In Europe, best practices have been synthesized and are widely disseminated by the European Commission's Sustainable Urban Mobility Planning guidelines [32]. This guide advocates four main stages of the planning process. Data plays an important role in all of them:

A. Preparation: data is used to analyse the current mobility situation and develop alternative scenarios that might result from different policies and measures.

B. Setting of the objectives: to set targets, the level of accuracy of the previously collected data should be assessed

C. Elaboration of the plan: monitoring and evaluation process should be defined, and the impact of a particular measure will be assessed on the basis of data.

D. Implementation: data is collected to measure target user behaviour and target achievement, allowing for a better understanding of the system and correction actions.

Structured guidance in the specific scope of cycling has been given by European projects like PRESTO [40], BYPAD [41] and CHAMP [42], which include a role of data in the scope of their normative planning frameworks. They put a particular emphasis on planning related linear aspects like the diagnosis of the current situation and on the monitoring and evaluation of actions carried out. A structured approach towards the collection of data for cycling policy is given by [33], which attempts to provide guidance to cities. Depending on the aims of data collection, several questions are presented as to how to communicate the data, such as:

- Who is the primary target group?
- Who are secondary target groups?
- How should data be presented?
- Should other media also be involved?
- Who is to draw up the final cycling account?
- Is the cycling account to be politically approved or are they simply informative?
- How can it be ensured that politicians, municipal staff and citizens are aware of the cycling account?

As assumed by several of these guidance initiatives, the advocated planning stages and their intermediate steps are actually a dynamic, non-linear process. In the real world, not strictly shaped by the desirable approaches of guidelines, the processes are often chaotic and strongly framed by political and organizational short-term issues. In that scope, it is an interesting and rather under-studied issue what is the actual role of data in real world urban mobility planning and policy.

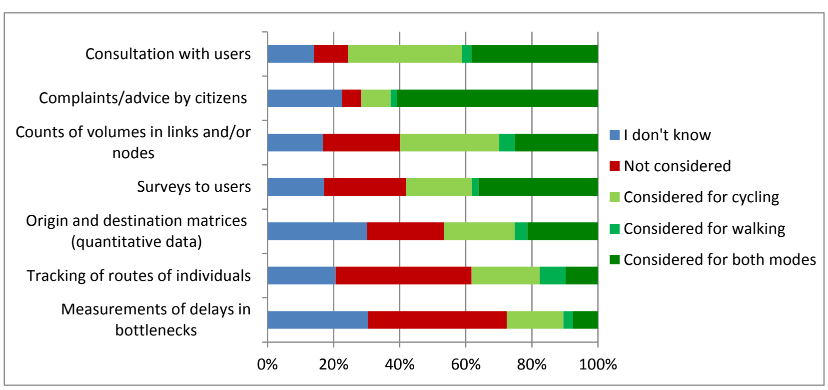

Figure 1. Type of information considered for cycling and walking (planners survey)

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While we did not find such analyses in the strict scope of data collection, they are embedded in a wider field within the scope of mobility, which is the use of planning support systems (PSS). PSS refer to information and analysis tools which provide support by identifying problems and testing solutions, by translating data into relevant information applicable for planning purposes. In other words, PSS may be defined as “an information framework that integrates the full range of current (and future) information technologies useful for planning" [3], with the purpose of either projection to some point in the future or estimation of impacts from some form of development [4].

The accumulated experience, including the evaluation of its (lack of) success, is interesting to interpret the ability of data in ultimately influencing planning and policy processes.

Reference [5] describes the advantages of PSS as providing analytical and communicative support. From an analytical perspective, the PSS can provide valuable feedback on the necessary iterations that are part of a negotiation task. From a communication perspective, the PSS may spark an active and content-based dialogue among the involved participants and improve the collaboration and communication among different disciplines. However, the authors warn that the support capabilities of a PSS can also have a negative effect on conducting a task, an idea also supported by [6], who argue they can become performative, thereby steering rather than supporting the process.

Reference [8] assesses the history of PSS use, claiming that there has been a significant evolution, powered by new technologies for disseminating information. This, coupled with the development of intrinsically visual tools such as GoogleMaps [43], has led to the common media of communication becoming predominantly visual. As such, PSS have evolved to graphic and related media in contrast to its origins in numerical data processing. The interactivity of these systems has also developed considerably. An assessment of spatial planning practice at the end of the 20th century however suggested that the adoption and use of geo-information tools are far from widespread and far from being effectively integrated into the planning process.

Reference [4] claims that the largely successful history of urban transportation modelling systems in the United States suggests that three factors are required for computer-based tools to be widely used in practice: a shared commitment to a well-defined methodology, extensive government support, and the ability of available tools to provide needed outputs for a substantial user community.

Some authors [9] attempted to identify the main factors blocking the widespread usage of PSS by launching a web survey directed to people involved in planning practices from all around the world. The participants were asked to classify the importance of potential bottlenecks. The main obstacles were identified as:

- Little awareness among planners of the existence of PSS and for the purposes for which PSS can be used;
- Lack of experience with PSS;
- Low intention to start using a PSS among users.

The authors suggest that marketing actions accompanying the launch of the PSS are essential in order to give PSS a good chance to prove itself as a means for improving spatial planning practice. Other researchers [10] consider that the PSS are stuck in a vicious cycle: although there are many PSS in existence, generally speaking PSS have not yet become widely applied in planning practice. As a result, few lessons are actually being learned about the effective integration of PSS in planning practice, and this lack of experience hampers the further improvement of PSS technology and its application.

Reference [11] considers that there are several barriers that explain this lack of integration, which can be divided in institutional/procedural discrepancies (*i.e.*, separate planning institutions, formal processes, financial arrangements, *etc.*) and substantive differences (*i.e.*, different planning objects, information *etc.*). In a web survey, the author identified additional barriers to the widespread usage of PSS, noting that these relate mostly to “softer issues”:

- PSS are implemented too late rather than too early in the planning process;
- PSS are implemented too far removed from the political process;
- They do not fit the land use and transport planning process,
- PSS do not sufficiently support the generation of new strategies, although they do support the evaluation of strategies;
- Lack of transparency;
- Low communication value (*i.e.*, PSS which are not understandable for planners, stakeholders and politicians);
- Conflicting interests between land use and transport actors are the main barrier to successful integration, with ‘lack of a common language’ in second place and ‘lack of political commitment’ as third.

Other authors [12] consider that there is an implementation gap between the PSS and the actual planning decisions. In order to overcome this gap, it is advisable for the development of the PSS to be intertwined with the planning process itself. The authors consider that the transparency of the output and the assumptions of the models that are part of the PSS are improved through discussions and continuous explanations by the modellers.

A relevant conclusion for our analysis is that the application and influence of data in planning and policy processes is more complex than the picture provided by linear urban mobility guidance, being framed by diverse and contextual political, organizational and individual elements.

Another dimension to this review of PSS use processes is that the influence of data in this context also depends on how it is presented. As pointed by [1], an “activity or option may seem desirable and successful when measured one way, but undesirable and ineffective when measured in another. It is therefore important to understand the assumptions and implications of different types of measurements”. For example, bicycle counting and surveys may provide different conclusions regarding the bicycle use trends [13]. This calls for data collection methods and an appropriate choice of accurate indicators.

In further sections of this paper, we try to understand how tracking data can influence planning and policy, not in view of desirable normative planning frameworks, but rather actual planning and policy processes.

III. DATA COLLECTION METHODS FOR MONITORING TRAVEL BEHAVIOUR

Travel behaviour may be monitored either by observing what users do or by asking them about what they do. In the scope of cycling and walking, the traditional methods used are counting and surveys.

Counting allow to quantify the number of users passing in a given place. They are a physical measure associated with a point, a section or an area. The most relevant indicator collected from counting is the volume of users or vehicles in the given element of infrastructure. The most common motivation of local authorities to apply counting is related to the measurement of the achievement of some type of target with regard to bicycle traffic, while prioritising certain measures among others, or to monitor specific measures on individual routes are also found to be related to counting [13]. With the later scope, it is also possible for example to measure speeds or delay times through more sophisticated technology.

Counting does not allow knowing who the user is, from where to where he goes or why. To obtain more detailed data about the users and their trips, surveys are used. Different survey methods can be used and survey data can be quantitative or qualitative. Three broad types of surveys may be identified: general/population-based surveys, intercept surveys and travel diaries [14].

General surveys are of static nature, in the sense that they do not relate to specific trips or sites, but they tend to capture routine travel behaviour of the users, focusing on general behaviour, like for example usual mode of transport to work, usual distance, or usual number of trips. General surveys also provide a good opportunity to know the personal characteristics of the user. Their application is frequently made in the scope of the elaboration or monitoring of general mobility plans [13]. They may also be used to predict what users would do in the face of some transport supply change, in the form of a stated preference survey.

The intercept survey refers to directly interviewing cyclists or pedestrians, *i.e.,* capturing them while they are cycling or walking. This allows both to approach directly the user target in question but also to target by the place where users are passing.

Travel diaries provide the transport planner specific information about each trip realized during a period. This data collection method has a number of drawbacks, however: large burden placed on respondents, high costs, decrease in the quality of the recorded data and missing trips, especially if the diary is made over several consecutive days. Reference [15] highlights 'non-response' as the most pressing problem in all surveys (response rates around 20-30 percent from a mail-back survey, 40-60 percent from a telephone survey, and 60-75 percent from a face-to-face interview).

A problem faced in many travel surveys, and in particular in the scope of cycling and walking, is that they assume trips are taken by only one mode, while many trips involve more than one mode. "Last-mile" connections to and from public transport trips are the best-known example of missing multimodal information, such as walking to a bus stop, or carpooling to a park-and-ride station [16].

TABLE I. IDENTIFICATION OF GAPS IN DATA RELEVANT FOR TRANSPORT PLANNING AND POTENTIAL OF TRACKING DATA TO FULFIL THOSE GAPS

Input data for transport planning	**Traditional methods**		**Tracking based methods**			
	Surveying	**Counting**	**GPS**	**GPS + GIS**	**GPS + SMS/app**	**GPS + GIS + SMS/app**
User data - socioeconomic						
Gender, age, occupation, address, *etc.*	yes	no	no	no	yes	yes
Travel data - individual						
Origin	yes	no	yes	yes	yes	yes
Destination	yes	no	yes	yes	yes	yes
Journey start time	yes	no	yes	yes	yes	yes
Journey end time	yes	no	yes	yes	yes	yes
Exact routes	no	no	yes	yes	yes	yes
Transport mode(s)	yes	yes	no	yes	yes	yes
Travel purpose	yes	no	no	yes	yes	yes
Transfer nodes	yes	no	no	yes	yes	yes
Transfer time	yes	no	no	yes	yes	yes
Network data						
Road data (type and condition)	yes	no	no	yes	no	yes
Nodes data (bottlenecks, delays, *etc.*)	no	yes	no	no	no	yes
Links data (link speeds, bottlenecks, delays)	no	yes	no	yes	no	yes
Absolute volumes	no	yes	no	no	no	no
Public transport data (stops, lines, routes, *etc.*)	yes	yes	no	yes	no	yes
Parking data (location, quantity)	yes	yes	no	no	no	yes
Zones data	yes	no	no	no	no	yes

Note: The classification given in the table to each item is subjective. In some cases with classification "no", the data in question may potentially be extracted by the concerned method but it would imply high costs and is not common (*e.g,*. surveys could incorporate GIS tools allowing the user to provide exact routes). In other cases with classification "yes", the capability may not yet be fully developed (or fully accurate) with current tools, but such may be expected in the near future (*e.g.*, transport mode identification from tracking tools).

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IV. What does tracking data add?

A. Tracking and traditional data collection methods

The growing importance of promoting and improving conditions for cycling and walking is evident in today's urban planning practice. One of the major issues for not putting cycling and walking on an equal footing with motorised transport modes is arguably the lack of data. Good quality and reliable input data are crucial for efficient transport planning processes.

Table I indicatively reviews gaps in data relevant for transport planning from traditional data collection methods. Surveying lacks or implies high costs in obtaining network and travel data. Additionally, for some relevant types of data, it does not provide necessarily accurate data, but only the perceptions of users (concerning, for example, travel time), which may be both an advantage and a disadvantage. On the other hand, counting only gives partial network data, while socioeconomic and travel information is absent.

Tracking allows to characterize network data with a level of detail and capability to obtain indicators that is not possible by other methods. This is achieved if combined with GIS tools, through which a map matching operation allows to allocate GPS trajectories to the existing network. When movement trajectory is obtained via an application from mobile phones, the same application is an opportunity to establish a channel of communication with the user, allowing to obtain the type of socio-economic information normally extracted by common surveys. Tracking data combined with GIS tools and an application interface with users thus seems to at least potentially cover all data needs, with one exception and one significant difficulty:

- Tracking data does not allow to infer absolute volumes, only relative volumes, since it does not capture all users. To obtain absolute flow volumes, counting are still essential;
- Tracking combined with an application allows asking specific question to users; however, it is questionable that this is possible to do within reasonable representativeness of the sample.

Overall, the comparison of these methods suggests that tracking provides network data that was previously not possible or difficult to obtain. At the same time, traditional methods will still fill some gaps, as also suggested by [31].

B. New indicators and visualizations

The location and time data provided by tracking allows for a variety of analysis fields and approaches. Table II outlines the most relevant and potentially feasible indicators identified in the stakeholder consultation [27]. These indicators can be grouped into origins/destinations, flows and volumes, level of service and surface quality. Additionally, relevant derived visualizations like isochrones or parking spot attraction (based on local arrivals) were particularly highlighted as useful. Another element referred was the ability to visualize and compare the tracking based indicators with other indicators like slopes, pollution or accident data.

TABLE II. TRACKING DATA INDICATORS

Indicators	Space dimension	Unit
Volume of users	Link, node, area	users/time
Number trips originated and ended per zone (origin/destination)	Area	users/time
Volume per origin-destination	Area-Area	users/time
Speed average	Link, area	kilometre per hour
Speed standard deviation	Link, area	kilometre per hour
Level of service and/or congestion	Link, path, node, area	percentage
Distance average	Area-Area	meters
Trip time average	Area-Area	minutes
Waiting time	Link, path, node, area, area-area	time
Waiting time per user	Link, path, node, area, area-area	time /user
Quality of surface	Link	rugosity index

An additional interesting outcome of the planners' consultation is that the importance given to different types of indicators varies with local context (Fig. 2). If divided into two groups according to the local modal cycling share – into *champions* and *starters* – it becomes clear that in *champion* cities, respondents give more importance to indicators related to the performance of the existing network (like speeds and delays), while in *starter* cities they tend to be more interested in indicators that help to define a network (like number of trips per origin and destination).

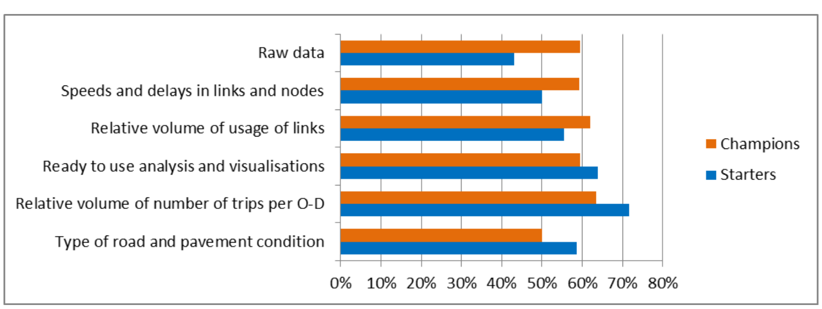

Figure 2. Indicators planners would like to obtain from tracking data, according to the city profile in terms of level of cycling adoption

C. Contributions to a mobility vision (Workshop)

The “Tracking data for planning and policy” workshop explored how tracking data could influence planning and policy, from mobility vision to operations [27].

A starting point of the workshop conclusions was that changing the mobility paradigm away from car use is a difficult task, which requires a strong dialogue between actors that promotes the sharing of information and ideas. In this process, tracking will help redefining the policy vision by providing evidence and helping quantifying goals: vision is not a technical matter, but it needs technical support.

More particularly, it was a wide belief that tracking data could give visibility to ideas and groups of users commonly disregarded by traditional planning and data collection methods, helping to increase the community engagement and participation. Tracking will help reinforce the idea that users are persons, not numbers, thus enabling setting goals and approaches more suited to the target groups: if you want to build a city for people, you have to have data on people. The underlying vision is to drive change based on the evidence of user demand, i.e., on what people actually want.

Another dimension of reflection referred to the trends in collection of tracking data. According to the recent trends, tracking data will be pervasive and standard within few years. Coupled with the widespread use of other big data, it might have significant impacts on the planning process. Tracking data provides continuous and current information, richer detail, user segmentation, and can complement other types of data. This contributes to making better diagnoses, test ideas, monitor and evaluate actions, develop multimodal policies and improve the network design.

Another relevant aspect raised is that by accessing data continuously, tracking will shorten the temporal horizon of activities and programs: with tracking there is no need to wait for the “elephant paths” (i.e., the destruction of grass by people walking along he shortest path across a field).

However, stakeholders also stressed that, when using tracking for planning, it is important to keep in mind that it should not be seen as a goal in itself or as the only basis for establishing goals and visions. Like motor traffic models, tracking may reinforce the idea that mobility is solely an engineering question, while personal choices, equity, lifestyle and citizens’ well-being should not be forgotten.

V. CASES OF APPLICATION

The stakeholder consultation allowed to identify some cases of influence of tracking based information in planning and policy processes. Five representative cases are presented, which refer to different aspects of those processes. None of those cases is part of a systematic use of tracking data in local planning procedures; they rather refer to applications of research projects or ad-hoc uses of the available data. All the collected cases refer to cycling, which is coherent with the fact revealed by the stakeholder survey that planners show a higher interest to apply tracking in the scope of cycling.

A. Case 1: Identifying user preferences through Strava to select the ideal path for a cyclepath (Lisbon)

In Lisbon, there was an internal discussion in the municipality about the ideal path for a new cycle path, considering a balance between distance and slopes. The question was put which path would the users prefer. The observation of the Strava Heat Map (Fig. 3) available in the web allowed to conclude that most users preferred to follow the path with the shortest distance, even if it had a higher slope and more intense traffic. This led to the decision to build the cycle path in this link instead of the alternatives.

Figure 3. Path development choices in Lisbon (Source: author’s elaboration based on Lisbon municipality staff’s description and Strava Heat Map)

B. Case 2: “Cycling is faster” area definition and communication to citizens (Leuven)

In Leuven, the cycling and car tracking data allowed to map the areas of the city from which each of the modes of transport is faster in trips towards the train station (Fig. 4). This information was then used to communicate to citizens with the objective to promote more cycling in relation to car use. The campaign was based on outdoor posters spread in the frontier within which cycling was faster than car [28].

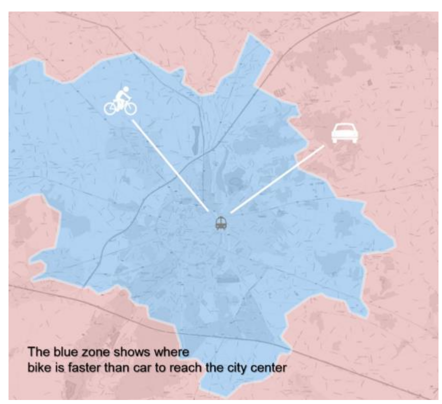

Figure 4. Areas where each mode (cycling vs car) is faster towards train station in Leuven (Source: [28])

C. Case 3: Defining position for bike parking (Bologna)

In 2015, the Municipality of Bologna decided to install 1.000 new bike racks in the city centre of Bologna. The issue was to determine the places and the number of racks per place in order to maximize their efficacy. The Local Mobility Agency and the Municipality decided to study the origins/destinations coming from GPS data collected during the European Cycling Challenge 2015 [44] (Fig. 5). The result was a set of locations and a number of racks per location based on real needs of cyclists, an "evidence-based" approach that gave strength and concreteness to the decision.

Figure 5. Bicycle parking location selection (right) based on tracked trip destinations (left) in Bologna (Source: SRM – Reti e Mobilità Srl,)

D. Case 4: How would a new cycle highway improve travel times? (Eindhoven)

In Eindhoven (Fig. 6), an analysis of the cycle tracking data through the BikePrint tool allowed to closely calibrate the speeds practised in each link, as well as the travel times from each zone to the city centre. Based on that information, a test was made to check what would be the time benefits per zone of building a cycle highway [18].

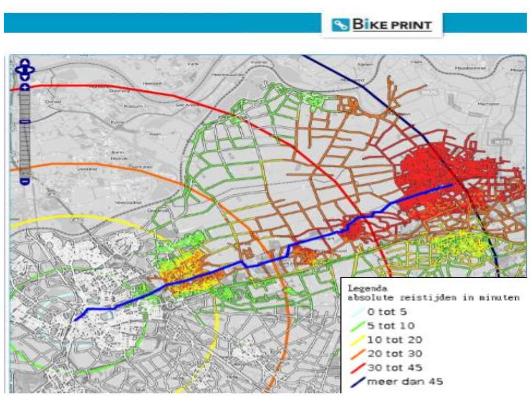

Figure 6. Analysis of travel time reduction by implementation of a high speed cycling lane in Eindhoven (Source: [18])

E. Case 5: Identification of user sub-optimal choices and improve information to users (Leuven)

A new high speed cycling route was developed at the north side of the rail line in Leuven (Fig. 7).

Figure 7. Bicycle user route choices between a high speed route and an old route in Leuven (Source: [28])

However, the tracking data revealed about half of the users coming from the south side of the line were still using an old route when they would be able to ride faster if they followed a certain link towards the north route. From this information, the municipality put better information at the relevant intersection to inform the users that they could proceed to the high speed cycle route [28].

VI. HOW COULD TRACKING DATA INFLUENCE PLANNING AND POLICY PROCESSES? SOME SPECULATIVE HYPOTHESES

When asked whether they believed that tracking data would be useful to their municipality or region, most respondents of the planners' survey replied that it would – 85% and 68% respectively in the scope of cycling and walking. When asked if tracking based information could be useful for a set of elements, the respondents replied positively to all of them. But it is noteworthy that despite they valued technical aspects like effectiveness of the actions and defining priorities, the one which was rated the highest is "communication to policy makers" (Fig. 8).

A different perspective is the perspective of the users (cyclists and walkers). In the user representatives' survey, 74% agreed that the use of tracking data would have the potential to "radically" improve planning practises. About the uses of tracking data, user representatives saw the highest potential in using it for their own purposes as a communication tool for lobbying policy interventions, followed by understanding priorities for intervention and providing information to users (Fig. 9).

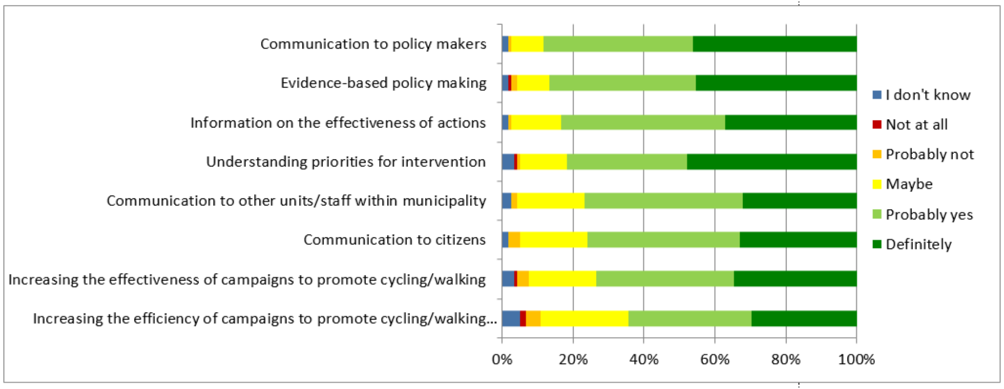

Figure 8. Planners survey responses: "Do you believe tracking based information could be useful for…?"

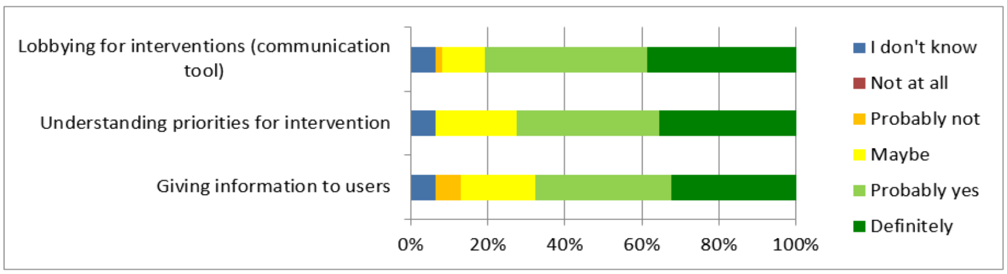

Figure 9. User representatives survey responses: "In your opinion, would tracking based information be useful to your organization for …?

Considering the collection of stakeholder views and the observations described in the previous sections, we elaborate on plausible *hypotheses* about the future role of tracking in cycling and walking planning and policy.

A. *Functions of tracking data*

Tracking data may have multiple functions interfering in policy and planning process:

A simple tool for Communication. A potential of tracking data is its apparently powerful communication ability. Because it makes cyclists or walkers visible to the decision maker, to the general public or to planners themselves, tracking visualizations seem to have the ability to influence opinions and decisions, at least in the short term.

Demand and infrastructure performance analysis. The location and time data provided by tracking allows for a variety of analysis fields and approaches, whether they be about the level of service of the infrastructure or knowledge about the demand and its preferences, at a micro or macro level, per type of user, schedule, weather or location.

Monitoring of measures. Tracking data allows to see in much detail how demand changed whenever a measure is introduced in the local mobility system.

Like other policy and planning tools, it may be that tracking data and related tools will become intrinsically connected within the process of planning and decision making. We could say that it will have become a building block of the process. At that point, its influence would be structural and part of the paradigm of urban mobility. It is desirable that such influence of a tool is a positive one and not biased towards certain objectives opposed to others, or that it is not only illusionary contributing to some objective. This was the case in the past of transport models, which ignored other modes of transport and failed to show planners and decision makers that addressing congestion through more space for cars was feeding a never ending feedback loop. In its own ways, cycling and walking tracking information use has a risk of creating biases.

B. *Stakeholders under influence of tracking*

Stakeholders may use or be influenced by tracking information in several ways. We will describe a scenario where tracking influences a system of interrelations between different actors in the planning and decision making process. The system is constituted by planners in the field of cycling and walking, planners from other fields, decision makers and the citizens, which may include the general public but also user activists (Fig. 10).

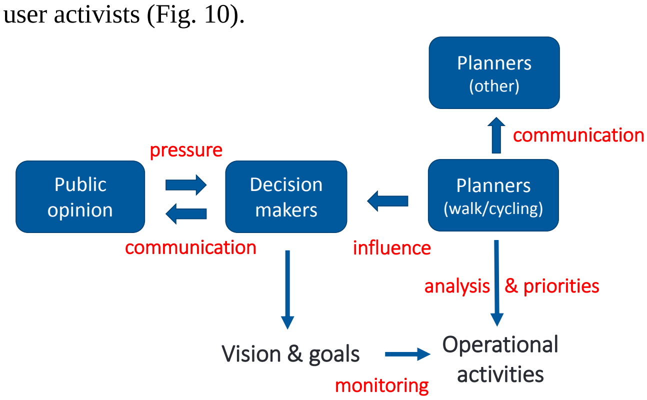

Figure 10. Roles of tracking data in the planning process (Source: author)

First of all, cycling and walking planners may use tracking information to develop better analyses and properly define priorities for action. But they can also use tracking information to communicate and sometimes influence other actors. That could be the case with other technicians within the organization who might have different views or distinct languages –the visual and quantitative power of tracking data helps to show that cyclists and walkers have needs and face movement constraints. 55% of the planners' survey respondents said that conflicting views were one of the main barriers in relation to achieving the existing priorities in the scope of cycling (30% for walking).

The same goes for the planners' relation with decision makers. Here, the influence might happen not only on operational decisions but also at a higher level of vision definition. Showing the evidence on the entropy of walking, or the choices of cyclists towards safer or quicker paths, may trigger the decision maker's appetite for giving priority to improving the conditions for walkers or cyclists.

Tracking information will also give decision makers the additional assurance that will be able to communicate with the public in an effective way. Through the network information provided by tracking data, they will be able to use numbers to describe the problem and show the positive effects of solutions. This ability to argue based on empirical evidence will provide decision makers more confidence to take politically risky decisions.

The communication between decision makers and public will also occur in the opposite direction. Activism towards cycling or walking can in the same way find in tracking data a powerful tool to argue for the improvement of their conditions, showing that there are users and describing their problems through data, makes it more inevitable for the interlocutor politician to act.

VII. QUALITY OF DATA

The quality of input data in transport planning analyses may have significant influence on the accuracy of the conclusions. [19] claim no study has systematically examined the implications of using low-quality big data for traditional analyses. Nevertheless, there are two main elements related to quality of data for the purpose of realizing analysis meaningful for mobility planning.

The first one is the accuracy of the location data, which depends on the instruments and methods of measurement used by the application. Several issues affect the accuracy of GPS data: trees and buildings obscuring GPS signals, the geometric arrangement of the GPS constellation of satellites, and the quality of the GPS unit [20]. Because of this, GPS routes can appear to bounce around to either side of an actual route when accuracy is decreased. But for tracking routes longer than only the shortest walking trips, modern GPS devices represent a relatively accurate and inexpensive way to record natural travel data [21]. A recent study that tested algorithms for calibrating GPS-observed walking trips to actual trips had the best results when trips were more than 3 minutes long and more than 30 meters in distance [22]. This deficiency of GPS can be mitigated by implementing a primary data processing phase prior data usage for planning and/or other purposes. Some authors [23] have described a series of procedures that have been developed to manipulate data collected from GPS devices carried by people or placed in personal vehicles, and used to produce records of the trips made over a period of days or weeks. In their paper they give insight on different steps within data processing, from converting continuous GPS logs into trip-based records and trip identification, to overcoming of various deficiencies. These include cold start problems, particularly the case for movements of a vehicle over a distance of one or two kilometres and for short walks with a wearable GPS, where a ''cold start'' receiver may not record position, or when the trip is long enough for position to be acquired, but the resulting trip will be shown to be shorter in length and duration than the real trip). Another issue addressed is the correction for signal loss in ''urban canyons'', tunnels, and under other circumstances. The authors claim to have reached a 95% correct rating in identifying real trips, while at the same time reducing the time and effort required to process data up to 75-80% of the amounts of time required for a manually assisted procedure.

The other issue is the representativeness of the sample. Since different user groups have distinct preferences and behaviour profiles [30], it tends to be important that the sample has a realistic representation of those user groups. To guarantee that this happens, it is not enough to obtain a sufficiently large sample, but also that specific groups are not being excluded from the sample for some reason [25].

[24] gave a comprehensive review on a state-of-the-art of the travel behaviour studies categorized by trajectory data types. All selected empirical studies have drawn conclusions about the population based on the sampling dataset. According to [19], there have been three large-scale travel surveys that have relied entirely on GPS technology, two of these in the USA. The first exclusively GPS household travel survey conducted was by the Ohio Department of Transportation, in the Cincinnati metropolitan area with a sample of 2608 households [15]. Sampling for the pilot and the main surveys used an address-based sampling procedure [15]. GPS data was complete in 80% cases and the data was used to derive travel parameters, *i.e.*, average daily No of trips (mobility rate), trip distance, travel time, travel purpose, *etc.* Data was presented for all days and weekdays, and on the personal and household level. Reference [15] has reported that a high level of representativeness for the sample was achieved. Their primary conclusion was that it is feasible to undertake a GPS-only household travel survey. They also recommend a longer period of measurement to be used in future surveys.

According to the results of the stakeholder consultation, there are three typical problems of sample representativeness:

- *Leisure vs. utilitarian cyclists:* the most developed segment of tracking applications is related to the promotion of sports or physical activity in general. For example, the STRAVA [45] heat map is available for any user and site. In starter countries with a low level of cycling, even applications primarily targeted at utilitarian trips, like the

European Cycling Challenge, do attract individuals who cycle for leisure. Leisure minded cyclists have different preferences in terms of destinations and path choice to utilitarian cyclists and are generally not suitable as a sample for the purpose mobility planning. In European Cycling Challenge application in Bologna, currently the tool attempts to distinguish utilitarian from sports users by filtering the trips by some areas of the city or schedule.

- *Experienced cyclists vs. starters:* this distinction is particularly relevant in the context of starter or climber cities, where the cycling network is not fully developed and there are very significant differences between users in terms of their ability and willingness to use the car network for cycling. Initiatives that collect data about existing cyclists tend to attract experienced cyclists, who are the more willing to participate in these kind of initiatives. However, the stronger is their identity as a cyclist, the more likely are they to be far away from the average in terms of choice preferences. When the target of the planner is to take into account the preferences of users who are not very experienced or have a strong cyclist identity, this effect should be considered. A possible way to isolate the differences among different groups is to ask the application users how they identify themselves in terms of their experience and cycling identity.
- *Info excluded users:* walkers with specific needs like elder people and children are also the ones who tend to be excluded from the use of smart mobile phones, which are the devices that make it viable to track the movements of users. This biasing factor is difficult to overcome and the planner may have to assume that the data is not representative for these types of users. If data from these users is particularly important, the planner may require different data collection methods and a specific campaign targeted at these users.

Overall, it seems to be important that the analyst is critical about the type of sample represented by the data and the implications that may have for the validity of the analysis that is realized. The application of samples from different sources may minimize the problem or, at least, provide an opportunity to compare data. Obtaining specific information about user characteristics also provides the chance to compare results for different user groups.

VIII. CONCLUSIONS

With the aim of assessing the potential of tracking data to change cycling and walking planning and policy processes, this paper reviewed (i) the analytical capabilities resulting from tracking data, considered (ii) the views of relevant actors in a stakeholder consultation and collected some (iii) initial experiences on the application of tracking data.

Tracking data obtained though users' mobile devices opens up an opportunity to obtain new cycling and walking activity information. Such data can be treated through GIS tools to produce quantified information about the state and performance of the cycling or walking network. Indicators like speeds, delays, relative volumes, trip origins and destinations and their paths, collected for every part of the network, become possible. This information allows to better assess bottlenecks, user information, monitoring the effects of measures or studying user preferences in ways

Mobile applications doing tracking (and possibly interacting with the user) could thus complement and significantly replace traditional data collection methods. Two main limitations to this were identified: firstly, tracking data does not provide absolute volumes in the network, for which countings data will still be needed; secondly, the sample of tracked users may have biases.

Considering the new technical analyses that are made possible, such new tool theoretically promises to enable better diagnoses and decision making towards cycling and walking provision. This is also the belief of the planners and user representatives consulted under this work.

However, such capability does not guarantee by itself that the use of tracking data will be embraced within planning and policy processes. The review of past applications of planning support systems shows that not always they are successful in penetrating the planning and policy practices. Or, in cases where they are, there is a risk that these planning support systems end up steering decisions based on partial information rather than supporting a conscious decision making – as motor traffic models which ignored costs on cycling and walking.

A different, perhaps even more crucial dimension of the influence of cycling and walking tracking data, is its communication ability. "Communication to policy makers" was evaluated as the most relevant application of tracking information by planners. According to these actors, tracking data makes cyclists and pedestrians more "visible", and thus more prone to be considered as a priority in decision making processes. Communication between staff of the local authorities and communication to citizens have also been cited in the survey as important functions of tracking data. Some of the practical cases presented in this paper show actual examples of how the tracking data has been applied both in internal dialogue between planners and decision makers and in citizen information. Tracking data does therefore not only provide potential analytical ability, but could also be a powerful instrument for communication.

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