


A smartphone based DSS platform for assessing transit service attributes

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Abstract This paper presents a methodology for determining public transportation quality attributes, based on a decision support system (DSS). The platform, once set up, combines the capability of geographic information systems (GIS) to analyze spatial attributes and the smartphone mobile technology, which is a “smart” solution to collect dynamically bus locations and their cinematic variables. The DSS has been applied to a real case study in order to test its reliability. The results highlight a good flexibility of the platform combined with a good level of scalability and interoperability of the system that can be applied in any context. Moreover, the high penetration rate of smartphones among users and the system capability of disaggregating data in both space and time, makes the DSS useful to identify operational problems and take appropriate actions with a non-intrusive approach.

Keywords Public transportation · Transit service performances · Decision support system · Smartphone · GIS

1 Introduction

Public transportation planning is mainly based on collecting quality data to support analytical and decision-making processes. However, the procedures and the tools needed to collect all the information necessary to make a good planning level are

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very expensive and, in many cases, require a lot of experience in their use and their calibration.

The social, behavioral and cultural differences among the different categories of users and the level of service performed by each transport system do not allow the development of a unique set of specific procedures for collecting and analyzing data. Furthermore, a customized approach is required due to the diverse priorities of users with regard to service improvements.

Data on different service measures can be obtained by manual and automatic methods. Manual methods require observation of service attributes by operators, whereas automatic methods record some transit service measures without the aid of physical operators.

Smartphones are a low-cost collection tool for obtaining data. Whereas information on bus locations is commonly provided by the on-board data collection systems (AVLs), smartphones can be used as new systems to obtain a set of data useful to evaluate comfort and convenience attributes, such as dynamic load.

Advantages in the use of smartphones for transit systems data collection include:

- less expensive technology than sensors or cameras,
- more coverage (GPS embedded sensor allows a point-to-point localization),
- less maintenance and faster to set up tools.

Smartphones are coming up as a technology useful to provide an inexpensive AVL solution for smaller transit agencies which do not have presently advanced vehicle location information. Generally, transit agencies buy the information systems from a CAD/AVL vendor in a bundle including all on-board and central hardware, network, software systems, and licenses. Today most smartphones have a GPS chip that, coupled with the standard phone features, can offer a high performance in terms of reliability of positioning and could be used as surrogate AVL systems (Thiagarajan et al. 2010). Some tests were recently performed to analyze the accuracy of dedicated GPS units from companies like Garmin compared to the GPS data collected via smartphones (Singletracks 2014) showing that smartphones can yield errors in distance accuracy less than 3 %. Furthermore, like the AVL systems, also the smartphones have a user-friendly interface providing a bus operator with options for sending pre-defined messages to the dispatcher.

Automatic data collected by the smartphone probes on the buses could also be used as floating car data to evaluate the performances of the road networks (Bertini and Tantiyanugulchai 2004; Kumar and Vanajakshi 2014), but they are not necessarily the best to be used in urban areas due to several issues including exclusive bus lanes (no other vehicles use those lanes), bus stops (a bus stop made for passengers pick-up/drop-off could be wrongly referred to a stop light or a traffic congestion), and kinematic features (speed and acceleration profiles for buses are usually different from cars).

However, when this technology is applied to collect transit data, many aspects have to be considered, such as bias, aggregation error, inconsistency, and irrelevancy to the customer. In order to overcome the above-mentioned problems, a post-processing step for data preparation is required involving the use of a desktop

Geographic Information System (GIS) tool combined with Map Matching techniques (Bierlaire et al. 2013).

This paper presents a new methodology to explore the operational performances of public transport services using a decision support system (DSS) platform based on smartphone mobile technology and GIS. In particular, the smartphone device, equipped with a GPS sensor, is adopted to collect transit performance variables (e.g. bus speed, service reliability, travel times and dwell times) and passengers loads. A new app for smartphones has been set up to collect location data continuously; when the location does not change during a configurable threshold (e.g. 1 min), it indicates a bus stop location. The app allows the operator to update bus stop locations with dynamic load and dwell time, defined as the time in seconds that a transit vehicle is stopped for the purpose of boarding/alighting passengers. It includes the total passenger service time and the time needed to open and close doors, considering the GPS timestamp difference from the last stop time and the next departure time.

GIS is adopted to explore spatial patterns of performance (i.e. accessibility), owing to its capacity to make sophisticated spatial computations in addition to a distinctive spatial database capability which greatly facilitates spatial decision making.

The proposed methodology implies the use of a smart technology commonly diffused worldwide (smartphone) that does not require implementation of on-board systems and expensive smart card ticketing systems, which may result in increased individual travel costs. The main purpose of this paper is to demonstrate the usefulness of low-cost tools for the evaluation of the quality parameters of transit systems. Operators and managers, on the one hand, and the passengers, on the other hand, would benefit from the use of such systems as a surrogate of AVL systems.

The recent innovations in mobile technology have been employed in this work to develop a decision support system (DSS) platform integrating a smartphone mobile technology and a Geographical Information System to overpass some limitations of the current AVL/AVS systems (i.e. excessive equipment costs, not open source software, high operating costs). The proposed DSS platform can support the strategic planning of public transportation systems. Furthermore, the framework of the platform allows generating a dataset according to general transit feed specification (GTFS), that defines a common format for public transport timetables and related geographic information. The specifications are designed for the analysis of the level of service and other performance measures, but they are also useful to provide several features for trip scheduling. They may also include real-time information through specific GTFS-realtime.

The paper is organized according the following structure: the next section provides a state of the art of the quality attributes of public transportation commonly adopted to evaluate transit service quality; the third section focuses on a methodology description of the entire platform considering the operational performances of public transport services determined and the description of DSS architecture; this is followed by an application of the methodology described in the previous section to a case study; finally, the paper concludes with a summary of results and a discussion of the implications for future research.

The next section tends to investigate in detail the attributes used to assess the quality of the transit service classifying them into two main categories: objective and perceived. The in-depth dissertation on the quality attributes was necessary to select those attributes evaluable through the proposed solution, and hence to identify the spectrum of data to be acquired from the smartphone devices useful to this purpose.

2 Literature review

A large number of attributes have been proposed in attempts to define public transportation quality. These attributes can be preliminarily classified as objective or perceived. Whereas objective attributes are referred to observed measures not involving users, perceived attributes can be directly or indirectly evaluated by user opinions. Service providers make various efforts to identify the most important attributes for improving service quality, allocating resources and catching new potential users. Generally, transit operators adopt customer satisfaction surveys to capture passengers' perceptions as a qualitative measure of transit service quality to identify which attributes have to be better explored to improve the service quality. Some objective and perceived attributes are introduced below.

2.1 Objective quality attributes

2.1.1 Reliability

Reliability is one of the most frequently physical attributes used in determining public transportation quality (Eboli and Mazzulla 2010; Cantwell et al. 2009; Hensher and Prioni 2002; Parkan 2002; Too and Earl 2010). While it is generally associated by users with punctuality and travel time, transit operators use to refer this attribute to running time adherence, on-time performance and headway regularity (Transportation Research Board 1999, 2003; Lin et al. 2007). Vuchic (2005) defines reliability as “one minus the probability of failure”. Results from a study by Turnquist and Blume (1980) highlight that control of headways between transit vehicles is considered as a means of improving service reliability. As defined by these authors, reliability can be considered as “the ability of the transit system to adhere to schedule or maintain regular headways and a consistent travel time”.

Concerning the methods of data collection, several intelligent transportation systems (ITS) have been adopted in order to enable transit operators to collect advanced operational data for analyzing service reliability (Bertini and El-Geneidy 2003; Furth et al. 2006; Sleep et al. 2013). Strathman et al. (1999) introduce an automated bus dispatching to analyze service reliability. Cham (2006) and Feng and Figliozzi (2011) analyze transit service reliability through data obtained by AVL systems.

2.1.2 Frequency

Service frequency is also considered an important factor to determine the public transportation quality (Tyrinopoulos and Antoniou 2008) and refers to how often transit service is available. Generally, frequency can be calculated as the average value of runs performed hourly in a day. The higher the frequency in public transport service, the lower the waiting time between services and the higher the observed ridership (Transportation Research Board 2003; Levinson et al. 2003). Wall and McDonald (2007) highlighted that increased frequency could increase user numbers by 20 % in the first year, even with a frequency elasticity of up to 0.4.

2.1.3 Accessibility

Accessibility can be evaluated based on the available facilities, and refers to the ease of reaching bus stop locations. Researchers focused their studies on strategies to be implemented for improving accessibility for all users, and hence public transportation quality (Murray et al. 1998; Chien and Qin 2004; Vuk 2005; Rastogi and Krishna Rao 2003, 2009; Loader and Stanley 2009). Rodriguez and Targa (2004) found that passenger accessibility is an important quality in public transportation services, and that an increased access travel time of 5 min is relevant for users. Alshalalfah and Shalaby (2007) explored the relationship between walk access distance to transit and several transit service characteristics and transit users in Toronto, highlighting that the dense transit route network in the downtown area results in shorter walk access distances than in other parts of the city. They found also that transit service frequency, dwelling type of the household, number of vehicles available in the household show a noteworthy relationship to access distance in Toronto. Ji and Gao (2010) found that both accessibility and personal characteristics are significant factors affecting public transportation service quality.

2.1.4 Pricing

Transit use is commonly promoted by pricing changes involving the increase or decrease of the fare charged to a transit rider (Transportation Research Board 2004). Several pricing mechanisms, as well as integrated tariff systems, seasonal passes, transferrable passes and automated ticketing, attempt to combine price attributes with convenience, customer loyalty and service provider cooperation. Most of the studies highlight that public transportation pricing mechanisms are very successful in terms of increased ridership levels (Dargay and Pekkarinen 1997; Abrate et al. 2009; Sharaby and Shiftan 2012). In several studies (Fujii and Kitamura 2003; Thøgersen 2009; Thøgersen and Møller 2008) free fares for public transportation were found to attract car users to the public transportation service. Despite ridership decrease when the free period ends, fare promotions are effective in encouraging increased ridership. Redman et al. (2013) demonstrated that reduced fare promotions and other habit-interrupting transport policy measures can succeed in encouraging car users to try public transportation services initially. In order to

describe the ridership's response, elasticity is commonly used to assess the effects of transit pricing and fare changes.

2.1.5 Information provision

The availability of information on transit service, especially on timetables, routes and access locations, affects the transit service quality. Generally, two main categories of information are available: pre-trip and on-trip. Pre-trip information allows users to access a complete range of real-time information on where the trip originates, including the bus stop locations, routes to the desired destination, transfer locations, departure and arrival times, and fares. Based on this information, travelers can select the best departure time, route and modes of travel, or perhaps decide not to make the trip. On-trip information allows users to make decisions during the trip; real-time information is given to users on board or at transfer points. Several studies focused on the perceived value of real-time information primarily in reducing uncertainty about arrival times (Atkins et al. 1994; Balogh and Smith 1992). Other studies found that real-time information offers benefit in terms of increasing public transport patronage, increasing willingness-to-pay and reducing waiting time (Dziekan and Kottenhoff 2007; Caulfield and O'Mahony 2009). Nevertheless, Hickman and Wilson (1995) highlighted that real-time information yields modest improvements in the origin-to-destination travel times and the variability of trip times. Peng and Huang (2000) presented a web-based transit information system design using Internet Geographic Information Systems (GIS) technologies to integrate Web serving, GIS processing, network analysis and database management.

2.2 Perceived quality attributes

2.2.1 Comfort

Comfort is considered as one of the most important factors affecting the perceived service quality by passengers. This attribute is generally related to both on board and at stop conditions. Comfort on board refers to availability, cleanliness and softness of seats, passengers load, temperature, level of noise, air quality, and vibrations. Whereas usual transit passengers perceive vehicles with low-floor and air-conditioning as "very good and very comfortable", car users perceive buses as uncomfortable, overcrowded, smelly and airless (Beirão and Sarsfield Cabral 2007). Wall and McDonald (2007) found that the introduction of a fleet of new and low-floor buses concurs to improve the level of comfort. Iseki and Taylor (2010) highlight that "comfortable, informative, and attractive stops and stations can make traveling by public transit more agreeable", but "what passengers really want most is safe, frequent, and reliable service, plain and simple". A study from dell'Olio et al. (2011) shows that comfort, as well as cleanliness and waiting time, is one of the most valued public transport variables; this study also underscores that desired quality is variable with user category. Litman (2008) demonstrated that users choose public transportation rather than private cars when service is comfortable and convenient.

2.2.2 Safety

The safety attribute generally refers not only to safety from accidents and crimes on board or at bus stops, but also to safety issues related to the operators' management. Ingalls et al. (1994) made a survey of bus riders and residents in Greensboro, North Carolina, to determine attitudes, ridership levels, and motivations for transportation choice; they found that high-crime perceived areas negatively affect ridership, even though the bus service is perceived as quite safe. Another study evaluating the overall safety of public transit taking into account also risks of terrorist attacks (Litman 2005) shows that "transit is an extremely safe mode with total per-passenger-mile fatality rates approximately one-tenth that of automobile travel". Nathanael (2008) defines safety during the trip as the number of passenger fatalities caused by the transit operator's responsibility. A study from Ma et al. (2010) aims to identify crash risk factors associated with demographic characteristics and the behavior of drivers of public transportation vehicles; the study underscores that "drivers' attitudes toward rule violations and speeding significantly affect risky driving behaviors".

2.2.3 Convenience

The convenience of the public transportation service is mainly referred to the travel cost and to the simplicity of paying. Algiers et al. (1975) investigated the impacts of suggested changes in travel comfort, convenience and waiting times. A study from FitzRoy and Smith (1998) highlighted that the introduction of integrated ticketing systems concurs to increase ridership on public transportation. Murray (2001) found that specific strategic approaches could improve the convenience of the public transportation service, and hence higher regional utilization of public transportation. Some policies have been shown to be effective in influencing car use and reducing its frequency when properly targeted at a specific market segment, making public transportation more convenient (Beirão and Sarsfield Cabral 2007).

3 Methodology

3.1 Assessing service quality attributes

The main factors involved in the determination of transit service performances are determined significantly by the perspective considered (customers or transit agencies) (Transportation Research Board 2013). Many researchers (i.e. Berry et al. 1990) consider the customer's point of view the most relevant for evaluating transit performances. Indeed, in the last few years, a new transport planning concept emerged not only targeted to optimize the use of the supplied capacity, but also at orienting the demand towards sustainable forms of mobility. The above described vision includes every action or set of actions aimed at influencing user choices regarding a trip and its relative modality. A part of these actions includes the

improvement of the quality of supplied services (from the user's perspective), so as to rebalance the modal rates in favor of public transportation.

For these reasons, in this paper, the indicators of service quality have been determined according to the Transit Capacity and Quality of Service Manual (TCQSM), to reflect how passengers perceive the quality of the transit service offered and provided, also taking into account the transit provider's needs and objectives.

This section presents the quality of service measures for fixed-route transit services determined for this study. The measures have been grouped into two areas: (1) availability and (2) comfort and convenience. As availability measures, the accessibility of each bus stop of the line and frequency have been considered; while, as comfort and convenience measures, crowding degree and service reliability have been determined. All the measures considered have been determined using a Decision Support System platform that is described in the next section of the paper.

3.1.1 Accessibility

Transit can occur in a number of ways (walking, cycling, auto drop-off, auto park and ride). In this paper, accessibility was considered only in terms of walking access, owing to its dominance with respect to local bus access and at destination.

As stated by TCQSM, in most cases, between 50 and 95 % of transit passengers (with an average value of 75 %) walk no farther than 400 m to reach a local bus stop. Therefore, the service coverage area of a local bus stop is defined as a circular surface with a radius of 400 m. Thanks to the great potentiality of GIS, the buffering feature of GIS software can be used to draw these circles around bus stops. For a more realistic and detailed analysis, each stop's service coverage area has been reduced in proportion to several impedance factors, taking into account, for example, the additional time spent by users to climb hills, cross busy streets, and so on. In this way, each stop is characterized by an individual service radius that, in most cases, is smaller than the distance considered initially (400 m), serving a smaller number of people and activities.

The transit stop service radius can be expressed as:

$$r_s = r_a \cdot i_{sc} \cdot i_g \cdot i_{pop} \cdot i_{pc}, \quad (1)$$

where r_s = transit stop service radius (m), r_a = ideal transit stop service radius (m), 400 m for bus stops, i_{sc} = street connectivity impedance factor, i_g = grade impedance factor, i_{pop} = population impedance factor, i_{pc} = pedestrian crossing impedance factor.

The street connectivity impedance factor (i_{sc}) is related to the configuration of the street network. It is affected by the available walking patterns, and its values are variable from 1 (in the case of a perfect grid system) to 0.45 (in the case of a low connectivity of the road network). The intermediate case is defined hybrid and assumes the value of 0.85.

The grade impedance factor i_g takes into account that the horizontal distance that pedestrians travel in a given period of time decreases as the climbed vertical

distance increases, particularly when the grade exceeds 5 %. Its values are variable from 1 (for grades of less than 5 %) to 0.65 (for grades between 12 and 15 %).

For transit stops where 20 % or more of the boarding volume consists of elderly pedestrians, the population impedance factor (i_{pop}) assumes a value of 0.85, taking into account the reduced walking distance traveled during a determined temporal interval.

Considering the pedestrian crossing impedance factor (i_{pc}), it can be assumed that wide and busy streets pose a barrier to pedestrian access to transit stops and any street crossing delay in excess of 30 s results in added travel time to reach a transit stop (Transportation Research Board 2013).

3.1.2 Frequency

Determining actual frequencies on transit routes helps planners in finding solutions to improve the level of service. Accurate passenger counts can provide ridership information useful to assess this availability measure, and then to suggest efficient frequencies and headways for a specific transit route. Indeed, most of the methods used to derive frequency on transit route are based on available load profiles that allow schedulers to evaluate the minimum expected vehicle runs when passenger loads are heavy and avoid overcrowded conditions.

The large amount of ridership data acquired from the smartphone devices were adopted as input for three methods in estimating vehicle frequencies based on *point-check* (max load) and *ride-check* (load profile) data (Ceder 2007).

The first applied method (Method 1) is called *daily max load point* method, in which the frequency (for a period j) is calculated based on the heaviest daily load point along the route as:

$$F_j = \max\left(\frac{P_{mdj}}{d_{oj}}; F_{mj}\right), \quad (2)$$

where P_{mdj} = average observed load at the daily max load point at period j , d_{oj} = desired occupancy on the vehicle at period j , F_{mj} = minimum required frequency (reciprocal of policy headway) for period j .

The second *point-check* method (Method 2) is based on the max load observed in each time period (*hourly max load point* method). According to this method, the number of vehicles required for period j is:

$$F_j = \max\left(\frac{P_{mj}}{d_{oj}}; F_{mj}\right), \quad (3)$$

where P_{mj} = maximum observed load (across all stops) in each period j .

In order to consider the load variability among the transit stops, the additional information supplied by the load profile obtained through the smartphone application were also used to determine the frequency standards based on passenger-km rather than on a max load measure. A lower-bound level on the frequency is considered in the *load profile* method (Method 3) used in this paper. According to this method, the frequency for period j is determined as:

$$F_j = \max\left(\frac{A_j}{d_{ojL}}; \frac{P_{mj}}{c}; F_{mj}\right), \quad (4)$$

where A_j = area in passenger-km under the load profile during period j , L = route length, c = capacity of a vehicle (number of seats plus the maximum allowable standees).

3.1.3 Crowding degree

The passenger load on a transit vehicle affects the comfort inside the vehicle in terms of seat availability and the crowding level within the vehicle (from a passenger perspective). On the other hand (from a transit operator's perspective), a poor quality of service can result in an increase of service frequency or vehicle size to reduce crowding and increase passenger comfort.

For transit vehicles designed for mostly seated passengers, passenger load can be defined by the number of passengers per seat. For transit vehicles designed for mostly standing passengers, the on-board level of crowding can be expressed as the average standing passenger space (expressed in square meters per passenger). TCQSM provides an indication of the quality of service, considering different levels of crowding both for vehicles designed for mostly seated passengers and vehicles designed for mostly standing passengers.

The crowding degree of a bus is a critical element that must be taken into account to increase the attractiveness of a public transportation system. Indeed users perceive the degree of crowding at each bus stop as a positive or negative influence on the bus run total travel time and in general on service quality level (Tirachinia et al. 2013). The comfort level, expressed in terms of crowding degree, must be evaluated based on the number of seats and standing places available on each vehicle used for the service.

Commonly, load-profile data are gathered every specific time interval along the entire length of the transit route (ride check); however, passenger-load information can also come from one or more selected stops along that route's segment where the heaviest loads occur (point check).

As described in the previous section, the crowding degree is affected by passenger loads, obtained from the calculation of passengers' pick-ups and drop-offs manually entered by the user for each stop (Fig. 3.3). In this step, the user's task is supported by the *Digital Bus Ride* application for Android smartphones. A user-friendly interface has been implemented which greatly simplifies the passenger count, generating dynamic loads automatically by difference of total pick-up and drop-off counts.

3.1.4 Reliability

There are several different measures of reliability in the literature. The most common of these is the *on-time performance* measure, defined as the percentage of schedule deviations (the difference between actual departure and scheduled departure) that fall within a defined range (TCQSM defines *on-time* as a departure

from a timepoint as 1 min early to 5 min late or an arrival at the route terminal up to 5 min late). On-time performance has been measured at the first-to-last timepoint. It can be determined for all transit services that operate according to a published timetable, although, according to the TCQSM manual, its application is recommended for services operating at headways longer than 10 min. This measure can be derived from measured bus departure times, tracking the bus during its path using a GPS-based technology. For the determination of service performances in terms of reliability, TCQSM presents the passenger and operator perspectives for different ranges of on-time performance.

Investigating transit travel time variability provides other reliability measures including the *standard deviation* of actual transit times and the *coefficient of variation*. Standard deviation of actual transit times is widely considered as a good criteria for the route's reliability estimation (Turnquist and Bowman 1980; Robinson and Polak 2007); however, the coefficient of variation of route travel time is more appropriate when examining routes or route sections of different length (Mesbah et al. 2012).

The monitored service reliability is expressed using the on-time performance and coefficient of variation measures. The first indicator is obtained by dividing the number of on-time departures and the total number of departures at each stop of the considered bus route. A statistical analysis of early and late departures was also assessed to better understand the results expressed in terms of this reliability measure.

The dataset used for the determination of on-time performance measure was obtained by the use of the smartphone application *Digital Bus Ride*. The application, thanks to the embedded GPS sensor, recorded the departure time at each stop in Unix Timestamp format. Each measured departure time, suitably converted to date format, was compared with the scheduled departure time at a stop level.

A second measure of reliability was assessed in this paper to integrate the comparison between actual and scheduled performance (expressed as on-time performance measure) with the measure of the variability of actual transit times. Specifically, the service reliability was assessed in terms of standard deviation of actual transit times (SD) and coefficient of variation (CV).

$$SD = \sqrt{\frac{\sum_{i=1}^n (tt_i - \bar{tt})^2}{n}}, \quad (5)$$

where tt_i = transit time for run i , \bar{tt} = average transit time.

$$CV = \frac{SD}{\bar{tt}}. \quad (6)$$

As the coefficient of variation of travel time is directly proportional to the standard deviation (SD), the smaller the coefficient the more reliable the service.

The process of geo-referencing requires further validation phases based on visual feedback of aerial cartography and map matching on the route. The GIS software utilized was QuantumGIS, which has several plugins available for data processing,

including GRASS GIS, commonly referred to as GRASS (Geographic Resources Analysis Support System), a free Geographic Information System software suite used for geospatial data management and well known to the scientific community as the major open source tool for geospatial data management.

The framework allows generating a dataset according to General Transit Feed Specification (GTFS), which defines a common format for public transportation schedules and associates geographic information usable in an interoperable way.

3.2 Decision support system framework

In order to detect the transit quality of service parameters automatically, an application for smartphones (*Digital Bus Ride*) has been developed using the Android software development kit. Android software development is the process by which new custom applications for the Google smartphones operating system are created. The main advantage of a custom smartphone application is to allow the user to achieve the precise perception of the parameters captured during a bus run.

The Google location service available in the development kit provides a framework that automatically handles location, smartphone movement and location accuracy in relation to the location provider used. In fact, a location-aware application can obtain coordinates using GPS and the smartphone network location provider as well (Zandbergen 2009; Bierlaire et al. 2010; Zandbergen and Barbeau 2011). Although the smartphone network provider determines location using a cell tower and Wi-Fi signals, it responds faster and uses less battery power. GPS is most accurate and the level of accuracy allows a proper calculation of transit quality parameters.

With the purpose to achieve the best results in terms of accuracy of the survey, the developed application allows the geo-referencing of bus runs exclusively through GPS location strategy. In order to achieve satisfactory results in the survey, it is necessary to ensure high charge levels of the smartphone battery and a startup time of the smartphone application due to the GPS fixing required time interval (however, the total time does not exceed 2 or 3 min). Power consumption of smartphones has been well investigated over the years, especially referred to location based services (Carroll and Heiser 2010; Mane and Khairnar 2013; Huang et al. 2015). Recently, energy management systems have been improved in software and hardware elements to better control the energy efficiency of the smartphones (Paek et al. 2010; Oshin et al. 2012; Hans et al. 2015; Qi et al. 2015). The proposed application is designed to maintain the appropriate charging levels of the smartphone battery during its use.

Data security and privacy have been considered in developing the platform. A disclaimer has been predisposed to be subscribed by the platform users; the main focus of the disclaimer is on the acceptance of the user's localization. Moreover, each user is profiled, and an individual secured account is assigned. Each user is then anonymously tracked and no access is available for his data except for the user himself and for the administrator. The complete procedure that leads to the acquisition of the transit quality parameters is shown in the flowchart reported in Fig. 1.

The *Digital Bus Ride* application (Fig. 2) generates a CSV (Comma Separated Values) file at the end of every route and saves it on the memory card of the smartphone, which includes the following information:

- latitude and longitude, both expressed as three rational values giving the degrees, minutes and seconds, respectively;
- altitude, that indicates the reference altitude expressed in meters as height from sea level;
- timestamp, that indicates the time as UTC (Universal Time Coordinates), expressed as a unique value in milliseconds;
- satellites, indicating the number of GPS satellites used for the measurement;
- heading, indicating the heading to the destination point;
- accuracy, expressed in meters and representing the maximum error from the real position;
- passengers pick-ups and drop-offs, manually counted and entered by the operator at each stop;

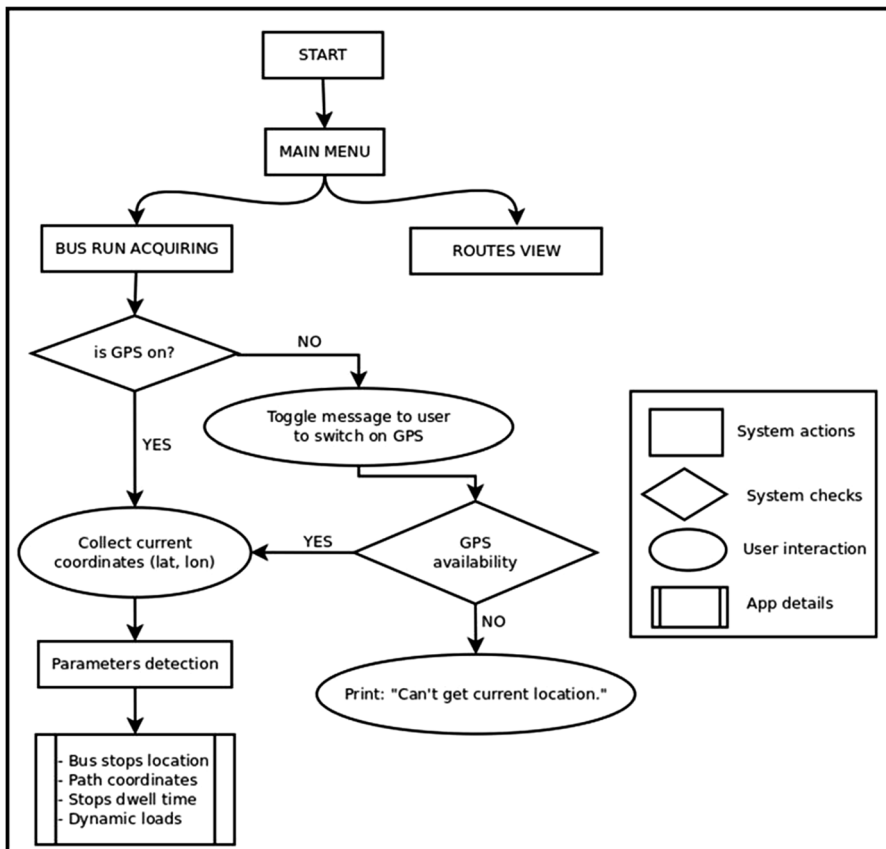


Fig. 1 Flowchart of quality of services parameters collection

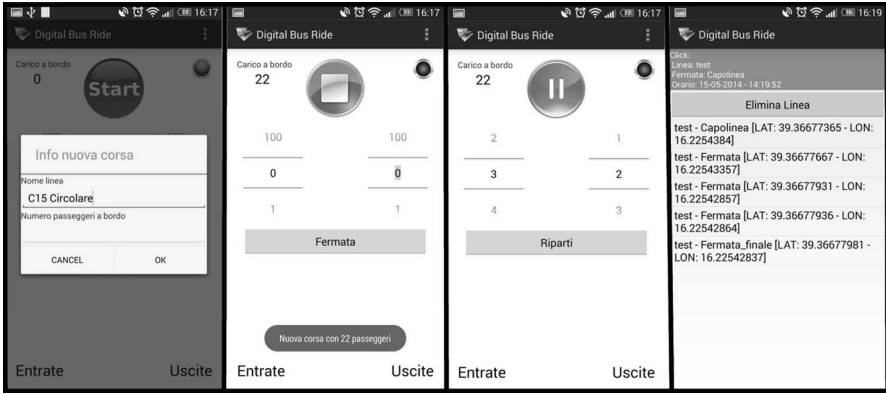


Fig. 2 Screenshot of digital bus ride application

- dynamic load, calculated by subtracting the passenger drop-offs and adding the passenger pick-ups from the number of passengers at the previous stop.

The data collected through the smartphone application and stored in the CSV file are processed through several GIS operations in order to evaluate the level of the Transit Quality of Service parameters.

The first operation relates to the identification of stop locations and bus routes. Stop locations are deducted in post-processing from latitude and longitude information, after cutting the outliers identified by satellite and accuracy data. In

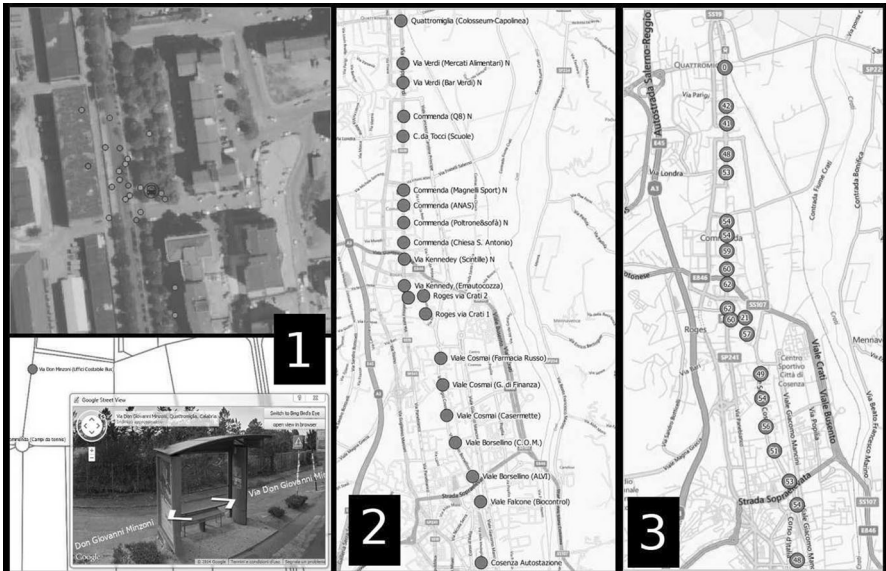


Fig. 3 Stop locations (1, 2) and passenger loads (3) visual feedback

particular, positioning data with less than 5 satellites or with an accuracy value less than 20 m were considered outliers. These ranges have been identified as values associated with points recorded out of the way of the bus path, usually caused by dense vegetation or urban canyon. At last, a set of centroids of convex polygons constructed on point clouds recorded along every path have been identified, as representatives of bus stops. For visual feedback, aerial mapping and “Google Street View” GIS plugin have been used (Fig. 3.1, 2).

Bus routes are obtained tracking the GPS signal from the terminal to the last bus stop entered during the survey. Latitude, longitude and heading included in the CSV file are used in GIS to build the full path traveled by the bus and represented as a shapefile (Carstensen 2013; Randall et al. 2005; Stopher et al. 2005; Stenneth et al. 2011; Ma and Wang 2014; Vija and Shankari 2015).

4 Case study

An application of the proposed methodology was carried out for a bus route of the conurbation of Cosenza-Rende, in the Calabria Region.

Public transport in Calabria is almost exclusively by bus. The local by bus public transport supply is in slow, but continuous growth. The public transport services supply system presents an extensive series of critical points, which concur to create complexity and low quality of service or, if one prefers, to configure a supply system no longer in step with the expectations and needs of the users.

In the urban context, globally, 9000 daily home-to-work trips were recorded. The global daily home-to-school trips, instead, amounted to 3065. Regarding the modal choice, for home-to-work trips the individual mode is in net prevalence (as driver or as passenger), with a percentage of 70.2 % (with a percentage for the bus choice of 29.8 %); for the home-to-school trips the public transport mode is characterized by a higher percentage of 36.5 % (63.5 % of the users choose to travel using individual modes of transport).

The analysis was carried out on the route Cosenza-Quattromiglia. Considering as origin Cosenza and destination Quattromiglia, the route length is 6.36 km with 20 stops. For the opposite direction the route length is 9.94 km with 29 stops. The overall service productivity (Vuchic 2007) is characterized by 278,862 bus \times kilometers per year (bus \times km/year), 23,703,283 seats \times kilometers per year (seats \times km/year) and 5,200,617 passengers \times kilometers per year (pax \times km/year).

The scheduled transit frequency is four vehicles per hour corresponding to a policy headway of 15 min. According to TCQSM, from a passenger perspective, based on the scheduled frequency, this service can be defined as a relatively frequent service, but it corresponds to the maximum desirable wait time for the next service when a bus is missed. According to the operator’s perspective, this type of service is often branded as “frequent service” in conjunction with long service hours and is typically the longest feasible off-peak headway that would justify light rail or BRT service. The application of the DSS platform to the case study provided point-check and ride-check data useful to assess the most suitable frequency (vehicles/hour) for the analyzed route.

The scheduled number of hours of service is about 15 h. This measure, according to the TCQSM, from a passenger perspective, indicates a service provided late into the evening and early in the morning, allowing a broad range of trip purposes to be served (e.g., night classes, retail and industrial employee work trips, social and entertainment trips, early morning flights/train trips). From an operator's perspective, this service can require more than two full-time drivers per vehicle or overtime pay and, for the evening, the service may be operated on a different set of routes than those for the rest of the day.

The surveys were conducted on 17–26 March and 1–3 April 2014, for a total of 13 days. For each day of the survey, all rides were analyzed in order to have a sufficient coverage of the dynamic passenger load during the entire daily service period.

The operator detected dynamic load (pick-ups and drop-offs passenger counts) at each stop, with the aid of a smartphone application, for each monitored bus run. The embedded GPS chip on the smartphones enabled the geo-referencing of all the bus stops and the real path of the vehicle on the road network tracking location with a frequency of 1 Hz, which determined a data rate of one data point per second.

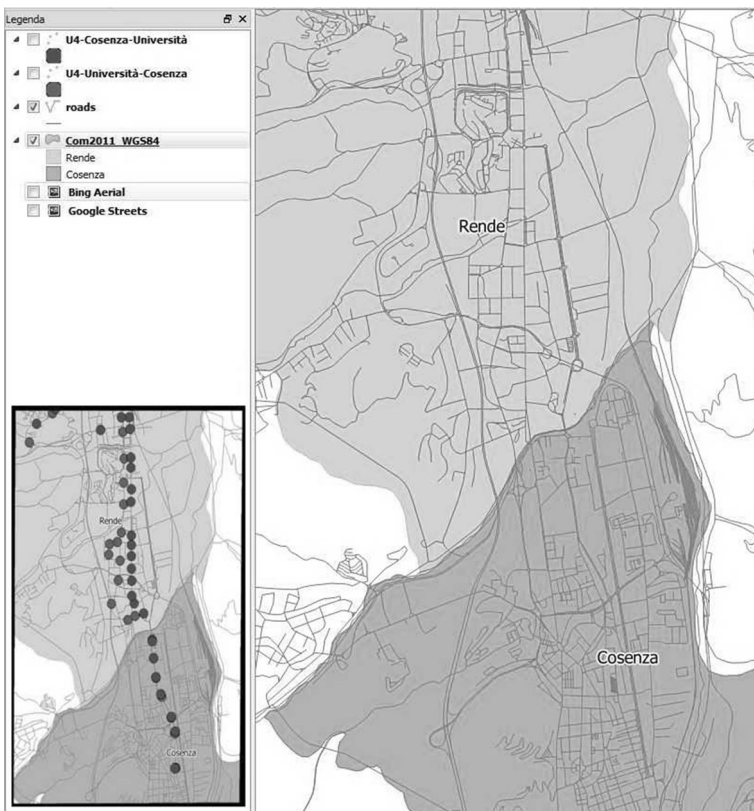


Fig. 4 Street connectivity factor determination on quantum GIS

At the end of every bus run, the logged data stored on smartphones was loaded on the desktop GIS framework for spatial analysis, related to the calculation of service quality attributes.

5 Results analysis

Considering accessibility, as can be seen from Fig. 4, the street connectivity impedance factor assumes the value of 1 for the portion falling within the Municipality of Cosenza with a street connectivity type *grid*, and it assumes the value of 0.85 for the portion falling within the Municipality of Rende with a *hybrid*-type street connectivity, according to the TCQSM as mentioned in Sect. 3.

Regarding the grade impedance factor (i_g), as in proximity to all the stops there are no roads with slope greater than 5 %, set equal to 1, does not affect the transit stop service parameter in the multiplicative formula as the neutral element for multiplication.

The population impedance factor, according to the ISTAT data warehouse, the official up-to-date database on the resident population in Italy, is set equal to 1 for Rende with an elderly pedestrian rate of 20 %, and 0.85 for Cosenza with an elderly pedestrian rate of 22 %.

The factor related to pedestrian crossings was set equal to 0.85 when there are traffic lights in proximity of each bus stop and 1 when not.

Once obtained the value of transit stop service radius for each stop, a buffer operation in Quantum GIS was performed. By the overlapping of the two different layers, one relating to the ideal transit stop service radius (400 m) and the other relating to transit stop service radius calculated as in Eq. 1, it is possible to estimate the difference in surface for each sub-route (Fig. 5).

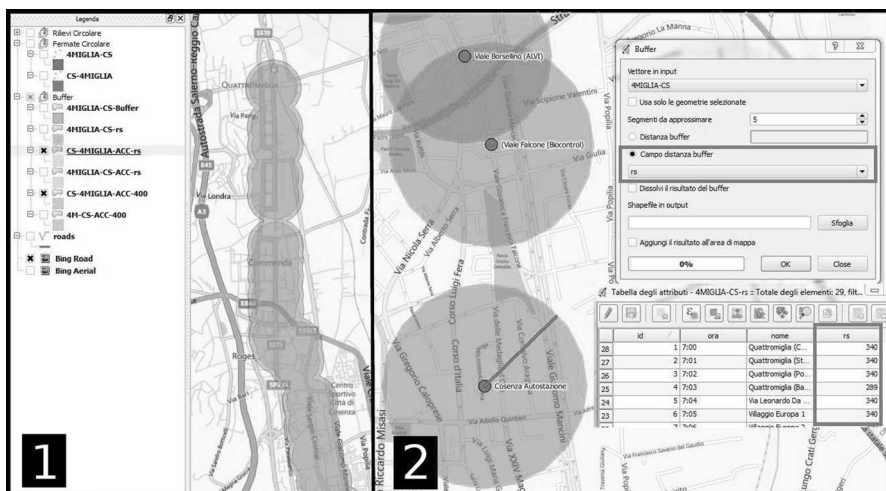
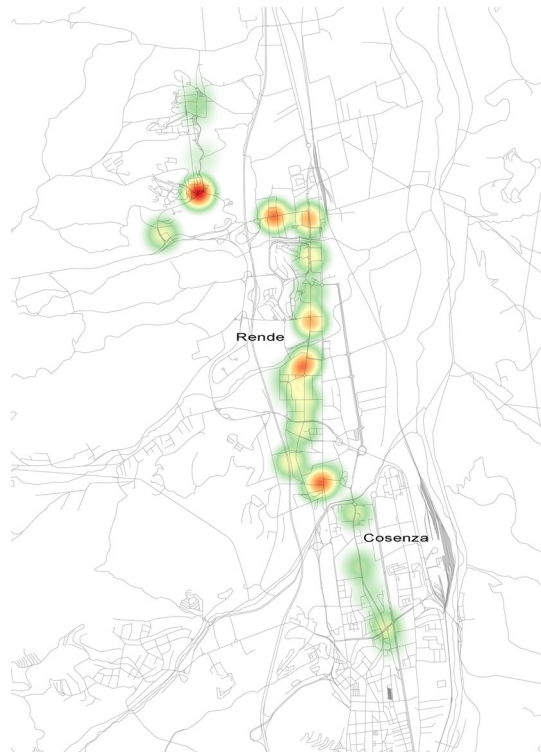


Fig. 5 Visualization of bus stop accessibility

Bus stop accessibility could also be represented by using heatmaps offering a simple visualization of the coverage of the city areas by the public transport network ready for use with mobile and web applications. Heatmaps can be adopted to represent some spatial analyses for assessing other transit service quality parameters (i.e. transit times, dwell times, waiting times, etc.). An example of heatmap application is shown in Fig. 6 representing the coverage of a single bus route in the case study area. It is evident that the coverage of a single route is not representative of the accessibility of the whole public transport network; it would be appropriate to extend the analysis to all the bus routes.

From the GIS software analysis, the calculated service coverage area results are about 19 % smaller than the ideal service coverage area for both directions of the route considered. The detailed service coverage method was used to identify the effective area served by each bus stop, bearing in mind the street pattern, the difficulty pedestrians have crossing streets, and other factors. The contribution of each factor allows the calculation of the reduction in the coverage area, compared in a sequential step with the ideal area. The difference in surface of the two different sizes of coverage areas is about 19 % for both directions of the Cosenza-Quattromiglia route. According to the Transit Capacity and Quality of Service Manual, from a passenger perspective, most destinations within higher-density areas are served, but not all. The same results, from the operator's perspective, correspond to balance coverage and cost-efficiency objectives.

Fig. 6 Bus stop coverage heatmap for the Quattromiglia-Cosenza route



The level of passenger comfort was evaluated in terms of square meters per passenger. For this analysis, rides that were taken into account were chosen considering the peak period runs, coinciding with the beginning/ending of hours of work and entry and exit from schools (8:00 am, 12:15 and 6:15 pm), and the off-peak runs (9:45 am, 3:45 pm). Considering that, on average, a seated passenger occupies an area of 0.4 m² and a standing passenger occupies 0.24 m², according to the TCQSM, the indicator representing the level of passenger comfort was calculated in terms of square meters per passenger.

For the case study, the passenger load for each bus run was detected manually by the user. These counts were combined to perform the analysis on crowding degrees and frequency standards.

Figures 7 and 8 show a sample of load profiles obtained from a peak hour (8–9 am) and an off-peak hour (10–11 am).

The results show that the crowding degree ranges from 0.47 to 1.54 m²/p. In the different timeframes considered for this analysis, the critical value (less square meters per passenger) is 0.47 m²/p that, compared with the values recommended from the TCQSM, fall into the range 0.40–0.49 m²/p. This result highlights a good level of comfort that in the passenger perspective translates into standing load without body contact and for standees a similar amount of personal space to seated passengers.

The frequency determination methods described in the previous section were applied to the case study route based on the observed load profiles and the vehicles features (capacity = 84 pax; policy headway = 15 min; desired occupancy on the vehicle = 29 pax). Table 1 shows frequencies (F) and headways (H) calculated for six periods (from 8 am to 2 pm) according to Methods 1, 2 and 3.

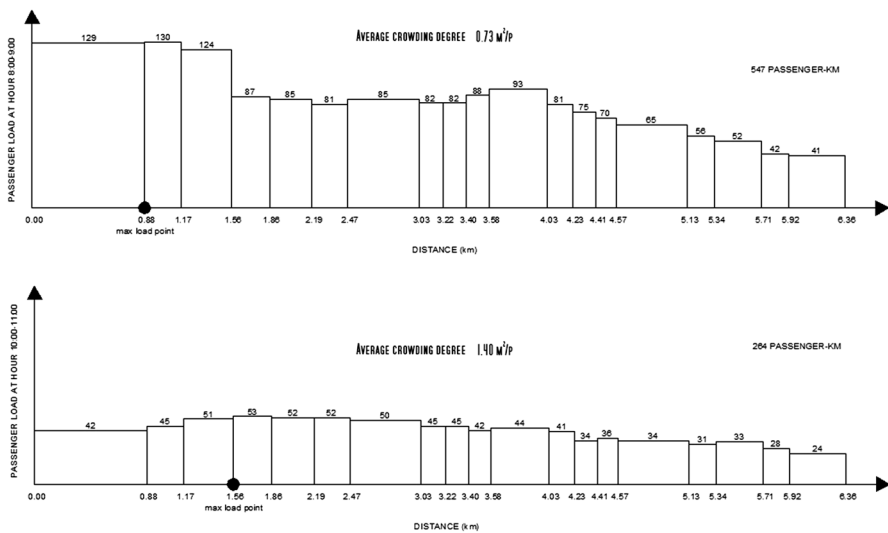


Fig. 7 Load profiles from Cosenza-Quattromiglia route (8–9 am, 10–11 am)

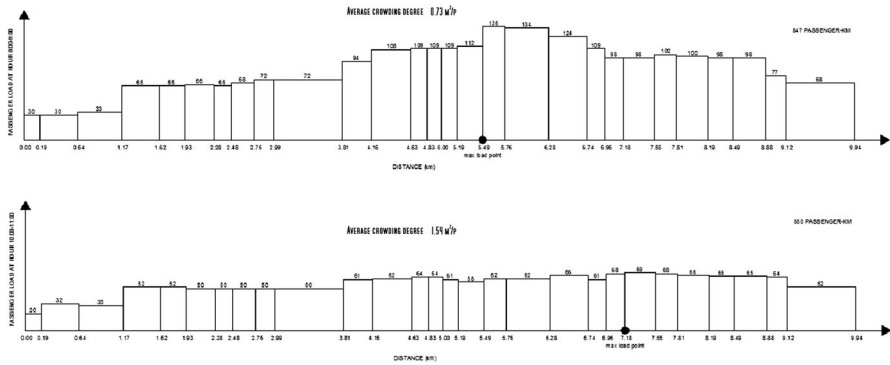


Fig. 8 Load profiles from Quattromiglia-Cosenza route (8–9 am, 10–11 am)

Table 1 Frequency and headway results for Cosenza-Quattromiglia route in both directions (from 8 am to 2 pm) according to Methods 1, 2 and 3

| Period | Method 1 | | Method 2 | | Method 3 | |
|------------------------------|-----------|---------|-----------|---------|-----------|---------|
| | F (veh/h) | H (min) | F (veh/h) | H (min) | F (veh/h) | H (min) |
| Cosenza-Quattromiglia | | | | | | |
| 8–9 am | 4.3 | 14.0 | 4.5 | 13.4 | 4.0 | 15.0 |
| 9–10 am | 4.1 | 14.5 | 4.1 | 14.5 | 4.0 | 15.0 |
| 10–11 am | 4.0 | 15.0 | 4.0 | 15.0 | 4.0 | 15.0 |
| 11 am–12 pm | 4.0 | 15.0 | 4.0 | 15.0 | 4.0 | 15.0 |
| 12–1 pm | 4.0 | 15.0 | 4.0 | 15.0 | 4.0 | 15.0 |
| 1–2 pm | 4.3 | 14.0 | 4.3 | 13.9 | 4.0 | 15.0 |
| Quattromiglia-Cosenza | | | | | | |
| 8–9 am | 4.7 | 12.8 | 4.7 | 12.8 | 4.0 | 15.0 |
| 9–10 am | 4.5 | 13.3 | 4.7 | 12.8 | 4.0 | 15.0 |
| 10–11 am | 4.0 | 15.0 | 4.0 | 15.0 | 4.0 | 15.0 |
| 11 am–12 pm | 4.0 | 15.0 | 4.0 | 15.0 | 4.0 | 15.0 |
| 12–1 pm | 4.0 | 15.0 | 4.0 | 15.0 | 4.0 | 15.0 |
| 1–2 pm | 4.0 | 15.0 | 4.0 | 15.0 | 4.0 | 15.0 |

As highlighted in Table 1, actual transit service could be improved for heavily travelled route hours (peak periods) based on daily max load point method (method 1) and hourly max load point method (Method 2). The peak-load factor Method 2 yields upper bounds for the frequency, especially for heavily travelled route hours in peak periods, while the load profile method (Method 3) yields lower bounds for frequency values, coinciding with those adopted by the agency. These results suggest that the agency has correctly scheduled the vehicle runs on the analyzed route avoiding overcrowding.

Table 2 On-time performance parameter evaluation

| On-time performance Cosenza-Quattromiglia | |
|---|--------|
| On-time departures | 358 |
| Early departures | 58 |
| Late departures | 133 |
| Total departures | 549 |
| Indicator | 0.65 |
| | 65.2 % |
| On-time performance Quattromiglia-Cosenza | |
| On-time departures | 459 |
| Early departures | 129 |
| Late departures | 129 |
| Total departures | 717 |
| Indicator | 0.64 |
| | 64.0 % |

The evaluation of reliability was performed measuring on-time performance parameter. As shown in Table 2, the route performance in terms of reliability reported less than 70 % of on-time performance, identified by the TCQSM as a service perceived by passengers as highly unreliable. From the operator's perspective, this result may be the best possible for mixed traffic operations in congested city centers.

As observed during the survey, the cause of this result could be attributed to 10.6 and 18.0 % of early departures for Cosenza-Quattromiglia and Quattromiglia-Cosenza routes, respectively, and to 24.2 and 18.0 % of late departures. Indeed, a total of 187 departures left more than 1 min early with respect to the scheduled time and are also considered not-on-time. The main cause of the delay is essentially due to high levels of traffic congestion on the bus route (there is an absence of bus priority lanes). Table 3 shows statistics for early and late departures.

A more in-depth analysis was performed to investigate the variability of the travel time as a measure of transit operational performance. As previously defined, travel time reliability was assessed in terms of standard deviation of actual transit times and coefficient of variation. Table 4 illustrates the results obtained from the analysis of travel time variability as introduced in Sect. 4.

Table 3 Early and late departures statistics

| | Early departures | | | Late departures | | |
|--|------------------|---------------|----------|-----------------|---------------|----------|
| | # (%) | Average (min) | SD (min) | # (%) | Average (min) | SD (min) |
| Cosenza-Quattromiglia (20 stops–6.36 km) | 58 (10.6) | 1.96 | 0.66 | 133 (24.2) | 7.74 | 3.16 |
| Quattromiglia-Cosenza (29 stops–9.94 km) | 129 (18.0) | 2.43 | 1.39 | 129 (18.0) | 12.69 | 4.94 |

Table 4 Analysis of transit times variability

| | Scheduled (min) | Average (min) | Median (min) | SD (min) | CV |
|---|-----------------|---------------|--------------|----------|------|
| Cosenza-Quattromiglia (20 stops–6.36 km) | 26.00 | 22.71 | 22.16 | 3.05 | 0.13 |
| Quattromiglia-Cosenza (29 stops–9.94 km) | 29.00 | 32.35 | 31.71 | 3.95 | 0.12 |

Results illustrated in Table 4 show that the coefficient of variation of transit times related to the entire route ranges from 0.12 to 0.13, indicating good reliability for the analyzed routes. These results seem to be in contrast with the analysis related to the on-time performance; however, actual transit times differ systematically from the scheduled ones as we have observed during the survey. This suggests to use different measures of reliability for the same case study to avoid an incorrect assessment of the level of service for a transit system.

6 Conclusions

This paper outlines a methodology based on a Decision Support System that combines smartphone and GIS technology to analyze operational performance and reliability of a bus route. In order to detect several quality of service transit parameters automatically, through a GPS location strategy, an application for smartphones was developed (Digital Bus Ride). The dataset collected from the smartphone application was transferred to Quantum GIS Platform to take advantage of the powerful potentialities in spatial analysis. The entire platform was developed via Open Source, which means rapid bug-fixes and increased reliability, with the possibility of additional future development through the modularity of the platform.

The proposed methodology was applied to a bus route in an urban context. In terms of accessibility of the provided service, the results of the study showed a calculated service coverage area 19 % smaller than the ideal service coverage area. The availability of the transit service was also assessed in terms of frequency. Three methods based both on point-check and ride-check data were applied to estimate minimum frequency and headway standards, allowing not only for efficient frequency-setting but also for a sensitivity analysis of possible changes in planning service. For the analyzed route, results provided by these methods suggest that the agency has correctly scheduled the vehicle runs avoiding overcrowded conditions. The service is also characterized by high comfort levels in terms of crowding degree. From a passenger perspective, low levels of reliability were determined, based on on-time performance indicators; this is mainly caused by the high traffic congestion levels on the bus route. This assessment suggests that a priority lanes can be viewed as a possible intervention to increase service reliability. Nevertheless, from the operator's perspective, this result may be the best possible for mixed traffic operations in congested city areas. The variability of the transit time was

investigated as a further measure of transit operational performance in terms of standard deviation of actual transit times and coefficient of variation.

The information provided by the GPS chip of the smartphone can be translated into reliable indicators that will allow decision-makers to monitor bus service operational performances over the network. The high proportion of smartphones among users and the disaggregation capability of the proposed tool in both space and time, is very useful for generating and prioritizing actions by identifying operational problems at the required level of detail, with a non-intrusive approach. Indeed the physical installation of on-board instruments is not required. Moreover, once set up, the platform architecture guarantees an easy-to-use framework and a high level of scalability to other transit systems and application contexts.

The proposed DSS is directly addressed to operators and managers who, despite not having the availability of AVL data, can assess their performance based on data provided by this platform and make appropriate changes for improving service's quality, and hence increasing the ridership potentials. On the other hand, passengers can be involved in the processes, being DSS based on the use of smartphones as a pro-active method of collecting data aided by mobile technologies. Furthermore, reliability and availability performances can be assessed based both on operators and passenger perspective as discussed in the previous sections.

Information systems such as the one presented in this paper can improve the efficiency of the smaller transit agencies that need to maintain or increase their performances. Particular attention must be paid on new technologies that can provide more economical and more sustainable solutions for real-time information systems.

At this stage, some measures are manually done; however, the authors are developing a tool based on a Raspberry platform with a camera module that can be mounted on-board to acquire some data (e.g. pixel data). These data can be processed by a specific algorithm (based on an OpenCV library) to detect, for example, dropping off and picking up passengers useful to validate the proposed methodology. Hence, future efforts will focus on the automation procedures, by applying video or GSM detection technologies, and real-time information systems.

Furthermore, the authors are developing a new feature that allows automatically tracking all the access/egress paths to transit service. This feature could improve the DSS capacity to support public transportation strategic planning for large scale application.

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