Performance indicators for an objective measure of public transport service quality

Laura Eboli[1*], Gabriella Mazzulla[1*]

[1]*Department of Land Use Planning, University of Calabria*

Abstract

The measurement of transit performance represents a very useful tool for ensuring continuous increase of the quality of the delivered transit services, and for allocating resources among competing transit agencies. Transit service quality can be evaluated by subjective measures based on passengers' perceptions, and objective measures represented by disaggregate performance measures expressed as numerical values, which must be compared with fixed standards or past performances. The proposed research work deals with service quality evaluation based on objective measures; specifically, an extensive overview and an interpretative review of the objective indicators until investigated by researchers are proposed. The final aim of the work is to give a review as comprehensive as possible of the objective indicators, and to provide some suggestions for the selection of the most appropriate indicators for evaluating a transit service aspect.

*Keywords:*Service Quality, Public Transport, Objective Indicators.

1. Introduction

Transportation system is a source of considerable environmental damage affecting a wide range of receptors, including human health, flora and fauna, and the built environment. The main environmental effects concern air pollution, climate change, noise, impacts on nature and landscape, soil and water deterioration; other effects include, as an example, visual intrusion in cities (Bickel et al., 2006).

Mobility demand of people living in urban and metropolitan areas is continuously growing because of the desire to participate in increasingly varied activities motivated by physiological, psychological and economic needs. Interdependencies among activities entail complex travel choices involving the generation of trip-chains and travel patterns. In order to satisfy this ever-changing mobility demand, people tend to use individual motorized transport modes (Cirillo et al., 2011). Nevertheless, the continuing trend of modal shift in favour of the private car produces the increase of environmental

* Corresponding author: Laura Eboli (laura.eboli@unical.it)
* Corresponding author: Gabriella Mazzulla (g.mazzulla@unical.it)

externalities, while these impacts have to be reduced in order to make the transport sector more environmentally sustainable (Rienstra and Vleugel, 1995). Making progress towards more sustainable transportation systems and mobility patterns, and at the same time increasing the economic prosperity and quality of life, are policy aims shared by countries (Gudmundsson, 2001).

Recently, transit has been called on to contribute to improve air quality in many major urban centres and to have a transportation system that is balanced, efficient, and intermodal. An effective transit system can make contributions toward improving the environment, thus elevating itself in the hierarchy of funding decisions (Transportation Research Board, 1994). Modal substitution represents hence an important strategy of demand management for the achievement of a sustainable transportation; this can be accomplished by providing better modal options (Deakin, 2001), such as transit systems characterized by high quality levels.

In order to ensuring continuous improvement of the delivered transit services, performance measures are an essential tool for focusing transit agencies on their strategic goals. Performance measures can be useful also for the allocation of funds but, for this aim, a more thorough understanding of the applicability and appropriateness of performance measures to different types of transit systems is necessary (Transportation Research Board, 1994).

There is a variety of performance measures developed for describing different aspects of the transit services. Transit performance measures can refer to the passenger, agency, and/or community’s point-of-view. Passenger’s viewpoint reflects the passenger’s perception of the service. The agency point-of-view reflects transit performance from the perspective of the transit agency as a business. The community’s point-of-view measures transit’s role in meeting broad community objectives. Measures in this area include measures of the impact of a transit service on different aspects of a community, such as employment, property values, or economic growth. This viewpoint also includes measures of how transit contributes to community mobility and measures of transit’s effect on the environment. Perceived performance of a transit service from the passenger’s point of view can be defined as quality of service (Transportation Research Board, 2003b).

The aim of this research work is to provide an interpretative review of the different performance indicators adopted for measuring transit service quality in an objective way.

The paper is organized as follows. The next section aims to give an extensive overview of the various transit performance measures. Then, we provide a summary of the different sources of data which can be used for calculating objective service quality measures, and the main methods that agencies use to develop standards or target values. After that, we attempt to provide a compendium of the traditional and not traditional objective service quality indicators which allow the transit service aspects to be analysed and the service performances to be monitored, by particularly referring to bus services. We also provide a literature review of the studies focused on this kind of service quality measures, and indicate standard values for some indicators analysed in the research work. Finally, we conclude with a general discussion of the research findings.

2. Transit performance measures

Performance measurement can be defined as the assessment of an organization's output as a product of the management of its internal resources (money, people, vehicles, facilities) and the environment in which it operates (Transportation Research Board, 1994, 2004b). Performance measurement is very useful for different aims: assisting in evaluating the transit system's overall performance, assessing management performance expectations of the transit system in relation to community objectives, assessing management performance and diagnosing problems such as disproportionate cost in relation to service, allocating resources among competing transit properties, providing a management control system for monitoring and improving transit services, facilitating the accountability sought by government funding agencies and demanded by legislators, regional and transit authority boards, and the general public.

Performance in general terms refers to any evaluation or comparison measure. A performance measure can be considered as a quantitative or qualitative characterization of performance. Each of these measures has certain indicators that are used to signify transit performance for each particular measure. A performance indicator is more specifically a performance measure used to document progress toward a performance goal, and to monitor performance. A review of the literature on transit performance reveals that not all agencies use the same terms for performance measures (e.g. Fielding, 1987). In addition, views of performance-based allocation and how indicators are calculated vary tremendously. Therefore, in the literature, there are various classifications of the transit performance measures, some are more schematic, and others more articulate.

As an example, the TCRP Report 88 (Transportation Research Board, 2003a) proposes a classification which considers indicators of cost-efficiency, defined as the measure of service output compared to unit of input (cost), cost-effectiveness, defined as the measure of outcome compared to unit of input in terms of cost, and service-effectiveness, which is the measure of outcome compared to unit of input in terms of service.

According to Litman (2009) there are three general types of performance indicators: measures of service quality, which reflect the quality of service experienced by users; indicators of outcomes, which reflect outcomes or outputs; indicators of cost efficiency, which reflect the ratio of inputs (costs) to outputs (desired benefits).

A classification more oriented to the agency's point of view is proposed by Dalton et al. (2000) who consider input, output, or outcome measures. Input measures look at the resources dedicated to a program (e.g. spent money, kilometres of pavement placed); output measures look at the products produced (e.g. materials consumed, kilometres of lanes); outcome measures look at the impact of the products on the goals of the agency (staff time consumed, hours of bus service added, reduced travel time). Outcome measures are preferred because they directly relate the agency's strategic goals to the results of the activities undertaken to achieve them; however, these measures might not be evident until months after product delivery and can be difficult to define.

Meyer (2000) classifies the performance indicators into three more comprehensive categories. A first category is represented by general performance indicators such as service area population, passenger trips, vehicle kilometres and hours, and so on. The second category is represented by the effectiveness measures including the following subcategories: service supply (passenger trips per capita, passenger trips per hour); quality of service (average speed, average headway, number of incidents); availability (weekday span of service, route kilometres per square kilometre). The third category includes efficiency measures divided into: cost efficiency (operating expenses per passenger trip, operating expenses per revenue hour); operating ratios (local revenue per operating expenses); vehicle utilization (vehicle kilometres per peak vehicle, vehicle hours per peak vehicle); labour productivity (passenger trips per employee); energy use (vehicle kilometres per kW-h); fare.

Also Vuchic (2007) proposes an enough comprehensive classification of performance indicators: transportation quantity or volume (number of vehicles or fleet size, fleet capacity, number of lines and network length, annual number of passengers); system and network performance (intensity of network service, average speed on a transit system); transportation work and productivity (annual vehicle-kilometres, annual space-kilometres, annual passenger-kilometres); transit system efficiency indicators (vehicle-kilometres/vehicle/year, passengers/vehicle-kilometres, daily passengers/employee, vehicle-kilometres/kilowatt-hour); consumption rates and utilization indicators (operating cost/passenger, operating cost/vehicle-kilometre, scheduled vehicles/fleet size).

A similar classification was proposed by Carter and Lomax (1992) structured in six categories of indicators: cost efficiency (cost per kilometre, cost per hour); cost effectiveness (cost per passenger trip, ridership per expense); service utilization/effectiveness (passenger trips per kilometres, passenger trips per hour); vehicle utilization/efficiency (kilometres per vehicle); service quality (average speed, vehicle kilometres between accidents); labour productivity (passenger trips per employee, vehicle kilometres per employee).

What is important and vital in the performance and delivery of a transit service depends significantly upon perspective (Transportation Research Board, 2003a). As an example, the traditional cost efficiency and effectiveness indicators can be considered as performance measures from the transit agency perspective, while they are not linked to customer-oriented and community issues, which are fundamental perspectives in the evaluation of a service (Transportation Research Board, 2003a). Many researchers consider the customer’s point of view the most relevant for evaluating transit performance; as an example, Berry et al. (1990) pointed out that “customers are the sole judge of service quality. Passengers evaluate services in many ways that may not be systematically associated with the amount of use of the service, because the measures of efficiency and effectiveness, as aggregate indicators of total output, implicitly assume homogeneity of service quality (Hensher, 2007). So, from the passenger’s point of view, transit performance must be evaluated by considering indicators of service quality (Transportation Research Board, 2003b).

Transit service quality can be measured by a range of simple disaggregate performance measures which can be used for measuring the ability of a transit agency to offer services that meet customer expectations (Transportation Research Board, 1999b). These performance measures are quantitative measures expressed as a numerical value, which provides no information by itself about how “good” or “bad” a specific result is, and for this reason it must be compared with a fixed standard or past performance. These measures can be considered as objective measures.

Service quality can be also evaluated on the basis of transit user judgements. These judgements, which can be considered a subjective measure of service quality, generally derive from the well-known Customer Satisfaction Surveys (CSS), which help transit operators to identify which service quality factors are considered the most important by their customers. Customer judgements can be expressed in terms of expectations, which represent what customers expect of the service, and perceptions, which represent what customers receive from the service (Parasuraman et al., 1985). Service quality measurement based on customer opinions allows the perceived performances of a given transit service to be analysed. The main disadvantages of this type of measure are the strong subjectivity of transit users' judgements and the failure to take non-users' perceptions into account. In addition, considerable statistical errors could occur when respondents are not correct sampled, or users' judgements are too heterogeneous. In order to minimize these problems, several researchers have proposed methodologies based on the use of SP or mixed RP-SP survey, as a consequence of their belief that passengers behavioural intentions significantly depends on the perceived value of service quality linked to their level of satisfaction. Interesting readers can take some examples in Hensher and Prioni(2002), and in Eboli and Mazzulla (2008, 2010).

In order to provide a more useful and reliable measurement tool of transit performance, current research about the topic is ever more oriented to consider both objective and subjective service quality measures (e.g. Tyrinopoulos and Aifadopoulou 2008; Nathanail, 2008). In addition, the authors experience suggests that very promising results could be obtained through the combination of the two types of measures. As an example, in Eboli and Mazzulla (2011) a methodology for measuring transit service quality is proposed which aims to develop an indicator with an intermediate value between subjective and objective measures, calculated by considering the bias of the two different measures. The final indicator was obtained by solving a problem of optimization which minimizes the distance of the desired indicator from the subjective and objective ones.

In addition to the above mentioned approaches, Zak (2011) emphasizes that there are several stakeholders interested in the efficient, comfortable, and effective operations of the transit systems; as a consequence, a conflict of interests is observed. As an example, while passengers insist on high level of transportation services, operators are focused on cost-effective operations of the transit system, as well as the authorities play a double role of a stakeholder and decision maker at the same time. In order to search for compromise solutions, Zak (2011) proposed the application of the methodology of multiple criteria decision making/aiding for public transportation analysis. This methodology enables the decision maker to take into account several contradictory points of view, and assures that the most satisfactory and compromise solution is finally selected.

Definitively, both subjective and objective transit performance measures support transit agencies for monitoring, evaluating, and implementing improvements in service. For this purpose transit agencies might be interested in collecting a wide array of information. As a result, data collection and analysis activities should be concentrated on those aspects of transit service that are crucial and that more accurately reflect the needs of customers and potential customers. The objective is to match the most important perceptions to specific aspects of transit service and to identify one or more corresponding service performance indicators (Transportation Research Board, 1999b).

3. Sources of data and performance standards

In the past, measuring transit performance was very difficult and collecting the data necessary to evaluate transit systems was very costly. A number of performance measures has been traditionally calculated from information an agency would normally have on hand for other purposes, like schedule data, system maps, service design standards, accident and incident records, financial data, fleet data, complaint records, and so on. In addition, alternative data has been provided by national transit database and other transit agencies.

Recently, as a result of the widespread implementation of Intelligent Transportation Systems (ITS) and Advanced Public Transit System technologies (APTS), data collection is no longer a limiting factor (El-Geneidy et al., 2007). Nowadays, a large amount of data is provided by Automated Vehicle Locators (AVL), which detect in real-time a vehicle's time at locations and supply schedule deviation information, and Automatic Passenger Counters (APC), which allow passenger boarding and alighting to be detected by means of infrared sensors and optical imaging. Also the commons electronic fare-boxes (as substitution of the operator trip cards) are an excellent source of ridership data because of their ability to register passenger boarding by fare category (Transportation Research Board, 2000). A specific report of the Transportation Research Board (1997) emphasizes the importance of adopting advanced technologies for improving safety, efficiency and quality of the services offered by the public transport agencies. Particularly, the report focuses on the AVL systems by examining the main aspects linked to implementation, management and maintenance of these systems on the bus lines.

Automation of data collection usually enables data to be collected quickly and efficiently, but the real value of automation is realized when speed is coupled with increased accuracy, precision, and repeatability of the data. However, automated collection methods are not always the best way to collect data (Dalton et al., 2000). In fact, some objective measures of transit performances are more appropriately derived from other different sources of data, such as manual data provided by operators, dedicated trained checkers or field supervisors. A particular form of manual data collection can be represented by the Passenger Environment Survey (PES), which generally assesses qualitative elements which are difficult to measure by any other way. In fact, PES use a "secret shopper" technique, according to which mystery riders travel through the transit system and rate a variety of trip attributes in order to provide a quantitative evaluation of factors that passengers would think of qualitatively (Transportation Research Board, 2003a).

In order to evaluate and monitor service quality, performance standards should be established for each objective measure. Alternatively, the performance indicators can be expressed in a format that provides built-in interpretation. An example of such formats is represented by Levels-of-Service (LoS) analogous to those developed by the Highway Capacity Manual for the evaluation of the road traffic flow quality levels (Transportation Research Board, 1965). Another format is represented by ratios, which are developed by dividing one individual measure by another; they facilitate comparisons between routes, areas, or agencies. Finally, index measures are adopted when service quality aspects involve a number of different factors; these indexes combine results from several other performance measures in an equation to produce a single output measure (Transportation Research Board, 2003a).

In the TCRP Report 88 six main methods that agencies use to develop standards for measures regularly tracked were defined; a combination of all the methods is suggested (Transportation Research Board, 2003a). A first method is the comparison to the annual average. The average value for each measure is determined annually, and the bus lines that fall into the lowest (and sometimes highest) groups for each measure (e.g., lowest 10th percentile, lowest 25th percentile) are identified for further action. The second method is a variation of the method described above and entails the comparison to a baseline. In this case, the value of each measure is compared to the average value of the measure in the first year when the performance-measurement system was implemented. Measures that fall below a certain percentage of the baseline value are targeted for further action. Another option is a trend analysis, or setting the standard based on the previous year's performance measure value. In this case, the standard would be expressed as improvement from the previous year (generally in percent). Measures that show worsening performance, compared to the previous year, would be targeted for further action. A method which allows customer and community issues to be considered is the self-identification of the standard values. Under this method, transit agency management sets targets based on a combination of current agency performance, professional judgment, and agency goals. The last two methods are based on the comparison to typical industry standards or to peer systems. In the first case, the agency surveys other representative agencies or finds examples of standards in the transit literature and applies an average or typical standard to its own operations. In the second case, an agency identifies other agencies with similar conditions (e.g., city sizes, fare levels, cost of living index values, or other similar criteria), and determines how well those agencies are performing in the measurement categories. Standards are based on the average values of the peer agencies for given measures, or alternatively, on some percentile value.

The concept of LoS as a measure of transit service quality was introduced in the TCRP Report 100, in which some threshold values for a selection of performance indicators were proposed (Transportation Research Board, 2003b). LoS are measured on a scale varying from the "A" level (which means high service quality) to the "F" level (low service quality). Based on the LoS methodology, Nocera (2010) proposes a tool for evaluating the performance of both private car and transit services; in the work threshold values of some parameters for six levels of service were identified.

4. Transit service aspects: a interpretative review of the objective indicators

4.1 Overview.

In the last few years, researchers showed great interest in customer satisfaction and service quality measurement, besides in the definition and implementation of service quality indicators which can be used by a transit operator in order to evaluate their performances. Primarily in the USA, the Transportation Research Board (TRB) was promoter of the Transit Cooperative Research Program (TCRP), from which some guidebooks and manuals were developed for measuring customer satisfaction in public transport (Transportation Research Board, 1999b), calculating transit performance measures (Transportation Research Board, 2003a), and evaluating transit capacity and quality of service (Transportation Research Board, 2003b). Several reports and syntheses focused on specific transit bus service aspects, like bus route (Transportation Research Board, 1995a), customer information (Transportation Research Board, 1996; 1999a), transit bus service line and cleaning functions (Transportation Research Board, 1995b).

Also in the European Union (EU) countries some programmes were encouraged, and the European Committee for Standardization (CEN) introduced a manual for measuring public transit quality, in which the categories of parameters which constitute the criteria of the benchmarking of the service were established (European Committee for Standardization, 2002). Among the various EU research and development efforts, we would like to mention QUATTRO (EU Transport RTD programme, 1998), EQUIP (EU Transport RTD programme, 2000), and PORTAL (EU Transport RTD programme, 2003). Specifically in Greece, the Hellenic Institute of Transport promoted quality control programmes for public transport operators in which a variety of performance and quality indicators were introduced and applied (Hellenic Institute of Transport, 2003; 2005).

The aspects generally describing transit services can be distinguished into characteristics that more properly describe the service (e.g. frequency of runs), and characteristics depending more on customer tastes and less easily measurable (e.g. comfort).

Starting from the various studies regarding quality determinants in public transportation the aspects mainly characterizing bus services are: service availability, service reliability, comfort, cleanliness, safety and security, fare, information, customer care and environmental impacts. Each of these aspects can be measured in many ways by considering different indicators. In the next subsections some of these indicators will be fully described, and some target values will be suggested.

4.2 Service availability.

The attributes belonging to this category of service aspects are represented by characteristics of the route of the bus line in terms of path and coverage, number of bus stops, distance between bus stops, location of the bus stops, and characteristics of the service, like service frequency, span of service, travel time, need for transfers.

TCRP Synthesis 10 (Transportation Research Board, 1995a) proposes to evaluate the characteristics of the line path through indicators of the route directness expressed in terms of the additional travel time for a one-way bus trip, or the additional travel time required over an automobile making the same trip, or a time limit increase in average travel times per passenger, or an absolute limit to the total number of path deviations. For each of these indicators TCRP Report 88 (Transportation Research Board, 2003a) suggests some standard limitations. In Eboli and Mazzulla (2011) the indicator regarding line path was evaluated on the basis of the travel speed of the runs observed during a survey period. Also in Friman and Fellesson (2009) travel speed is introduced as indicator of the line path; the authors highlight that in public transport travel speed corresponds to the perceived travel time. Nathanail (2008) introduces an indicator of the itinerary accuracy calculated as the average delay estimated for the considered network, weighted out by the number of offered seats, passenger occupancy, and itinerary length. The same author introduces a speed indicator assessed through trip duration; the indicator obtains 0 when it exceeds double the five-year average, 10 when it is less than half the five-year average, and intermediate values for intermediate cases. For buses on urban arterials, target values for travel speed were suggested in term of Level-of-service in TCRP Report 88 (Transportation Research Board, 2003a).

In TCRP Synthesis 10 (Transportation Research Board, 1995a) route coverage was considered as the spacing distance between adjoining routings. Target values for spacing between bus routes were suggested as a function of such factors as the population density of an area, the proximity of an area to the central business district (CBD), and the type of bus services or routes in operation within an area (e.g., grid versus feeder, local service versus express service, and so on). Coverage can be also considered as a measure of the proportion of a metropolitan area, corridor, or population served by transit. TCRP Report 95 suggests the presence or lack of transit service within 400 metres as a rule-of-thumb indicator of coverage (Transportation Research Board, 2004a). In TCRP Report 88 (Transportation Research Board, 2003a) route coverage is expressed in terms of route miles per square mile, and some target values were suggested for these indicators.

Another indicator regarding route characteristics refers to the stop spacing, or the distance between adjoining service stops of a path. Transit operators have developed standards regarding bus stop spacing as a part of their effort to balance the trade-off between rider convenience (stops with easy walking distances) and speed. Examples of target values of stop spacing were suggested in TCRP Synthesis 10 (Transportation Research Board, 1995a); also in TCRP Report 88 (Transportation Research Board, 2003a) target values were suggested for local bus, automated guideway transit, light rail, heavy rail and commuter rail.

Eboli and Mazzulla (2011) suggest as indicator of the bus stop location the walking distance (or time) from home to the access bus stop. In fact, the time spent in walking for reaching the bus stop defines the level of accessibility to the transit services. Therefore, a transit stop must be located within walking distance, and the pedestrian environment in the area should not discourage walking (Transportation Research Board, 2003a). As reported in TCRP Report 100, about 80% of the passengers walk 400 metres or less to bus stops; at an average walking speed of 5 km/h, this is equivalent to a maximum walking time of 5 minutes. These times and distances could be doubled for rail transit and bus express services that emulates rail transit in terms of frequent service, long stop spacing, passenger amenities at stops.

Among service characteristics, service frequency is the most distinctive aspect. Service frequency measures how often transit service is provided. It is an important factor in one's decision to use transit; in fact, the more frequent the service, the shorter the waiting time when a bus or train is missed, and the greater the flexibility that customers have in selecting travel times (Transportation Research Board, 2003a). Tyrinopoulos and Antoniou (2008) found that service frequency is the most important attribute across transit operators. Also, in Eboli and Mazzulla (2008) service frequency resulted to be the attribute with the highest weight on the overall transit service quality. The indicator regarding service frequency can be calculated as average value of the number of runs scheduled for each hour of the day. Levels-of-service were suggested as a function of the average headway among vehicles expressed in minutes (Transportation Research Board, 2003b). Friman and Fellesson (2009) propose an aggregate measure of the vehicle km per inhabitant as indicator of the service frequency and coverage. In Nathanail (2008) service frequency is assessed through the number of train-kilometres; the indicator is graded based on the comparison of actually observed values to the average value of the five-year period preceding the analysis year, and obtains 0 when no train-kilometre have been realized, 10 when they exceed double the five-year average, and intermediate values for intermediate cases.

Span of service is the number of hours during a day that transit service is provided. Hours of service can vary by day of the week, by route, and even by stop. Then, an indicator can be calculated as average value of the number of hours per day in different periods of the year (winter, summer, etc.) and/or for different routes/stops. The length of the service in a day can impact the convenience of using transit system and constrain the types of trips that the passengers are able to make by transit. The level-of-service thresholds reported in TCRP Report 100 (Transportation Research Board, 2003b) can be adopted as target values for the service span.

4.3 Service reliability.

Service reliability is one of the most investigated transit service aspects and it is considered as a very important aspect for the transit users. Turnquist and Blume (1980) define transit service reliability as “the ability of the transit system to adhere to schedule or maintain regular headways and a consistent travel time”. Strathman et al. (1999) and Kimpel (2001) agree that reliability is mostly related to schedule adherence, as well as Beirao and Sarsfield-Cabral (2007), who state that the lack of control due to the uncertainty of the vehicle arrival makes the service unreliable. Unreliable service results in additional travel and waiting time for passengers (Wilson et al., 1992; Strathman et al., 2003). As a consequence, service unreliability can lead to loss of passengers, while improvements in reliability can lead to attraction of more passengers (El-Geneidy et al., 2007). A study proposed by Eboli and Mazzulla (2010) confirmed that service reliability is one of the most important service aspect for the users. Research studies conducted in the seventies have already shown that arriving on time at destination is often seen by travellers as more important than minimizing elapsed travel time (Nash and Hille, 1968; Hartgen and Tanner, 1970). The study of Wachs (1976) found that reliability or variance in travel time is an important component of attitude toward transportation modes, and also revealed that time spent in waiting, walking, transferring modes, or parking a vehicle is consistently viewed by travellers as more onerous than time spent on board.

Public transit agencies have developed multiple indicators to measure service reliability, but the three most common measures are on-time performance, headway regularity and running time adherence (Transportation Research Board, 2003a; Lin et al., 2008).

On-time performance can be evaluated by considering the percentage of transit vehicles departing from or arriving to a location on time. The indicator is generally calculated as the ratio of the number of runs that come on time to the number of total runs. Nakanishi (1997) introduces an indicator of on-time performance as the percentage of trips departing from all scheduled time points, not including terminals, between 0 and 5 min after their scheduled departing time, as well as suggested in TCRP Report 100 (Transportation Research Board, 2003b). However, TCRP Synthesis 10 suggests to consider on-time the runs up to 1 minute early and up to 5 minutes late (Transportation Research Board, 1995a), as well as the Italian legislation (DPCM 30.12.1998).

Headway regularity can be defined as the evenness of intervals between transit vehicles. An indicator (expressed in %) is calculated as the ration of the average difference between the actual and the scheduled headway to the scheduled headway (Transportation Research Board, 2003a). The same indicator is named by Tyrinopoulos and Aifadopoulou (2008) as excessive waiting time of the passengers at the stop points; the authors calculate the indicator for each line by taking into account the outcome of the operator's scheduling process and actual measurements on site. As reported in Nakanishi (1997) a transit vehicle was considered "regular" if it is within ±50% of the scheduled interval (for intervals of 10 minutes or less) or within ±5 minutes of the scheduled interval (for intervals greater than 10 minutes). In addition, TCRP Report 100 (Transportation Research Board, 2003b) defines Level-of-service ranges for headway adherence. Reliability of runs that come on schedule can be also easily evaluated on the basis of the runs removed from the daily schedule. An indicator can be calculated as the ratio of the number of runs executed in a period of data gathering to the number of runs scheduled for the same period.

Running time adherence can be defined, analogously to the headway regularity, as the average difference between the actual and the scheduled running times compared to the scheduled running time. Also this indicator is measured in percent. Lin et al. (2008) state that the concurrent use of more indicators of service reliability can make difficult the determination of the routes having the overall worst performance; in fact, routes doing well on some measures may be poor on others. Thus, they propose one comprehensive service reliability indicator by aggregating the various service reliability measures by means of data envelopment analysis (DEA). El-Geneidy et al. (2007) introduced a regression model for estimating the amount of time it takes a bus to travel along its route as a function of several determinants of bus running time, like segment length, number of signalized intersections, number of bus stops, number of passenger boarding or alighting, departure delay, stop delay time, and so on.

4.4 Comfort.

Comfort during the journey is important for transit users, both the physical comfort regarding vehicles and comfort regarding ambient conditions on board or at stops.

Comfort on board means having soft and clean seats, comfortable temperature, not many people on board, smoothness of the bus ride, low levels of noise and vibrations, not nasty odours. These many factors are differently evaluated across different groups of users. Beirao and Sarsfield-Cabral (2007) found that habitual public transport users consider the new vehicles with air-conditioning and lower floor as "very good and very comfortable", but the overcrowding on board at peak hours is considered a problem. On the other hand, car users and occasional public transport users usually see buses as uncomfortable, overcrowded, smelly and airless. Wachs (1976) underlined that vehicle comfort is less important to the traveller's decision process than other service aspects.

Comfort at bus stops can be considered as a function of the passenger amenities provided at the stops. Amenities include shelters, benches, vending machines, trash receptacles, lighting, phone booths, and so on. The effects of particular amenities on transit passengers are not well known. Some researchers have argued that the term "amenities" implies something extra and not necessarily required (Transportation Research Board, 2003a). Iseki and Taylor (2008) found that stop and station-area amenities were ranked as the least important by the users; however, these elements provided at bus stops or stations enhance also convenience and security.

The indicator most frequently used for evaluating comfort during the journey is linked to the degree of crowding on bus. Tyrinopoulos and Aifadopoulou (2008) estimate the load of the vehicles as the number of passengers on board divided by the capacity of the vehicles. The maximum vehicles load, the mean vehicles load and the lines percentage where the load exceeds were calculated. The calculation of the maximum load is based on the sum of the passengers on board the vehicles of all the journeys examined per line segment separately. In Eboli and Mazzulla (2011) the indicator was calculated on the basis of the number of passengers per run and the number of offered seats per run, by introducing a formula in which a quadratic relationship between the indicator and the ratio of the number of passengers to the number of offered seats is hypothesized; the indicator has values close to 10 when the number of passengers is small, and to 0 when the number of passengers is equal to or higher than the number of available seats. An indicator of the load factor is proposed by the TCRP Report 100 (Transportation Research Board, 2003b), which provides separate Level-of Service thresholds for bus and rail. Passenger load LoS is based on two measures: passengers per seat when all passengers can sit, and standing passenger area, when some passengers must stand or when a vehicle is designed to accommodate more standees than seated passengers.

The common indicator linked to air conditioning on bus can be calculated on the basis of the percentage of vehicles with functioning climate control systems; the indicator can be calculated as the ratio of the number of buses with the functioning air conditioning system to the total number of buses used for the line; a trained checker could verify the functioning of the air conditioning in different days of the same time period. Similarly, Nathanail (2008) evaluates the train temperature on the basis of the existence of air-conditioning. Specifically, the grade attributed to the trains is calculated as the proportion of the wagons equipped with air-conditioning over the total number of wagons, multiplied by 10. Therefore, a value of 10 or 0 is given to a train when all or not of its wagons, respectively, are equipped with air-condition. Intermediate grades are given to the intermediate conditions.

Nathanail (2008) also introduces an indicator regarding seat comfort measured by trained checker in terms of seat-back slope, seat width, and available leg distance, as compared to the desired values. Grade 10 is given when desired values have been measured, 0 when they fall below the lowest threshold values selected by the operator, and intermediate values are given to intermediate cases.

Eboli and Mazzulla (2011) propose a methodology for evaluating the availability of furniture at bus stop based on a score assigned to each line stop on the basis of the various available amenities (e.g. shelter or benches, or both, et cetera). The indicator varies from a minimum value of 0 to a maximum value of 10; the minimum value was assigned to the stops without any kind of furniture; the maximum value to the stops with all the furniture identified in a previous step.

4.5 Cleanliness.

The indicators regarding cleanliness refer to the physical condition of vehicles and facilities, and specifically the cleanliness of the bus interior and exterior, having buses and shelters clean of graffiti, cleanliness of seating and windows, and so on. Clean buses tend to promote a good public image and help to attract and maintain ridership (Transportation Research Board, 1995b).

In TCRP synthesis 12 (Transportation Research Board, 1995b) specific recommendations regarding transit practice which could be performed by transit agencies on cleaning functions are reported. These functions include exterior washing, interior cleaning, detailed cleaning, and graffiti removal and protection. In reference to the bus exterior washing a daily frequency is recommended; also periodic detailed cleaning is recommended, although a specific frequency is not suggested. Detailed cleaning functions are typically scheduled during off-peak hours such as midday or late evenings.

Every transit agency performs the cleaning of bus interiors on a daily basis, even if only to remove coarse refuse such as bottles and newspapers. As a consequence, transit agencies could perform periodic detailed cleaning of the entire bus, which includes the interior. Depending on the agency, detailed cleaning is performed monthly, quarterly, or annually; the level of detailed cleaning depends on how much is daily done as part of the service line function.

Lastly, transit agencies could adopt specific precautions to prevent graffiti and vandalism from occurring; graffiti cleaning and removal procedures could be defined.

As an example of the indicators regarding cleanliness the frequency of interior cleaning and exterior washing can be calculated. Standard values of interior cleaning and exterior washing services per week can be assumed by referring to the TCRP synthesis 12 (Transportation Research Board, 1995b).

4.6 Safety and security.

The aspect linked to safety indicates the degree of safety from crime or accidents and the feeling of security resulting from psychological factors; therefore, this aspect refers not only to safety from crimes while riding or at bus stops and from accidents, but also to safety related to the behaviour of other persons and to the bus operation. Generally, the term “safety” is used to indicate the possibility of being involved in a road accident, while the term “security” refers to the possibility of becoming the victim of a crime.

Safety during a journey may be considered as a not very relevant aspect in the modal choice decision; in fact, the probability of being involved in an accident or becoming the victim of a crime is not explicitly considered as a part of the choice mechanism. However, when explicitly queried about the importance of safety, this factor is given an extremely high rating of importance (Solomon et al., 1968). These findings are confirmed by Iseki and Taylor (2008) in their study about safety and security at stops, and by Eboli and Mazzulla (2010) who explicitly investigated safety and security on board.

In Nathanail (2008), safety during the trip was defined as the number of passenger fatalities, owing to the responsibility of the transit operator. Passenger fatalities are collected and retained by the operator for the year of analysis, and compared to the average number of fatalities in the last five years. Grade 0 is given in case that the fatalities of the current year are higher than double the five-year average, and 10 grade when the fatalities are less than the five-year average; intermediate grades are proportionally assigned to intermediate cases. Also in Eboli and Mazzulla (2011) the indicator concerning safety and competence of drivers was calculated on the basis of the number of road accidents verified during the last year, but this value was compared with a standard value equal to the average number of road accidents verified during the last three years. Analogously, the indicators of the service aspect regarding security against crimes on board and at bus stops were calculated on the basis of the number of complaints registered during the last year, and compared with the average number of complaints registered during the last three years.

4.7 Fare.

The service aspect regarding fare includes characteristics of the monetary cost of the journey by bus, like the cost of a one-way ride, the cost of a transfer, the availability of discounted fares (e.g. for students), the availability of volume discounts (e.g. for monthly passes), the cost of parking at bus stops.

There is an extensive literature supporting the thesis that costs affect mode choice behaviour of travellers. On the other hand, many studies about the attitudes toward transportation system alternatives found that the monetary travel cost does not constitute a salient factor in the modal-choice decisions. As an example, Wallin and Wright (1974) concluded that “cost does not play a major role in the choice of a transportation mode”, whereas Beirao and Sarsfield-Cabral (2007) stated that public transport is generally perceived as cheaper than car and monetary cost does not appear as a key factor for changing to public transport, with the exception of the users with low income, who consider travel cost as a very important aspect.

In Eboli and Mazzulla (2011) the average one-way ticket cost was adopted as indicator regarding ticket cost. The authors considered standard values corresponding to the average cost of the tickets for different typologies of service adopted by transit agencies operating in similar territorial contexts characterized by high standards of transit service quality.

4.8 Information.

Another service aspect affecting transit service quality is linked to the availability of information pertinent to the planning and execution of a journey. Passengers need to know how to use transit service, where the access is located, where to get off in the proximity of their destination, whether any transfers are required, and when transit services are scheduled to depart and arrive. Without this information, potential passengers will not be able to use transit service (Transportation Research Board, 2003a). Beirao and Sarsfield-Cabral (2007) found that several respondents think that the bus system is difficult to use and information is difficult to obtain; among bus users, the main problem occurs when bus companies change timetables or routes and do not provide enough information to users. In recent years, many transit agencies have taken steps for increasing and improving transit service information. These steps reflect the growing awareness among transit agency managers that service information is important to transit users and can be effectively used to increase ridership by retaining existing riders and potentially attracting new riders to the transit system (Transportation Research Board, 1996). For designing and preparing information materials which will meet the needs of all transit customers, TCRP report 45 (Transportation Research Board, 1999a) could be of interest to schedulers, transit planners and others. Ideally, passenger information should be available at every stage of the rider’s transit trip. Pre-trip information helps the rider to plan routes and connections. Pre-trip information needs consist of the location of the nearest bus stop, routes that travel to the desired destination and transfer locations, fare, time of departure, and approximate duration of the trip. In-transit information assists the rider at each decision point during the trip. In-transit information needs consist of the identification of the correct bus to board at the departure point; identification of bus stops for transfers or disembarking on the bus; how to transfer to another route at transfer points; cost, time limits, and restrictions; identification of the correct bus to board; area geography (i.e., location of the final destination in relation to the bus stop); return trip information at the destination (e.g., departure times and changes in route numbers). Supportive/confirming information repeats and reinforces data and decisions; it should be provided at any point during the trip when the rider may want to be reassured that he/she is progressing correctly and not getting lost.

Nathanail (2008) proposes an indicator of the passenger information during the trip, graded by a trained checker, depending on the type and quality of information provided at five, arbitrarily selected, stations along a train itinerary. The average grade of all five stations is used as the itinerary grade.

In Eboli and Mazzulla (2011) an indicator of the attribute “availability of schedule/maps on bus, and announcements” was calculated as the ratio of the number of vehicles with functioning information device on board to the total number of vehicles sampled in a certain time period; a trained checker verifies the functioning of the information devices on different days. In addition, an indicator of the attribute “availability of schedule/maps at bus stops” was evaluated on the basis of a score assigned to each stop of a line, from a minimum value of 0 to a maximum value of 10. The minimum value was assigned to the stops without any kind of information device at the stop; the maximum value to the stops with schedule and maps. The indicator was calculated as average value of the scores assigned to all the line stops. Similar indicators can be calculated by considering other user information devices; TCRP Synthesis 17 (Transportation Research Board, 1996) provides a useful review of the types and tools of information at bus stops, with an indication of the relative costs.

4.9 Customer care.

Customer care includes those elements needed to make easier and more pleasant the journey, like courtesy and knowledge of drivers, courtesy and helpfulness of ticket agents, personnel appearance, together with elements linked to the easiness of purchasing tickets or paying fare, presence and condition of the ticket issuing and validation machines, and effectiveness of the ticket selling network.

In Eboli and Mazzulla (2011) personnel appearance was evaluated by means of trained checkers who verified if personnel use the uniform. An indicator was proposed as the ratio of the number of uniformed staff to the total staff number. Personnel helpfulness was evaluated by means of a mystery rider who verified the behaviour of the personnel and assigned a score to each personnel unit, according to a scale from 0 to 10. In the same research work the authors propose an indicator for evaluating the ease of purchasing the ticket by taking into account the only opportunity of purchasing the tickets on bus by a manual operator or automatic ticket machines. This indicator was calculated as the ratio of the number of vehicles with functioning automatic ticket machines to the total number of vehicles sampled in the period of data gathering. A trained checker verified the functioning of the automatic ticket machines in different days of the same time period.

Tyrinopoulos and Aifadopoulou (2008) introduce an indicator aiming to access the sufficiency and effectiveness of the ticket selling network and the easiness to purchase tickets. For each selling point mystery-shoppers collect some data regarding tickets availability, existence of the special indication informing customers about availability of tickets, position and visibility of the indication. This information can be used for calculating the percentage and location of the selling points that do not have tickets to sell, and of the selling points having special and clearly visible indication.

4.10 Environmental impacts.

The service aspect regarding the impacts of the bus systems on the environment includes effects in terms of emissions, noise, visual pollution, vibration, dust and dirt, odour, waste, but also effect of vibrations on road and natural resources consumption in terms of energy or space. In the scientific literature, there is a considerable amount of models and procedures which allow the effects of the transport systems to be quantified, especially in terms of pollution and noise. In order to obtain some indicators one can refers to the well-known literature of the specific sector.

Most simply, the service aspect regarding environmental protection could be evaluated by considering the use of ecological vehicles, and the ratio of the number of vehicles in keeping with the CE 2001/27/CEE regulation to the total number of vehicles needed for the line can be proposed as indicator, as well as the regulation regarding vehicle noise emissions can be taken into account.

5. General findings

Some interesting considerations emerge from the review provided in the proposed research work. Firstly, there are some service quality aspects which were very much investigated in the scientific literature, such as service availability and reliability, and some aspects less analysed, such as customer care and environmental protection. A reason for which some service aspects are less investigated than others is linked to the easiness to find data for calculating the indicators; as an example, the most qualitative aspects are less easily measurable because of the difficulty of finding appropriate data and indicators for expressing the quality of the service aspects. There are some sources of data which more easily offer the information for calculating the indicators. As an example, automated data are usually quickly and efficiently collected, but they should be also characterized by a certain accuracy, precision, and repeatability. For this reason, automated collection methods are not always the best way to collect data. In fact, some objective measures of transit performances are more appropriately calculated from other different sources of data, such as manual data provided by operators, dedicated trained checkers or field supervisors.

Each service quality aspect depends on different factors, and each factor can be analysed by various indicators. In the scientific literature, there is an extensive collection of measures for evaluating transit service quality. There are indicators used for evaluating service factors which are more quantitative and indicators measuring factors having a qualitative disposition. By considering the indicators analysed in this work, we can distinguish between usual and unusual, easily and hardly measurable, simple and complex, single and composite, traditional and innovative indicators.

There are indicators more usually adopted by the transit agencies for evaluating and monitoring their performances; on the other hand, other indicators are less used. As an example, line path is traditionally evaluated in terms of travel speed; other less usual indicators of this service factor are linked to the itinerary accuracy or directness.

The most easily measurable indicators are represented by the measures based on more available data. These measures generally refer to the aspects which more properly describe the service, such as service frequency and service span, simply measured on the basis of the number of offered runs or the number of service hours, respectively. Less easily measurable indicators refer to more qualitative aspects, like comfort on board, for which a very appropriate parameter is difficult to be found.

Some indicators are expressed by simple mathematical formulations (e.g. the ratio of passengers to offered seats); others have a more complex formulation, such as the indicator proposed for calculating the load factor on board.

Some service aspects are properly evaluated by single indicators characterized by an only one parameter. An example is represented by safety which essentially depends on the number of road accidents. Sometimes composite indicators, made up of more single indicators, can be conveniently adopted to take into account more features of the same service aspect. As an example, service reliability, which is commonly measured in terms of on-time performance, headway regularity and running time adherence, can be more effectively measured through a composite indicator obtained by combining all the three single indicators.

Some indicators are more traditional, while others can be considered more innovative, such as the indicator regarding seat comfort measured by trained checker in terms of seat-back slope, seat width, and available leg distance.

The selection of the most appropriate parameters for evaluating the level of quality of a service aspect is a very important issue. In fact, some typologies of data and/or parameters provide more reliable and unbiased indicators, while some parameters could be not very appropriate for giving the real level of service quality of an aspect. As an example, the quality of the service factor linked to the air conditioning on board can be measured by verifying the presence on board of the climate control devices; however, a more appropriate measure could be derived by making use of a trained checker or a mystery rider who verifies the level of temperature on board by providing a measure of service quality which should be more oriented to the customer need and linked to the users' tastes.

Some problems are linked to the definition of the standards. Specifically, for some parameters standard values are not well defined or not available. Several times standard values are not established according to regulations; in these cases target values used by the main transit agencies can be adopted. Future research could be oriented to the definition of the standards for indicators for which a standard has not been established yet.

Given the wide variety of indicators, there is need to explore the applicability and appropriateness of the different types of performance measures for the different types of services (local versus express services, grid versus feeder). As a consequence, transit agencies should select indicators and standards that accurately depict performance level, in order to develop or update a performance measurement programme.

In the USA specific manuals and handbook, developed starting from research programmes supported by important research institutions, have been adopted as guidelines for evaluating transit service quality; on the contrary, in the EU countries, and specifically in Italy, there is lack of regulations and necessity to arrange univocal procedures for service quality measurement. However, an attempt was made by the European Committee for Standardization which establishes some criteria for encouraging the benchmarking among transit agencies, public transit practitioners and policy makers.

6. Some conclusive considerations

Service quality measure in general represents an essential tool for focusing transit agencies on their strategic goals of improving the delivered transit services. The scientific literature provides an extensive collection of measures for evaluating transit service quality. This research work has focused on the objective indicators. We retain that these indicators provide a quite reliable and realistic measure of the quality levels of a service. In fact, these measures, compared to the subjective indicators based on customers' perceptions, have the advantage of giving clearer and less biased information. However, sometimes there can be the difficulty of objectively measuring some more qualitative aspects and the risk of using not appropriate standard or target values. Despite of passengers' perceptions are considered as fundamental for evaluating a transit service, also subjective measures have some disadvantages linked to the heterogeneity of users' judgments and also the risk that users could have distorted opinions of the service.

Starting from these considerations, we can retain that both subjective and objective measures are necessary for evaluating the performance of a transit service. More effort could be made by the researchers in the analysis of the two types of indicators and in their combination, with the aim to provide a more useful and reliable measurement tool of transit performance.

References

Berry, L.L., Zeithaml, V.A., Parasuraman, A. (1990) "Five imperatives for improving service quality", *Sloan Management Review* Summer, pp. 9-38.

Beirão, G., Sarsfield-Cabral, J.A. (2007) "Understanding attitudes towards public transport and private car: A qualitative study", *Transport Policy* 14 (6), pp. 478-489.

Bickel, P., Friedrich, R., Link, H., Stewart, L., Nash, C. (2006) "Introducing Environmental Externalities into Transport Pricing: Measurement and Implications", *Transport Reviews* 26 (4), pp. 389-415.

Carter, D.N., Lomax, T.J. (1992) "Development and Application of Performance Measures for Rural Public Transportation Operators", *Transportation Research Record* 1338, pp. 28-36.

Cirillo, C., Eboli, L., Mazzulla, G. (2011) "On the Asymmetric User Perception of Transit Service Quality", *International Journal of Sustainable Transportation* 5 (4), pp. 216-232.

Dalton, D., Nestler, J., Nordbo, J., St. Clair, B., Wittwer, E., Wolfgram, M. (2000)

"Transportation Data and Performance Measurement", Proceedings from the 26th Annual Meeting on Performance Measures to Improve Transportation Systems and Agency Operations, Irvine, October 29-November 1.

Deakin, E. (2001) "Sustainable Development and Sustainable Transportation: Strategies for Economic Prosperity, Environmental Quality, and Equity", Institute of Urban and Regional Development, UC Berkeley, IURD Working Paper Series.

Decreto del Presidente del Consiglio dei Ministri 30 dicembre 1998, (1999)"Schema generale di riferimento per la predisposizione della carta dei servizi pubblici del settore trasporti (Carta della mobilità)", G.U. n. 26 del 2 febbraio 1999.

Eboli, L., Mazzulla, G. (2008) "An SP Experiment for Measuring Service Quality in Public Transport", *Transportation Planning and Technology* 31 (5), pp. 509-523.

Eboli, L., Mazzulla, G. (2010) "How to capture the passengers' point of view on a transit service through rating and choice options", *Transport Reviews* 30 (4), pp. 435-450.

Eboli, L., Mazzulla, G. (2011) "A methodology for evaluating transit service quality based on subjective and objective measures from the passenger's point of view", *Transport Policy* 18 (1), pp. 172-181.

El-Geneidy, A., Horning, J. and Krizek, K.J. (2007) "Using Archived ITS Data to Improve Transit Performance and Management", Minnesota Department of Transportation Research Services Section.

EU Transport RTD programme (1998) "Quality Approach in Tendering/contracting Urban Public Transport Operations (QUATTRO)", Final Report.

EU Transport RTD programme (2000) "Extending the quality of public transport (EQUIP)", Final Report and its Annex: Practical Handbook.

EU Transport RTD programme (2003) "Promotion of results in transport research and learning (PORTAL)", Final Report.

European Committee for Standardization (2002) "Transportation-logistics and services-public passenger transport-service quality definition, targeting and measurement".

Fielding, G.J. (1987) *Managing Public Transit Strategically: A Comprehensive Approach to Strengthening Service and Monitoring Performance*, Jossey-Bass Publishers.

Gudmundsson, H. (2001) "Indicators and performance measures for Transportation, Environment and Sustainability in North America", Report from a German Marshall Fund Fellowship 2000 individual study tour October 2000, Research Notes n. 148, National Environmental Research Institute, Roskilde.

Hartgen, D.T., Tanner, G.H. (1970) "Individual attitudes and family activities: a behavioral model of modal choice", *High Speed Ground Transportation Journal* 4, pp. 439-467.

Hellenic Institute of Transport (2003) "Handbook for the implementation of the quality control system of OASA", Stage 2 Final Report of the Project: An Integrated System for the Quality Assessment of the OASA Passenger Services.

Hellenic Institute of Transport (2005) "Application manual of the service and performance indicators", Stage 2 Final Report of the Project: An Integrated Quality Control System for the Public Transport Services in Thessaloniki.

Hensher, D.A. (2007) *Bus Transport: Economics, Policy, and Planning*, JAI Press, NY.

Hensher, D.A. and Prioni, P. (2002) "A service quality index for area-wide contract performance assessment regime", *Journal of Transport Economics and Policy* 36 (1), pp. 93-113.

Iseki, H., Taylor, B.D. (2008) "Style versus Service? An Analysis of User Perceptions of Transit Stops and Stations in Los Angeles", *Transportation Research Board*, Proceedings from the 87th Annual Meeting, Washington, D.C., January 13-17.

Friman, M., Fellesson, M. (2009) "Service Supply and Customer Satisfaction in Public Transportation: The Quality Paradox", *Journal of Public Transportation* 12 (4), pp. 57-69.

Kimpel, T.J. (2001) *Time point-level analysis of transit service reliability and passenger demand, Urban Studies and Planning*, Portland State University, Portland.

Lin, J., Wang, P., Barnum, D.T. (2008) "A quality control framework for bus schedule reliability", *Transportation Research* 44 (E), pp. 1086-1098.

Litman, T. (2009) "A Good Example of Bad Transportation Performance Evaluation", Working paper, Victoria Transport Policy Institute.

Meyer, M. (2000) "Measuring That Which Cannot Be Measured At Least According to Conventional Wisdom", *Transportation Research Board* - Proceedings from the 26th Annual Meeting on Performance Measures to Improve Transportation Systems and Agency Operations, Irvine, October 29-November 1.

Nakanishi, Y.J. (1997) "Bus performance indicators. On-time performance and service regularity", *Transportation Research Record* 1571, pp. 3-13.

Nash, A.N., Hille, S.J. (1968) "Public attitudes toward transport modes: a summary of two pilot studies", *Highway Research Record* 233.

Nathanail, E. (2008) "Measuring the quality of service for passengers on the hellenic railways", *Transportation Research* 42 (A), pp. 48-66.

Nocera, S. (2010) "An Operational Approach for the Evaluation of Public Transport Services", *Ingegneria Ferroviaria* 64 (4), pp. 363-383.

Parasuraman, A., Zeithaml, V.A., Berry, L.L. (1985) "A conceptual model of service quality and its implication for future research", *Journal of Marketing* 49, pp. 41-50.

Rienstra, S.A. and Vleugel, J.M. (1995) "Options for sustainable passenger transport: an assessment of policy choices", *Vrije Universiteit Amsterdam Serie Research Memoranda/VrijeUniversiteit Amsterdam*, Faculteit der Economische Wetenschappen en Econometrie, Amsterdam.

Solomon, K.M., Solomon, R.J. and Sillien, J.S. (1968) *Passenger psychological dynamics: sources of information on urban transportation,* American Society of Civil Engineers, New York.

Strathman, J.G., Kimpel, T.J., Callas, S. (2003) *Headway deviation effects on bus passenger loads: Analysis of Tri-Met's archived AVL-APC Data,* Center for Urban Studies, Portland.

Strathman, J.G., Kimpel, T.J., Dueker, K.J. (1999) "Automated Bus Dispatching, Operations Control, and Service Reliability" *Transportation Research Record* 1666, pp. 28-36.

Transportation Research Board (1965) *Highway capacity manual*, National Academy Press, Washington, D.C.

Transportation Research Board (1994) "The Role of Performance-Based Measures in Allotting Funding For Transit Operations", *TCRP Synthesis 6*, National Academy Press, Washington, D.C.

Transportation Research Board (1995a) "Bus Route Evaluation Standards", *TCRP Synthesis 10,* National Academy Press, Washington, D.C.

Transportation Research Board (1995b) "Transit Bus service Line and Cleaning Functions", *TCRP Synthesis 12,* National Academy Press, Washington, D.C.

Transportation Research Board (1996) "Customer Information at Bus Stops", *TCRP Synthesis 17*, National Academy Press, Washington, D.C.

Transportation Research Board (1997) "AVL systems for bus transit. A Synthesis of Transit Practice", *TCRP Synthesis 24*, National Academy Press, Washington, D.C.

Transportation Research Board (1999a) "Passenger Information Services: A Guidebook for Transit Systems", *TRCP Report 45*, National Academy Press, Washington, D.C.

Transportation Research Board (1999b) "A handbook for measuring customer satisfaction and service quality", *TRCP Report 47*, National Academy Press, Washington, D.C.

Transportation Research Board (2000) "Data analysis for bus planning and monitoring", *TCRP Synthesis 34*, National Academy Press, Washington, D.C.

Transportation Research Board (2003a) "A guidebook for developing a transit performance-measurement system", *TCRP Report 88*, National Academy Press, Washington, D.C.

Transportation Research Board (2003b) "Transit capacity and quality of service manual", *TCRP Report 100*, National Academy Press, Washington, D.C.

Transportation Research Board (2004a) "Bus Routing and Coverage", *TRCP Report 95*, National Academy Press, Washington, D.C.

Transportation Research Board (2004b) "Performance-Based Measures in Transit Fund Allocation. A Synthesis of Transit Practice", *TCRP Synthesis 56*, National Academy Press, Washington, D.C.

Turnquist M, Blume S. (1980) "Evaluating potential effectiveness of headway control strategies for transit systems", *Transportation Research Record* 746, pp. 25-29.

Tyrinopoulos, Y., Aifadopoulou, G. (2008) "A complete methodology for the quality control of passenger services in the public transport business", *European Transport* 38, pp. 1-16.

Tyrinopoulos, Y., Antoniou, C. (2008) "Public transit user satisfaction: Variability and policy implications", *Transport Policy* 15 (4), pp. 260-272.

Vuchic, V.R. (2007) *Urban Transit: Systems and technology*, Wiley, New York.

Wallin Rex, J., Wright, P.H. (1974) "Factors which influence modal choice", *Traffic Quarterly* 28, pp. 271-289.

Wachs, M. (1976) "Consumer attitudes towards transit service: An interpretive review", *Journal of the American Institute of Planners* 42 (1), pp. 96-104.

Wilson, N., Nelson, D., Palmere, A., Grayson, T.H., Cederquist, C. (1992) "Service quality monitoring for high frequency transit lines", *Transportation Research Record* 1349, pp. 3-11.

Zak, J. (2011) "The methodology of multiple criteria decision making/aiding in public transportation", *Journal of Advanced Transportation* 45, pp. 1-20.