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This is an abridged version of the paper presented at the conference. The full version is being submitted elsewhere. Details on the full paper can be obtained from the author.

ISBN: 978-85-285-0232-9

13th World Conference on Transport Research

www.wctr2013rio.com

15-18 JULY 2013
Rio de Janeiro, Brazil

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ABSTRACT

Travel surveys employing information and communication technologies (ICTs) has been long sought by a number of experts since lightweight GPS loggers became available in the 1990s. Recent rapid penetration of smartphones into the population may enable such deployment in a wider scale in the near future. Such ICT-based techniques are expected to provide inexpensive methodology for reliable data collection and also to eliminate the respondents' burden to answer with the conventional methods. On the other hand, it is questionable if the information needed to analyze the current travel behavior as well as to forecast the future travel demand is fully obtainable with such newly appearing techniques. In this paper, we first review the state-of-the-art ICT technologies that may be employed for data collection. Then, we assess the information needs by analyzing indicators required by models, evaluating information needs by various stakeholders (experts), and by analyzing the information collected by conventional travel surveys. With the results from these, we carry out a comprehensive assessment of information needs and data collection potentials.

Keywords: travel survey, information needs, ICT, demand forecast method

1 INTRODUCTION

Travel survey has a long history with conventional methods such as paper-and-pencil travel diaries or computer assisted telephone interview (CATI) having been widely used. Such traditional methods have several major drawbacks such as expensive cost to conduct the survey (Mohammadian et al., 2010), declining response rates in recent years, small sample size that is not representative (Stopher and Greaves, 2007), and imposition of lots of answering efforts to the respondents (Chen et al., 2010). In addition, traditional methods have several further drawbacks such as unreported or forgotten small trips and inaccurate answers about travel time (Wolf et al., 2004).

Employment of ICTs in travel surveys is expected to overcome such problems, and potentials of GPS-based travel survey have been sought for years by experts, starting with onboard GPS unit for vehicular travels and then seeking for possibilities with wearable GPS loggers. Much effort has been made to detect trips correctly and to impute trip mode and purpose in the last decade in various environments. (Murakami and Wagner, 1999, Stopher and Greaves, 2007, Bonnel et al., 2008, Stopher et al., 2008, Stopher, 2008, Chen et al., 2010, Mohammadian et al., 2010, KOMOD, 2011, Axhausen et al., 2012)

For decades, GPS has been only a technology to locate a mobile device and thus for an ICT-based navigation. It has several disadvantages for travel surveys that signal does not reach to certain places such as underground and so-called urban canyon, and cold (or warm) start problem that occurs when GPS receiver has long been turned off (Stopher et al., 2008, Gong et al., 2012). On the other hand, new mobile device localization techniques such as Wi-Fi or cell tower based ones are now rapidly being developed (Klaassen, 2012). Employment of RFID and other possible technologies have been also long sought (Bonnel et al., 2008).

From the viewpoint of the usage of the surveyed data, one of the most important usages is, apart from knowing current travel behavior of the citizens, to forecast the future travel demands (Du and Aultman-Hall, 2007, Stopher and Greaves, 2007). Various demand forecasting methods (models) need such data as their input and for their calibrations. Thus data from travel survey is inevitable to carry out future travel demand estimation, and therefore for developing transport policy and for further decision-making for investments onto infrastructures. A simple question arises then if the data needed by such models are obtainable from the ICT-based travel surveys, or even more basic question arise then what kind of potentials the state-of-the-art ICT technologies can provide for travel survey, not only in terms of the technique itself but also in terms of data collection frequency and so on.

Motivated by these questions, as a part of a European research project *COMPASS*, we reviewed and discussed potentials of deploying ICTs in travel surveys. We made an assessment of information needs by analyzing various representative demand forecast methods used in Europe to identify indicators that are needed by them, evaluating the data and information needs by various stakeholders (experts) and analyzing the information collected in conventional travel surveys. Finally, as a synthesis, we made a multi-dimensional assessment of data needs and data obtainability with ICTs.

The reminder of this paper is structured as follows. In Section 2, potential state-of-the-art ICTs are reviewed. In Section 3 to 5 respectively, results of our analysis on indicators needed by various demand forecast methods, assessment of information needs by various stakeholders, and analysis of information surveyed in conventional methods are presented. In Section 6, data obtainability with ICTs is discussed, and in Section 7, as a synthesis, the result of multi-dimensional assessment is presented. Section 8 concludes this paper.

2 OVERVIEW OF ICTS WITH DATA COLLECTION POTENTIALS IN TRAVEL SURVEYS

In this section, recent developments of ICTs that may be employed in travel surveys are briefly reviewed. Selection of technologies is based on a recently-published list of ICTs employed in transport summarized by a project partner (Enei, 2012).

2.1 Mobile device localization techniques

Satellite-based location detection / GNSS

GPS has been long used for navigation of vessels, aircrafts and vehicle. In the last decades, application of inexpensive GPS tracker to the travel surveys have been sought, and a number of researches have been undertaken to test its potential and also to tackle several problems and challenges arising when using GPS tracker in travel surveys such as trip detection, mode and trip purpose imputation, overcoming cold and warm start, urban canyon problems, battery and charging, validation by users, and so on.

It has to be mentioned that, in addition to the US-developed GPS, several other global navigation satellite systems (GNSS) are in operation or under development including European *Galileo*, Russian *GLONASS*, and Chinese *Beidou* (also known as *Compass*). In addition to these global services, quasi-zenith satellites (QZS) are planned in several countries that covers limited surface of the earth. Although there are several technical and organizational issues to be solved, some of these different GNSS may be combined to obtain the location with higher accuracy compared to the location obtained solely from GPS satellites.

Location detection with Wi-Fi

Wi-Fi (Wireless LAN) based localization techniques are being developed rapidly. Its development is rather designated for indoor navigation in a large building complex such as airports and shopping malls.

To the best of our knowledge, the concept of Wi-Fi-based “fingerprinting” technique for location detection has been sought over a decade (Bahl et al., 2000), but an application-level developments have been rapidly made only in the last years (Fraunhofer IIS, 2011, Klaassen, 2012). This “fingerprinting” technique uses received signal strength indicator (RSSI) and it provides a potential of location determination using Wi-Fi signals’ RSSI indicators. A pre-made “radio map” of Wi-Fi signals is compared to the ones detected by a mobile devices, and this comparison enables the mobile device to locate itself. Several deterministic and probabilistic methodologies are proposed for RSSI-based localization, and in the scale of rooms, some methodology provides localization as accurate as c.a. 85% success rate (Martin et al., 2010). It has to be noted that log-in to the wireless network is not necessary to detect location; only signal identifier and signal strength information is needed for fingerprinting. In addition, it has to be mentioned that several large databases of Wi-Fi station locations have been already created and made available by several private companies (Kaleem, 2010, Krazit, 2010). However, such large databases do not appear to contain RSSI data that may be used for precise location detection because these databases are rather intended to map Wi-Fi hot spots.

Location detection with cell tower (mobile phone masts)

Cell towers (mobile phone masts) are another potential source for location detection on mobile devices. Conventionally, location of the closest cell tower often determined by strengths of the signal is used as current location (Axhausen et al., 2012). Nowadays, triangulation or fingerprinting techniques using RSSI information from cell towers can be used as more accurate means of location determination (Kansal et al., 2007). Refreshment rate of RSSI information is slow and thus this seems not useful for indoor level localization (Martin et al., 2010); however, in the scale of urban or larger environment that is needed for travel surveys, cell tower information should be able to provide some location information especially in areas such as underground stations where GNSS signal does not reach while Wi-Fi-based location detection is not expected or the result from that is doubtful.

Other localization techniques

Other techniques including digital TV signals, conventional radio and Bluetooth are considered in some researches as potentials of localization similar to the three techniques mentioned above. These need extra infrastructure or dedicated hardware, and this is considered to a major drawback at the moment (Martin et al., 2010). Some application to use Bluetooth to monitor travel time in urban road network has been sought, while further development seems needed to make it reliable and feasible (Jie et al., 2011).

Smartphones and W3C Geolocation API

The localization techniques are often collectively called “geolocation service” nowadays. An important feature of this geolocation concept is that the determined location with abovementioned various localization techniques are stored in a synthesized format, while availability and accuracy of each source changes continuously as the mobile device moves. State-of-the-art smartphones store the geolocation history for a certain period such as for one week so that the apps can use the geolocation history (usually with prior consent by the smartphone user). A number of apps uses this information already; for example, travel planners use current geolocation information so that the user do not have to enter the trip origin or to provide information about public transport stops nearby (ÖBB-Personenverkehr et al., 2012, Wiener Linien et al., 2012). In addition, state-of-the-art smartphones often equips accelerometer and it can provide heading and speed of the mobile device.

Recently, W3C (World Wide Web Consortium) makes an effort to standardize an programming interface (API: application programming interface) to retrieve geolocation information (Popescu, 2012). This will enable that the geolocation information detection is obtained and stored as a general service on a device (for example, at operating system level) while this information is used by various apps on it.

2.2 RFID/NFC/DSRC

In the transport sector, RFID (Radio-frequency identification) smart cards are widely used as prepaid or seasonal tickets for public transport. London's *Oyster Card*, the Netherland's nationwide *OV-Chipkaart* and Hong Kong's *Octopus Card* are mere a few examples among the ones used in different corners of the world. Such RFID card is sometimes used for payment of road pricing and parking such as the one used in Singapore (Sim et al., 2003, Prakasam, 2008, Land Transport Authority, 2011). Each RFID smart card has an ID, and thus travel history with the transport modes using this system can be derived from this. The term NFC (near field communication) is becoming common as an industrial forum has been set with this name.

The term DSRC (dedicated short range communication) is used often in the road transport sector for electronic toll collection and so on. From the viewpoint of data collection, similar potential to RFID is sought, although this may remain in vehicular level and not in personal travel behavior.

2.3 Remote sensing and camera technologies

Remote sensing technologies cover various spatial relations from the satellite-to-earth to speed-gun-to-automobile scale. A classical application for transport is RADAR- or LiDAR[1]-based speed gun. Camera (CCTV) is often used as traffic control camera in combination with such technologies. Recently, OCR (optical character recognition) has been applied to automatic number plate reading enabling traffic monitoring and congestion charging. Another camera-based technology is to detect the vehicle occupancy factor along a road. These types of sensor technology, by its nature, are rather suitable to observe a mass of people or vehicle in a cross-section and do not suit to trace single person's travel behavior.

Recent rapid development of computer vision technique that recognizes human faces may enable it to use this as a key to detect travel behavior of a mass of passengers between two places such as two underground stations. Advanced computer vision technique even detects approximate age, gender, etc. Such technologies do not appear to be in the development status that they can potentially substitute or replace travel surveys; further technical development will be needed. In addition to that, relation to the privacy protection has to be carefully sought. Problem of high cost may also arise. (Huang et al., 2011)

[1] LiDAR stands for Light Detection and Ranging or Laser Imaging Detection and Ranging.

2.4 Cloudsourcing

Cloudsourcing is a concept used in various contexts today; here the focus is on obtaining various data from various mobile devices owned and used by various users. In the field of traffic engineering, floating car data has been long considered as a potential data source for traffic volume, speed and so on. Nowadays, various cloudsourcing may be possible for travel survey as geolocation-enabled smartphone with accelerometers is rapidly penetrating into the market. It is estimated that by 2017, approximately 3 billiion smartphones are estimated to be in the market in the world (Ericsson, 2012).

2.5 Summary of this section

In this section, mobile device localization techniques including satellite-based ones, Wi-Fi-based ones, cell-tower-based ones, as well as recent development of mobile devices, RFID/NFC/DSRC, remote sensing and camera technologies, and cloudsourcing techniques are reviewed.

From the viewpoint of the travel survey, which focuses on travel behaviors mainly at person level, these new technologies can serve as potentials as follows.

- Mobile device localization techniques can record geolocation history so that trips can be detected with some attributes including origin, destination as well as begin, end and travel time and other attributes such as purpose and mode to be imputed.
- Cloudsourcing technique can potentially enable to use survey respondents' mobile devices, especially smartphones, rather than distributing dedicated geolocation loggers. This may reduce the device cost incurred in ICT-based travel survey greatly.
- Simplified user interface of the mobile devices as well as other web-connected interface can reduce the survey respondents' burden to report some indicators that cannot be surveyed with the mobile localization techniques and also reduces the data input process on the surveyor side.
- Survey respondents may provide their RFID/NFC/DSRC history so that some information related to specific transport mode using such cards. This could substitute the imputed information using geolocation history of mobile devices.

On the other hand, several potentials for transport operators can be also identified from such ICTs as follows although we do not discuss them in this paper:

- RFID / NFC / DSRC data can provide a mode-specific passenger and/or vehicle flow data.
- Remote sensing and camera data can also potentially serve such mode-specific passenger and/or vehicle flow data.

3 INDICATORS REQUIRED BY DEMAND FORECAST METHODS

As mentioned in the introduction, one of the most important usages of the travel survey data is to forecast the future travel demand with models. In order to identify indicators needed by such demand forecast methods (models), nine models used in Europe are analyzed. Several project partners who are familiar with some specific models also contributed to this analysis. The models are selected so that they cover different spatial scale (e.g. from district level to Europe-wide scale) and different relevant aspects (e.g. land-use transport interaction, cross-border aspects, environmental aspects, etc.). The analyzed models are listed in Table 1.

Table 1 – Analyzed demand forecast methods

Name	Brief Description	Coverage	Developer	Dev. Begin	Dev. Status
Viseva-Visum Austria-Slovakia Model	4-stage Transport Demand Estimation Model	Region	TU Vienna (Austria)	2009	Ongoing
MOSAIC	Modal Split and Traffic Assignment Module based on TRANS-TOOLS OD matrixes, over a multi-modal graph (road, rail, air, ferry)	Europe	MCRIT (Spain)	2009	Ongoing
MARS	Land User Transport Interaction model originally developed to model a city or a conurbation.	District to City	TU Vienna (Austria)	2003	Ongoing
TransTools V2.5	Europe-wide Transport Demand Forecast Model	Europe	European Commission Joint Research Center	2006	Ongoing
ASTRA	European integrated assessment model applied since more than 10 years for strategic policy assessment in the transport and energy field.	Europe	Fraunhofer-ISI (Germany)	1997	Ended in 2000, continuous update thereafter.
LATIS	4-stage Transport Demand Estimation Model and Integrated Land Use model (Road Model part)	Region	Transport Scotland (UK)	1997	Ongoing
OmniTRANS Delft Demo	4-stage multimodal transport demand estimation model, using Delft, the Netherlands as an example	City	Omnitrans International (Netherland)	2011	Ongoing
ETIS & ETIS plus	Database for European transport model input	Europe	EU DG MOVE	2002	ETIS done, update as ETIS Plus ongoing
PRAISE	Composition of demand, cost and evaluation models for train services to assess the potential of competitions among rail operators.	UK	ITS Leeds	1996	Ongoing

First, all input and output indicators used in these models was listed. Here, input indicators means the indicators used as exogenous inputs to the models (input variables), and output indicators means data that are estimated by the models (output data). In this step, a raw list of 1231 indicators was made. This list is a result of “copy-and-pastes” of the list of the indicators used in each demand forecast method.

This list needed to be sanitized because the list contains a number of cargo indicators (e.g. carried ton-km) as some models handles both passenger and freight, some models have model-specific parameters as their input (e.g., “Alpha Parameter”), and there were several unclear indicators that we could not specify what they are exactly from the resources used during the research. 159 indicators were dropped as cargo indicators, 27 indicators as model-specific parameters and 9 indicators as lack-of-information indicators. Then, the duplications had to be merged as same indicators are used and/or estimated in several models and a number of indicators from one model are indeed one single indicator with several different classifications listed separately (e.g. "Residents 0-4, Residents 5-9, Residents 10-14, …, but these are indeed a same indicator "Residents" with age classifications "0-4, 5-9…"). Semantically same indicators (e.g. "number of residents" and "population") are manually looked up manually by sorting the sanitized list by name and unit so that no indicator is listed twice.

The list contains another type of incomprehensiveness. Some indicators designated to one mode while the same indicator for other modes are not in the list in some case. To eliminate such incompletion, the mode covered for each indicator was first marked (e.g. all, car, rail, air, etc.) and then, if an indicator does not cover any other mode, indicators analogically inheriting from an indicator dedicated for other modes are added. In this way, the indicator coverage by the list is made more comprehensive. Finally, a list of 208 indicators is obtained. The workflow up to this point is described in Figure 1.

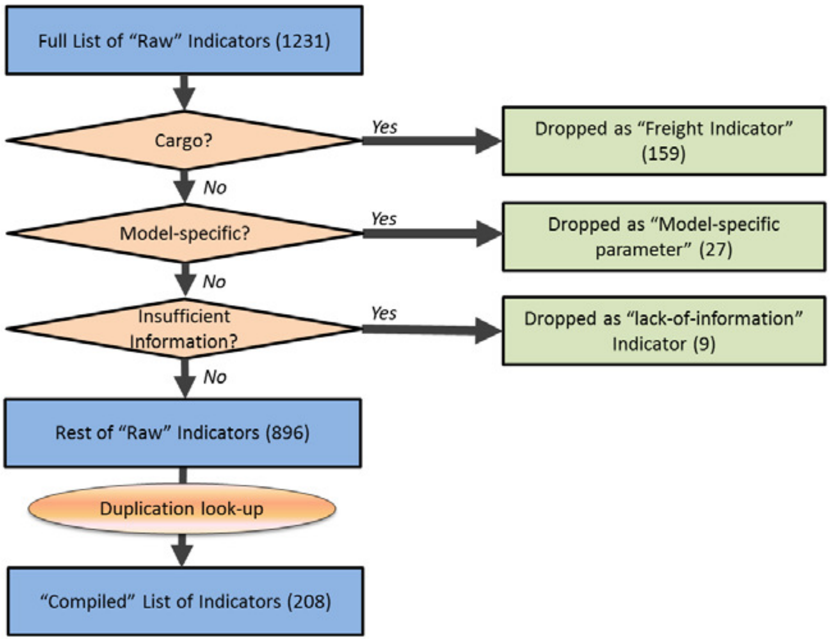

Figure 1 – Analysis workflow of model-used indicators

Among these 208 indicators, 23 indicators are identified as the ones that have to be in the subject of travel survey. Other 185 indicators include the ones about traffic flow, energy consumption, emission, traffic accidents, socioeconomic and macroeconomic indicators (e.g. GDP), attractivity (e.g. number of workplaces/shops in a zone), transport operators' finance, transport supply (e.g. "frequency of public transport"), and infrastructures (e.g. length of road). Although some of them might be relevant to the travel survey as indicators describing the respondents attributes, they are in principal not in the scope of our research. The indicators are not listed here due to the space limitation while the 23 travel survey indicators identified from the models are as same as the one in Table 2 in the following section.

4 TRANSPORT PROFESSIONALS' INTERESTS IN INDICATORS

In the next step, the variation of different extent of interests of a number of transport professionals in the 23 indicators was checked. An online questionnaire asking the respondents their subjective evaluations of the 23 indicators was carried out. This online questionnaire was sent to 60 transport professionals (practitioners and researchers). 27 professionals have completed the survey (11 researchers, 4 transport planners, 3 infrastructure managers, 2 policymakers and regulators respectively, and 5 others). In this questionnaire, respondents are asked to evaluate each of the 23 indicators subjectively if it is important, unimportant or neutral. Table 3 shows the result. The evaluation (Eval.) shows high if the number of important is larger than the sum of neutral and unimportant. Otherwise it shows low. This indicates an overall interest of the transport professionals.

Table 2 – Model-used indicators identified highly relevant to travel surveys and transport professionals' evaluation on them

Indicator [Unit]	Important	Neutral	Unimp.	No Ans.	Eval.*
Modal split [%]	25	2	0	0	High
Modes used in a single trip [modes]	21	4	1	1	High
Number of trips per person [trips]	27	0	0	0	High
Number of trips starting in a zone [trips]	20	7	0	0	High
Number of trips ending in a zone [trips]	21	6	0	0	High
Number of trips zone-to-zone (OD matrix) [trips]	24	3	0	0	High
Number of trips (by mode, aggregated) [trips]	25	2	0	0	High
Trip purpose [N/A]	25	2	0	0	High
Trip length (door-to-door) [km]	21	5	1	0	High
Ratio of trips requiring long-term parking [%]	11	14	2	0	Low
Percentage of intermodal trips [%]	20	6	0	1	High
Travel time [h, min]	24	2	1	0	High
Average time needed to find a parking place at the destination [min]	11	12	3	1	Low
Household transport expenditure [€/pers/a]	13	12	1	1	Low
Passenger trip costs (user cost) [€/km, €/trip, €]	15	10	0	2	High
Value of time [€/h]	14	11	2	0	High
Generalised cost [€]	14	10	1	2	High
Walking time to the parking place [min]	12	12	3	0	Low
Walking time to the closest PT stop [min]	14	11	1	1	High
Accessibility (number/ratio of people accessible to a place/PT stop/zone/node within certain time) [pers., %]	15	12	0	0	High
Number of people with car access [pers.]	17	7	1	2	High
Percentage of employed and residents owning a driving license for cars and motorcycles [%]	12	14	1	0	Low
Percentage / number of people with driving license [%, pers.]	11	16	0	0	Low

*Eval: evaluation by experts at large: if "important" is more than "neutral" + "unimportant", this column indicates "high"; otherwise "low".

In addition, the survey respondents were asked in the aforementioned questionnaire whether they find any "missing" indicator of the respondents' interests. Hundreds of indicators are suggested, while the ones in the scope of travel surveys are (1) "seasonal, monthly, weekly and daily trip fluctuation", (2) "modal split subdivided to distance class", (3) "modal split for specific journey purposes especially for commuting and going to schools", (4) "waiting time if travel time does not include", (5) "public expectation of travel and waiting time", (6) "average monthly cost spent for transportation", and (7) "average number of cars per household in a given area."

Among these, (1) calls for a certain frequency of travel survey, while (2) and (3) are calculable from other indicators. (4) to (6) are the ones that have to be surveyed. (7) is generally obtainable from the vehicle registration data. These are integrated to our assessment presented in Section 7.

5 DATA COLLECTED IN CONVENTIONAL TRAVEL SURVEYS

Various travel surveys undertaken in the past and the present provides us an insight over the indicators that are interested in from the viewpoint of survey itself as well as the information about the current travel survey. During the course of the research, the information from a number of recent Austrian household travel surveys carried out in various Federal States were synthesized (Socialdata GmbH, 1993, Amt der NÖ Landesregierung, 2003, Amt der Tiroler Landesregierung, 2003, Amt der NÖ Landesregierung, 2008, Herry Verkehrsplanung und Consulting, 2009) and three knowledgebase, namely German KONTIV design (Engelhart et al., 2002, Werner, 2009) which serves as one of the comprehensive set of the travel survey indicators, and two recently-published overviews of national travel surveys in a number of countries in Europe (KOMOD, 2011, Ahern and Weyman, 2012).

It has to be noted that, although these surveys and knowledgebase do not necessarily refer to each other, the information may be derived from actual travel surveys to the knowledgebase or one or more knowledgebase may be referred to design actual travel surveys. Thus the information derived from these resources should contain some overlap and they are not necessarily exclusive. However, the information obtained from this analysis can provide following information that is integrated into the synthesized table presented in the next section (Tables 4, 5 and 6), namely:

- Indicators surveyed but not much interested by the models;
- Information about interest in indicators by survey conductors;
- Status of indicators whether they are widely collected already, collected in some countries now, or future potential;
- Current data collection intervals;
- Data collection method widely employed currently.

The indicators in the subject of conventional travel survey contain ones with various scopes in terms of time and person. Thus the indicators are categorized as shown in Table 3. Most of the indicators that are categorized as travel survey indicators during the analysis of travel demand forecast methods described in Section 3 fall in trip attribute indicators or trip accumulation indicators.

Table 3 – Overview of the scopes flagged to each indicator

Scope	Description	Time scale	Targeted person
Trip attribute	Indicators that describes characteristics of each trip	Trip (~h)	1 person
Respondent attribute	Indicators that describes characteristics of each respondents	Year	1 person, household
Trip accumulation	Indicators showing accumulated trips	Day - Year	More
Vehicle possession	Indicators showing ownership and features of vehicle	Year	Household
Long-distance travel, second home	Indicators showing mobility tendency about long-distance travel and about second home	Year	1 person
Subjective assessment, satisfaction and values	Indicators showing subjective assessment and perception of the respondents	Year	1 person

Due to the space limitation and to avoid duality, the indicators analyzed in this section are not listed here – they are integrated in Tables 4, 5 and 6 in Section 7. The indicators in the categories “vehicle possession”, “long-distance travel and second home”, and “subjective assessment, satisfaction and values” are excluded from the further analysis because these are much beyond the scope of this paper and.

6 DISCUSSIONS ON DATA OBTIANABILITY WITH ICTS

In this section, discussions are made on data obtainability with ICTs for the indicators in each group. The result of this assessment is included in the column “potential data collection methodology” in the Tables 4, 5 and 6 in the next section.

6.1 Trip attributes indicators

Methodologies to identify trips from the chains of points are proposed by several researchers already (Stopher et al., 2008, Bohte and Maat, 2009, Chen et al., 2010). This includes identification of the basic trip attribute indicators, namely trip origin and destination, point of changing, begin and end time as well as travel time, and travel distance.

The point chains recorded in GPS logger or from geo-location information alone does not provide any information about trip purpose and mode. Several imputation methodologies are proposed by with GIS (geography information system) including information about multimodal transport network and business locations as well as land use (Stopher et al., 2008, Bohte and Maat, 2009, Chen et al., 2010, Axhausen et al., 2012). It has to be noted that some deterministic methodology appears to require prior information from survey respondents about home location, workplace and frequently-visited locations (e.g. grocery stores).

Despite this high potential to detect basic trip attribute indicators, it may be difficult to determine several indicators, namely distance and time to/from public transport stop from/to actual origin/destination, distance and time to/from a parking lot to actual origin/destination, as well as time spent on searching parking. In most of the GPS-based travel survey attempts, segmentation of trips is made after the initial trip identification step and thus they try to capture access and egress segments. However, at the trip identification stage, trip end (and thus begin of the next trip) is detected by a cluster of recorded points for certain period of time (120s-200s) and/or within certain area (e.g. 50m), sometimes with direction and speed information from accelerometer (Stopher et al., 2008, Bohte and Maat, 2009, Axhausen et al., 2012, Gong et al., 2012). Thus, in case the access and egress distance and time of a trip are within the threshold, which is likely to happen often, such access/egress will not be detected.

GPS or geolocation-based methodology clearly cannot detect other important indicators, such as vehicle occupancy, driver or passenger, and travel alone or in a group. For example, the surveys with distinctive mode classification of “car driver” and “car passenger” cannot be substituted with the GPS or geolocation-based travel survey. This applies especially to the indicators that are needed for detailed analysis, modeling and decision-making.

Therefore, at large, although GPS or geolocation based travel survey could provide an overview of travel behavior in a mass population, potentially for lower cost, several trip characteristics indicators needs to be still self-reported by the survey respondents to make the survey detailed and comprehensive.

It has to be noted that a number of technical issues have to be examined such as battery, the data storage on the mobile device and pre-made received signal strength indicator maps (RSSI-maps) of Wi-Fi and mobile phone mast, as well as the regular Internet connection. The Internet connection does not have to be available all the time; however, for the GIS database access and data transmission, stable connection at least once within the period that the geolocation history is held on the device is needed so that trip detection and following process can be ensured.

Travel history logged by RFID/NFC smart ticket may substitute the information about the usage of the transport mode that uses the RFID/NFC smart ticket. In most case, the log is limited to public transport. However, in some cities, the single RFID/NFC card is used as a public transport smart ticket and for Electronic Road Pricing and parking payments (e.g. in Singapore) or for payments for taxi rides (e.g. in Singapore, Tokyo), and thus some vehicular trips can be captured by this. The RFID/NFC data does not capture the trips made by other modes that are not covered by RFID/NFC payments; however, a matching between the geolocation-recorded data and RFID card log will be valuable as it can assist the trip identification and mode imputation of public transport.

To realize such matching, the simplest possible application for the data collection is probably to use NFC-enabled smartphones. Otherwise, a methodology to integrate operator-stored RFID usage history and geolocation-recorded data will be needed. It has to be noted that a difficulty might arise when an anonymous smartcard is shared by several people (e.g. within family) because travel history of such a card contains two or more people’s travel data. There is no practical way to differentiate data in such case. Thus, prerequisite of the RFID-card data usage is that a card is personalized and not shared by two or more people.

6.2 Respondent attributes indicators

Differently from the trip attribute indicators, it is difficult to collect these data with the aforementioned ICT technologies. Most of the existing ICT-based surveys ask this information by another method, often with Web-based user interface, prior to survey (Stopher et al., 2008, Bohte and Maat, 2009, Axhausen et al., 2012). These socio-demographic data and information of private means of transport do not have to be measured on daily or monthly basis. Thus, these data will probably remain to be surveyed not by the automated ICT methodology and collected by another methodology.

6.3 Trip accumulation indicators

The trip accumulation indicators are depersonalized, accumulated and classified representations of trips and they often required by models and also to capture the overall travel behavior within a certain area. They are highly dependent on trip attribute indicators. They will be easily calculated as far as each single trip and its attributes are correctly captured and imputed by representative samples in a designated area.

In addition to this general aspect covering all modes, mode-specific data may be collected from different sources. For example, RFID-card log including timestamp and card identifier information from the card readers (e.g. ticketing gates) at the entrances and exits of railway stations can provide origin-destination matrix data. This can be enhanced to location-aware readers on buses and trams if passengers have to tap the RFID-card twice onto the reader when getting on and off. The data can be subdivided into time, trip rate (within RFID-using transport mode), intermodal connections, ticket types (e.g. single ticket or monthly pass) if the identifier information can be joined with ticket types associated with each card, and so on.

Similarly, a cell tower targeted for a designated area can potentially provide similar OD data. If a cell tower is equipped in the middle of the platform, it is likely that most of the cell phones on the platform are connected to this tower; thus this cell-tower-based data may be applied to a closed public transport entrance such as an underground station. If a cell tower takes a log of cell phone connected to it with an identifier and a timestamp, an approximate number of people arriving and leaving stations can be captured from this. In addition, if the cell phone identifier data is compared among the stations within a reasonable time range corresponding to travel times, an OD matrix can be imputed form it. This may substitute the ticketing gate data that would be obtainable from RFID when open ticketing system (proof-of-payment system) is used with which there is no ticketing gate and passengers can enter into the platform freely. It has to be noted that certain groups of people with less number of mobile phones such as elderly and schoolchildren may be overlooked by this method. In addition, it is questionable if cell phone carriers are cooperative for this purpose. Perhaps there is a problem of privacy and data protection as well as of the coherence with cell phone carriers' privacy policies. Further researches are clearly needed onto this potential.

Camera combined with a human face recognition technology may do the same when automatically recognized human faces could serve as identifiers instead of RFID identifier.

Although this could provide a low-cost potential for data collection, resolution and recognition are technical questions. In addition, this could cause much privacy concern as passengers may feel much "watched" by face tracking.

7. DATA NEEDS AND OBTAINABILITY OVERVIEW

In this section, as a synthesis of all of the previous sections, a result of our assessment on data needs and potentials of ICTs are presented in Table 4 listing trip attribute indicators Table 5 listing respondents attribute indicators and Table 6 listing trip accumulation indicators. The list contains the indicators as a synthesis of the ones used by models (Section 3), evaluation of the information needs by the stakeholders (Section 4), the indicators surveyed already in travel surveys (Section 5) and data obtainability (Section 6). The list also includes "Interest by different user groups" as a result of our information needs assessment (briefly described in Section 4).

If the indicator is required by models, the column "used by models" is double or triple ticked depending on the number of models requiring it, while if it is not used, still this column is once ticked as such new data source may serve as a new potential data for new models. If the indicator is already surveyed in travel surveys, "Surveyor" column is ticked. The column "practitioners" and "researchers" correspond to our assessment presented in Section 4 – if the result is "high" in Table 2, respective column is triple ticked, and if "low", single ticked, while when no information is obtained during the course of our research, the column is left empty with grey background. The list also has the "status" column derived from the result of analysis of current travel surveys presented in Section 5. This column shows if the indicators are widely collected already, collected in some countries, or a future potential. It has to be noted that, if the indicator is collected in some countries, it tend to be collected by the nationwide travel surveys in Germany (*MiD* and/or *MOP*) and/or in Switzerland (*Mikrozensus Verkehr*), which are two of the European countries that conducts most detailed travel surveys.

The list also contains various metadata. Current data collection interval and methodology is derived from the review of conventional travel surveys. Optimal data collection interval is our own assessment considering whether the indicator is much needed especially for modeling, whether the data is obtainable with ICTs and what is the typical cycle that the object of the data changes. The reason to consider obtainability with ICTs is that the ICTs potentially allow surveys with shorter intervals for lower costs. Optimal data collection methodology relies on the review of potential ICTs presented in the section 2 and the data obtainability assessment presented in Section 6. The "collected/derived" column shows if the indicator can be measured by some devices, has to be asked to the respondents or by its nature it has to be calculated from other indicators.

The tables has a column "module" indicating that each indicator is rather basic ones or advanced ones showing the details so that the basic character of each indicator can be easily identified. This categorization is made for trip attribute and respondents' attribute indicators as there are many indicators, while it is not made for trip accumulation indicators as they are typically calculated from basic trip attribute indicators.

Table 4 Trip attributes indicators

Data collection module / methods			**Interest by different user groups**				**Status**			**Metadata**				
Module	**Indicator**	**Unit**	**Used by Models**	**Surveyor**	**Practitioners**	**Researchers**	**Widely collected**	**Cltd in some countr.**	**Future potential**	**Data collection interval actual**	**Data collection interval optimal**	**Data collection methodology, current**	**Data collection methodology, future potential**	**collected / derived**
Trip attributes – basic	Trip origin, destination, point of changing	N/A	+++	+++			x			1-10 years	1 Year	Questionnaire	Geolocation	Measure/ ICT
	Trip begin time, end time	timestamp	+++	+++			x			1-10 years	1 Year	Questionnaire	Geolocation	Measure/ ICT
	Trip purpose	N/A	+++	+++	+++	+++	x			1-10 years	1 Year	Questionnaire	Imputation	Ask
	Modes used in trip	modes	+++	+++	+++	+++	x			1-10 years	1 Year	Questionnaire	Imputation	Measure/ ICT
	If car is available for the trip	N/A	+	+++			x			1-10 years	1 Year	Questionnaire	Questionnaire	Ask
	Actual trip distance	km	+++	+++	+++	+++	x			1-10 years	1 Year	Questionnaire	Geolocation	Measure/ ICT
	Actual travel time	h, min	+++	+++	+++	+++	x			1-10 years	1 Year	Questionnaire	Geolocation	Measure/ ICT
	Distance/time to PT stop	km, min	++	+++	++	++	x			1-10 years	1 Year	Questionnaire	Geolocation	Measure /ICT
	Driver or passenger (car trip)	N/A	+	+++			x			1-10 years	1 Year	Questionnaire	Questionnaire	Ask
	Travel group (how many people travel together?)	persons	+	+++			x			1-10 years	1 Year	Questionnaire	Questionnaire	Ask
	Luggage weight carried	kg	+	+					x	N/A	1 Year	N/A	Questionnaire	Ask
	Reasons for "non-mobile" if there is no trip made on a single day	N/A	+	++				x		1-5 years	1 Year	Questionnaire	Questionnaire	Ask
	Weather on the day of reporting	temperature, quantity of rainfall, etc.	+	++				x		1-5 years	1 Year	Questionnaire	Derive from weather service	Ask / Derive
	Frequency of usage of each transport mode	N/A	+	+					x	1-10 years	1 Year	Questionnaire	Questionnaire	Ask
	If routine business trips undertaken, purpose, travel distance, mode	N/A	+	++				x		1 Year	1 Year	Questionnaire	Questionnaire	Ask
Trip attributes – in detail	Route path	N/A	+	+					x	N/A	5 Years	N/A	Geolocation	Measure/ ICT
	If shopping trip: number of shops visited, type of purchased goods	N/A	+	++				x		5 Years	5 Years	Questionnaire	Questionnaire	Ask
	Indicator if trip is routine trip or not (regular, several times a year)	N/A	+	+					x	N/A	5 Years	N/A	Questionnaire	Ask
	If car, type (own car, family member's car, rent-a-car, carsharing, etc.)	vehicle information	+	++				x		1-5 Years	5 Years	Questionnaire	Questionnaire	Ask
	Estimated trip distance	km	+	++				x		5 Years	5 Years	Questionnaire	Questionnaire	Ask
	Estimated travel time	h, min	+	++				x		5 Years	5 Years	Questionnaire	Questionnaire	Ask
	Access and egress means of transport to/from public transport	modes	+	+					x	N/A	5 Years	N/A	Questionnaire	Ask
	Distance/time to parking	km, min	++	+	+	+			x	N/A	5 Years	N/A	Geolocation	Measure/ ICT
	Waiting time	min	+	+					x	N/A	5 Years	N/A	Geolocation	Measure/ ICT
	Time to find a parking while driving	min	++	+	+	+			x	N/A	5 Years	N/A	Questionnaire	Ask
	Type of car parking lot and cost of it at destination	N/A	+	++				x		5 Years	5 Years	Questionnaire	Database or Questionnaire	Ask
	Type of ticket for public transport	N/A	+	+					x	N/A	5 Years	N/A	RFID Smartcard, Smartphone	Measure/ ICT
	Vehicle occupancy	passengers/ vehicle	+	+					x	N/A	5 Years	N/A	Questionnaire	Ask
	User cost, per-km cost	€/km, €/trip, €	++	+	+	++			x	N/A	5 Years	N/A	Questionnaire, calculation	Ask, then Calc.
	Generalised cost	€	++	+	+	+++			x	N/A	5 Years	N/A	Calculation	Calc.
	Trip's requirement for long-term parking	%	++	+	+	+			x	N/A	5 Years	N/A	Questionnaire	Ask

It has to be noted that, to simplify the list, we edited the units as follows. First, the units are replaced with SI units where appropriate. All currency units ($, £, ECU, etc.) are replaced with € (Euro) for simplification. The unit representing a number of people is unified as "persons", except for the ones representing a number of passenger ("passenger") and workers ("workplaces"). Metric prefixes are basically removed, except for the distance (km) and weight (kg), and other prefixes such as "thousand" are generally removed.

One of the important finding is that the more basic the indicator is, the more likely the data can be obtained through ICT-based methods regarding the trip attribute indicators. This still does not mean that all of the trip attribute indicators are obtainable – some of them have to be still self-reported by the respondents. However, this implies that the potential of ICT-based method to be employed in the travel survey is much higher in the area of the basic indicators.

Table 5 Respondents' attribute indicators

Data collection module / methods			Interest by different user groups				Status			Metadata				
Module	**Indicator**	**Unit**	**Used by Models**	**Surveyor**	**Practitioners**	**Researchers**	**Widely collected**	**Cltd in some countr.**	**Future potential**	**Data collection interval actual**	**Data collection interval optimal**	**Data collection methodology, current**	**Data collection methodology, future potential**	**collected / derived**
Respondents' attributes – basic	Household size, family composition	people	+	+++			x			1-10 years	1 Year	Questionnaire	Registration data	Ask
	Age of respondents	year-old	+	+++			x			1-10 years	1 Year	Questionnaire	Registration data	Ask
	Gender of respondents	N/A	+	+++			x			1-10 years	1 Year	Questionnaire	Registration data	Ask
	Educational level	N/A	+	+++			x			1-10 years	5 Years	Questionnaire	Questionnaire	Ask
	Nationality, citizenship	N/A	+	++				x		5 Years	1 Year	Questionnaire	Registration data	Ask
	Occupation, employment status	N/A	+	+++			x			1-10 years	5 Years	Questionnaire	Questionnaire	Ask
	Usual weekly working hours	h/week	+	+++			x			1-10 years	5 Years	Questionnaire	Questionnaire	Ask
	Work/education location	N/A	+	+++			x			1-10 years	5 Years	Questionnaire	Questionnaire	Ask
	Mode availability for often visited destinations (POI)	N/A	+	++				x		1-5 Years	1 Year	Questionnaire	Geolocation + GIS	Ask
	Personal/household income	€/year, €/month	+	+++			x			1-10 years	5 Years	Questionnaire	Questionnaire	Ask
	Mobility impairment	type of impairment	+	+++			x			1-10 years	5 Years	Questionnaire	Questionnaire	Ask
Respondents' attributes – in detail	Type of household (single, nuclear family, extended family etc.)	N/A	+	++				x		1-5 years	5 Years	Questionnaire	Questionnaire	Ask
	Housing type (rented/self-owned, flat/house etc.)	N/A	+	++				x		1-5 years	5 Years	Questionnaire	Questionnaire	Ask
	Years of living at current location	year	+	++				x		1-5 years	5 Years	Questionnaire	Questionnaire	Ask
	Social class and socio-cultural background	N/A	+	+					x	N/A	5 Years	N/A	Questionnaire	Ask
	Shopping facilities for daily needs in neighborhood	address, geocode	+	++				x		1-5 years	1 Year	Questionnaire	Questionnaire	Ask
	Leisure facilities in neighbourhood	address, geocode	+	++				x		1-5 years	1 Year	Questionnaire	Questionnaire	Ask
	Frequently used public transport stops	N/A	+	++				x		Ad-hoc	1 Year	Questionnaire	Questionnaire	Ask
	Household travel expenditure	€/year, €/month	++	+	++	+			x	N/A	5 Years	N/A	Questionnaire	Ask
	Landline and internet availability	N/A	+	+++			x			1-10 years	5 Years	Questionnaire	Questionnaire	Ask/ Derive
	PC and smartphone availability	N/A	+	+++			x			1-10 years	5 Years	Questionnaire	Questionnaire	Ask

Table 6 Trip accumulation indicators

Data collection module / methods			Interest by different user groups				Status			Metadata				
Module	Indicator	Unit	Used by Models	Surveyor	Practitioners	Researchers	Widely collected	Cltd in some countr.	Future potential	Data collection interval actual	Data collection interval optimal	Data collection methodology, current	Data collection methodology, future potential	collected / derived
Trip accumulation	Number of trips per person	trips	+++	+++	+++	+++	x				1 Year	Calculated	Calculated	Calc.
	Number of trips (by mode, aggregated)	trips	+++	+++	+++	+++	x				1 Year	Calculated	Calculated	Calc.
	Number of trips starting in a zone	trips	+++	+++	+++	+++	x				1 Year	Calculated	Calculated	Calc.
	Number of trips ending in a zone	trips	+++	+++	+++	+++	x				1 Year	Calculated	Calculated	Calc.
	Number of trips zone-to-zone (OD Matrix)	trips	+++	+++	+++	+++	x				1 Year	Calculated	Calculated	Calc.
	Modal split	%	+++	+++	+++	+++	x				1 Year	Calculated	Calculated	Calc.
	Percentage of intermodal trips	%	+++	+++	+++	+++	x				1 Year	Calculated	Calculated	Calc.
	Passenger km	pass-km	+++	+++			x				1 Year	Calculated	Calculated	Calc.
	Vehicle km	veh-km	+++	+++			x				1 Year	Calculated	Calculated	Calc.
	CO_2 emissions	t/year	+++	+++			x				1 Year	Calculated	Calculated	Calc.

8 CONCLUSION AND FUTURE PERSPECTIVES

In this paper, we reviewed state-of-the-art ICT technologies that may be utilized for travel surveys, analyzed the indicators needed by various transport demand forecast methods (models), obtained the level-of-interest information from various transport professionals, and then reviewed the indicators that are currently collected in various travel surveys. We also evaluated the obtainability of the indicators with the potential ICT technologies. Finally, we created a comprehensive table containing all of the analysis and assessment results.

The evaluation of the trip attribute indicators shows that most of the indicators required by the models currently in use and interested in by a number of transport professionals are potentially obtainable with ICT-based method. However, several indicators have to be imputed or are not obtainable with the ICT. The ones that are not obtainable still need to be self-reported by survey respondents. It has to be added that these non-obtainable indicators tend to be the one that are needed for in-depth analysis. The respondents attribute indicators are generally to be still obtained through questionnaires. The trip accumulation indicators as well as the other indicators should be calculable with trip attribute indicators or obtainable from other data sources. It also has to be noted that the respondent's subjective feeling (e.g. subjective perception of waiting time at public transport stop) cannot be captured automatically by the ICT-based method.

These imply that, although it could be satisfactory for some "classical" analysis and modeling, moving fully to the automated ICT-based travel survey could limit the data availability that are needed for analysis and modeling.

However, the ICT-based methods will be valuable in various terms. First, the recent rapid development of the smartphone and touch-panel PDAs as well as the tablet PCs will enable the direct user input just by tapping the touch-screen. This will reduce the respondents' burden to self-report trip attribute indicators that are not obtainable from the geolocation records as well as respondents attribute indicators.

Second, a highly cloudsourced travel survey will be possible that the geolocation records of Internet-enabled mobile devices of the survey respondents such as smartphones, touch-panel PDAs and tablet PCs are utilized and the necessary post processing including the trip detection and mode and purpose imputation is carried out on the mobile devices. As the computing power and the memory capacity of smartphones is becoming fairly large and Internet-enabled smartphones can obtain necessary GIS data for mode and purpose imputation over the cellular data network or Wi-Fi, the post-processing can be done on each smartphone instead of surveying organization's workstation. Furthermore, such post-processing on the mobile device will enable the respondents to validate the trip data soon after the trip, probably with the *push notice* functions that most of the recent smartphone features. Finally, such method is advantageous in that the data transmitted from the respondents to the surveyor will be necessary travel survey indicators instead of the whole set of the geolocation history and thus it will reduce the respondents concern to participate in such ICT-based travel survey especially when it comes to the privacy.

Needless to say, to realize such ICT-based travel survey, much development will be needed such as trip and mode detection. Furthermore, in-depth study regarding organizational and legal issues such as privacy protection has to be carried out. Comprehensive and accurate database of POI (points of interests) is another key for such ICT-based travel survey as the data is needed to input the transport mode and the trip purpose.

At large, considering the (non-)obtainability of some important indicators with the ICT-based method and the potential of cloudsourced travel surveys utilizing Internet-enabled mobile devices as well as the general fact that the ICT-based method enables more frequent surveys for lower cost and the needs for further technical development, the following points are proposed. This set of recommendations is mainly designated to the travel surveys in Europe while the principles can be applied to any travel surveys.

- As more ICT-based methods will be probably available in the future, employment of such techniques in the travel survey has to be sought. Further research and development are needed to overcome yet addressed barriers to employ such techniques in travel surveys. Employment of ICTs can potentially make it possible to carry out travel surveys more frequently for lower cost.
- However, the ICT-based method does not appear to allow the surveyor to capture all of the travel-behavior-related information that is needed by various stakeholders. Thus, questionnaire-based travel survey will be still needed in the future.
- Therefore, in the context of the national travel survey, a combination of frequent travel survey with a much automated ICT-based method and less questionnaire-based frequent travel survey with conventional method has to be sought.

- It does not appear to make sense to carry out ICT-based and questionnaire-based survey with a same interval – rather, the combination with different intervals with different extent of the depth of the information should enable the basic indicators that are needed more to be surveyed more frequently for lower cost, while the other important indicators are still collected with a certain interval.
- ICT-based travel surveys to collect basic travel behavior indicators that appear to be needed widely can potentially carried out annually or, should the resources permit, more frequently. Questionnaire-based travel surveys to collect in-depth travel behavior indicators can be carried out with a longer interval such as every five years.

ACKNOWLEDGEMENTS

We wish to thank Benedikt Mandel, Claudia de Stasio, Francesca Fermi, Kathryn Stewart and Oriol Biosca for their contributions to list the model-used indicators and to Christiane Bielefeldt for her commentary on the indicator compilation as project partners.

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