Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia - Social and Behavioral Sciences 48 (2012) 653 – 662

Procedia
Social and Behavioral Sciences

Transport Research Arena– Europe 2012

A methodology to define the Level of Safety of Public Transport bus stops, based on the concept of Risk.

Marco Amadori[a,*], Tommaso Bonino[a]

[a] *SRM Reti e Mobilità, Via Magenta 16, Bologna 40128, Italy*

Abstract

SRM is the Public Transport (PT) Authority of Bologna, managing PT 37 Mkm/year service contract and taking also care of the safety of the whole bus stops network, consisting of 6.700 stops.
Most of bus stops have been established more than 30 years ago. During decades, PT network, number of users and road characteristics changed a lot and some bus stops are now less safe than before.
A specific instrument was therefore needed in order to define a list of priority, also on the basis of what foreseen by the Regulation on service quality (ISO 13816).
In 2010 a survey on all the PT stops was carried out, collecting about 120 information each (concerning geometric features as user waiting area conditions, user's accessibility, road characteristics, GPS location, etc) and pictures. A database was fed by all these information.
At the same time, an algorithm able to calculate the Level of Safety of bus stops was defined, starting from the concept of Risk as a combination of Probability and Damage. The algorithm can now assign a mark from 1 (worst) to 10 (best) to bus stops, on the basis of all collected data and of external factors such as vehicular traffic, vehicles speed, number of users per day at the bus stop, number of buses per day. Also the statistic data of car accidents occurred close to stops in the last 8 years were taken into account.
Finally, a sort of catalogue of possible and standardized measures was produced in order to make a stop safer or to build a new safe bus stop. This catalogue can be also used to identify the maintenance works to be done to allow a bus stop to reach a predefined condition or mark. These features are now included in a specific software owned by the Authority, who is committed to spread information among administrations and operators.

Keywords: bus stop; public transport; safety

[*]Corresponding author. Tel.: +39-051-361328; fax: +39-051-361260.
E-mail address: marco.amadori@srmbologna.it.

doi:10.1016/j.sbspro.2012.06.1043

1. Introduction

The relationship between the Public Transport (PT) System and its users is based on a variety of factors, whose synergy contributes to the overall level of quality: efficiency, punctuality and regularity, vehicles, bus stops. A PT system, of course, consists of many other factors, but these ones define the link between the user and the service. The *efficiency* and the *punctuality/regularity* of the service relate mainly to the “operative field”, and they are the result of good service planning and programming. They are the “software” of the system. The *vehicles* and the *bus stops*, instead, represent the hardware, they and are the physical infrastructure of the system. A low-level software running on a good hardware makes the system poorly performing, as a good software installed on a bad hardware is very limited in its performance. In this study we will focus our attention on bus stops and their safety.

The PT bus stops are the starting/final point of pedestrian movements and of the system itself: in this space users have the first perception of the quality of the offered transport service.

The safety and accessibility conditions of a bus stop are the first approach of the users to the transport system and, consequently, they may influence future modal choices. The bus stops location is very important, but even more their configuration and their equipment, as they make safe and comfortable the passenger waiting: these are the elements that, combined with an efficient transport system, enhance the served area reducing the travel distance "perceived".

2. Scenario: the evolution of the bus stop network and of the Italian legal framework

Bus stops are small points within a space in continuous evolution. In the Greater Area of Bologna there are more than 6.700 bus stops, spread throughout 3.700 sqkm ranging from few meters above mean sea level to 1.000 meters a.m.s.l., from crowded populated areas to small groups of two or three houses, from rural to industrial areas. Because of this variety of conditions, bus stops characteristics are very different from each other, and in some cases the minimum safety and comfort requirements are not satisfied.

To better describe the existing scenario, it is useful to give some information about the evolution of the bus stops network in the last few decades and about the Italian legal framework.

2.1. The historical evolution of the bus stop network

Although it is quite difficult to know the exact birthday of the bus stops network, it is possible to briefly review the history of public transport operator: some public transport services have been already existing before WWI, but the first urban public transport company in Bologna (ATM) was founded in 1924 and the extra-urban company (APT) was founded in 1954. The two companies merged in the ATC in 1975, absorbing some other small private operators. The last change in the company happened few months ago, because the ATC and the last few small private operators merged in the TPB Consortium, which won the PT tender for the whole Greater Area of Bologna.

The bus stops network in the Greater Area of Bologna is supposed to date back to many decades ago: indeed, a map of the bus network in 1967 compared with the same map referred to 2011 shows that bus lines are quite the same, rather it was reduced during the years because long distance bus lines were cancelled.

Furthermore, during the years, the most part of economic resources available for the PT System, were mainly used to renew the bus fleet. Even if it led to good results (the bus fleet average age is 11 years, the 90% of buses is equipped with one or more specific devices for users with reduced mobility and the number of electric, euro3+CRT or more and CNG buses is equal to the 71% of the fleet), it didn’t allow an adequate improvement of the bus stops characteristics.

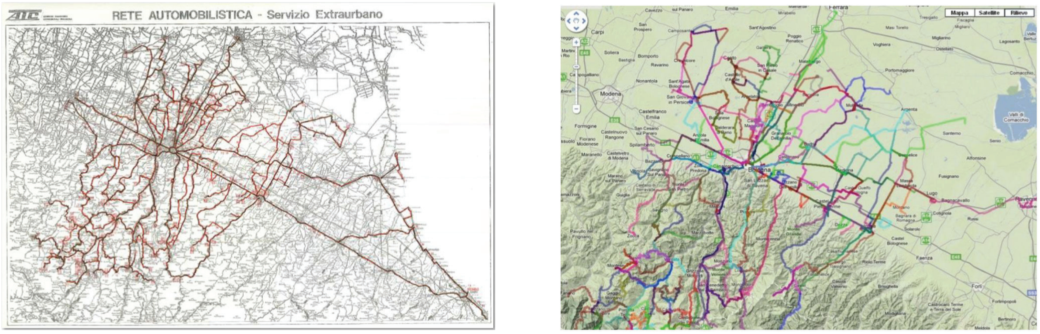

Fig. 1. (a) public transport network in 1967; (b) public transport network in 2011

Another important factor which affected the (not)evolution of bus stops conditions was the frequent changes of the subject in charge of verify their safety: until the ‘90s bus stops safety was in charge of the local office of the Transportation Ministry, then it was delegated to the Regions, that in turn in 1998 delegated it to the Provinces and the Municipalities, which in the area of Bologna were 8 (the Province and 7 Municipalities). Finally, in 2008, SRM Reti e Mobilità – the Public Transport Authority of Bologna – was appointed by Local Governmental Bodies as responsible for bus stops safety. This continuous transfer of competence, together with the problem to identify the responsible of the road (on which bus stops insist) that can be in charge of the Municipality, of the Province or of the State, depending on the kind of road, makes the scenario very complicated.

On the other side the external environment changed a lot. Table 1 shows the increase of cars in the Greater Area of Bologna since 1961 and gives an overview of how the traffic along the road network is subsequently changed.

Table 1. Number of cars during years in the Greater Area of Bologna

Year	1961	1971	1981	1991	2001	2010
Number of cars *(a)*	155.653	314.550	476.707	681.741	717.407	774.187

To give an idea about how PT services have increased, it is possible to analyze the evolution of covered kms by bus and the number of carried passengers. The data are available since 2002, and they are shown in Table 2. Traffic, number of passengers and number of trips a day, as we shall see later, are factors that affect safety conditions of a bus stop, and therefore cannot be underestimated in this study.

Table 2. Number of covered km, PT passenger and PT Share during years in the Greater Area of Bologna

Year *(b)*	2002	2004	2006	2008	2010
Number of covered kms by bus	36.428.248	37.135.245	36.287.666	36.949.815	37.846.009
Number of PT passengers	106.731.881	107.098.089	107.906.745	110.848.726	110.210.869
PT share	18,1%	18,8%	18,6%	22,7%	21,5%

The framework is then very complex and fragmented. This led to the difficulty to set up an organic and continuous methodology over time, thus leaving much room for the so-called "sensibility of the engineer" and forcing him to act only in response to users’ reports and requests, and not as a result of a technical-economic planning of the job.

2.2. The historical evolution of Italian legal framework

The legal framework evolved too, because of changes to the Road Code, ministerial technical standards and local regulations. However, the existing legal framework, although improved over time, is not exhaustive or always applicable to reality. The current laws, indeed, are not complementary each other, in some cases the level of detail is not adequate and there is no specification about geometrical features and their relationship with the surrounding environment (i.e. the many differences, in the suburban areas, between lowlands and mountain roads, embankments or trenches, main roads or local roads, etc. are not taken into account). This means that the technicians have not enough tools to make a coherent design of bus stops on the territory of their competence.

3. Purpose of the study

SRM, having received the responsibility of the bus stops safety, felt the need to know which was the state of the art, in order to set a "time zero" from which to start again with a new methodology of work. Until today, in fact, the safety of a bus stop was verified only after a specific request by users, by the bus operator or by the local body, but a global planning was never undertaken before. The target of SRM is, instead, to approach the issue of bus stop safety with an organic plan of actions, in order to evaluate for each bus stop if an improvement of its level of safety is necessary and, in this case, which infrastructural measures should be adopted. At the end of this work a report will be produced, which could be used to plan the realization of the infrastructural measures through the time, beginning from bus stops having the lower Level of Safety.

In order to carry out this ambitious work some key elements are necessary. This study aims to provide these key elements.

The study was carried out in three steps: the first step was the survey of all bus stops, a very detailed process that allowed to "take a picture" of the state of the art, namely the state of bus stops network at time zero. The second step was the definition of an algorithm to define the level of safety for each bus stop, and the third step was the creation of an abacus of possible infrastructural measures to make bus stops safer, that would provide a unique powerful tool valid throughout the whole area.

4. Methodology

4.1. Bus stops survey

There are lot of geometrical features identifying a bus stop: the typology of bus stop, the existence of a waiting area for passengers and its size, the distance from road intersections, the trend in horizontal and vertical alignment and the size of the road around the bus stop, the characteristics of road signs, etc. Many of these elements have an influence on the bus stop safety.

The information to be collected about a bus stop are then very important and the selection of these elements is a key step of in the whole process: the more information are available and the higher is the detail that can be achieved in the calculation of the level of safety (LoS), and, as the number of bus stop in the Greater Area od Bologna is very high (about 6.700 bus stops), the survey process can be carried out only once, requiring a very long time and a considerable amount of economic resources.

Then, at this stage as much information as possible was collected: this led to identify about 120 elements characterizing a bus stop. A very detailed survey form was prepared and it was filled in for each bus stop, furthermore 3 pictures were taken for each stop and the GPS position was recorded, in order to have also a complete photographic and geographic database.

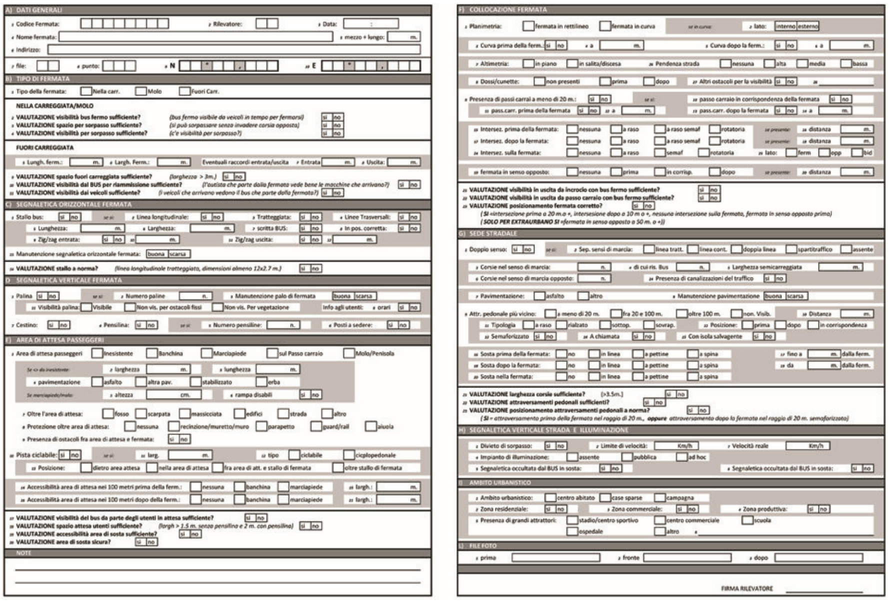

Fig. 2. The survey form

The safety of a bus stop can be influenced, from the probabilistic point of view, by some not-geometrical factors, then some other data were collected for each bus stop:

- vehicular traffic in the road where the bus stop is located;
- daily bus frequency and number of passengers at each bus stop;
- number and kind of car accidents around bus stops.

At the end of this step all collected information were entered into a database, which now counts more of 800.000 data.

4.2. The algorithm to calculate the Level of Safety

The easiest way to find out if a bus stop is safe or not is to compare its characteristics to the few geometric indications provided by the Road Code. However, the result would be entirely negative: for example the number of suburban stops equipped with bus bay (as requested by the Road Code) is less than 1%. So, it would be illogical to say that almost all of the bus stops is unsafe on the basis of these elements. It would also lead to an impossible situation to solve, because thousands of bus stops would need some interventions, but the economic resources are not infinite nor significant; furthermore, in many cases the conditions of surrounding environment do not allow the creation of those characteristics required by the Road Code.

It was therefore decided to distinguish between *safety* and *compliance*. On this basis it was possible to do some more concrete and achievable analysis and evaluations.

The *compliance* relates to the correspondence of the characteristics of a bus stop to the requirements of Road Code. The *safety*, instead, relates to the intrinsic *risk* of each bus stop.

The algorithm was then based on the concept of level of *risk (R),* as the result of the product of the *probability (P)* of occurrence of harmful events and the intensity of the *damage (D)* that may result.

$$R = P \times D \tag{1}$$

The concept of *risk* is widely accepted and it is used in the national legislation for the evaluation of safety at work. The same concept was then applied to the safety of the bus stops: the probability is proportional to the number of users, to the intensity of vehicular traffic and to the frequency of buses (the higher is the number of passenger at a bus stop and the higher is the probability of a damaging event) and the damage is closely linked, through an exponential relation, to the speed of the vehicles travelling along the road, both with regard of the user of the bus and with regard to relationship between the bus and other vehicles.

As previously said, about 120 geometrical features were collected for each bus stop. To better understand how these features could influence the level of safety of a bus stop we can make the following examples.

Consider two bus stops having exactly the same geometrical features: they have apparently the same level of safety. Now imagine that the first one is used by many passengers, the traffic on the road is very high and the speed limit on the road is high. Then imagine that the second one is, instead, used by very few passengers, since it is located in suburban area, where the traffic is very low and the speed limit is low. The "real" Level of Safety of these bus stops, the Risk, is then very different, and we get this result by the formula no. 1.

Now imagine that the number of passengers is the same, as well as the intensity of traffic and the speed limit, but the first bus stop is equipped with a bus bay and has a large sidewalk for passengers waiting, while the second one is located on the edge of the road without an adequate protection for passengers. In this case, the probabilistic elements (P, D) are the same, while the geometrical features affecting the level of safety of the bus stops are quite different: for this reason is very important to take into account also *geometrical features (G)*. The formula con be updated in this way:

$$R = G \times P \times D \tag{2}$$

Finally, there is one more important issue: road accidents. Each geometric feature (G) has been considered as a possible cause of one or more harmful events: a bus stop located in a hidden place could be the cause of collision by vehicles coming from behind, the lack of an adequate waiting area for passengers may be the cause of investment if he must wait for the bus along the road, etc. ...

The Province of Bologna is responsible, on behalf of the National Statistics Institute, of data collection relating to all accidents causing dead or injuries and occurred on its territory, and provided us data on accidents occurred over the past 8 years in a radius of 30 meters from each bus stops (the sample consisted of about 5.200 records): this allowed to determine the weight of each kind of accident in terms of social damage, and consequently to weigh the various geometrical deficiencies with regard to the kind of possible occurring accidents. The result is a *Safety index (Si)* which relates geometric features (G) with *car accidents (A)*. The formula of the *Level of Safety (LoS)* can be now rewritten in its final version.

$$Si = f(G, A) \tag{3}$$

$$LoS = Si \times P \times D \tag{4}$$

The algorithm, applied to all bus stops, gives as a result their LoS on a scale from 1 to 10, which is equivalent to a school mark: a mark of 6 means that the bus stop has an adequate LoS.

From the operational point of view, this algorithm was developed under Visual Basic and on MS Access database. A web version was developed too, in order to share the results of the study with the local bodies and the bus operator, so that all subject working in this field could have easy access to these data.

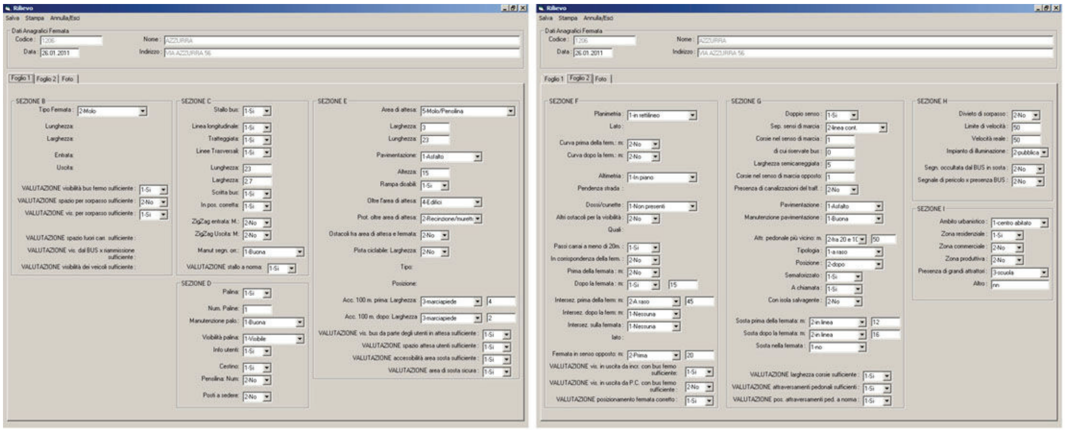

Fig. 3. (a) software's screenshot, first sheet; (b) software's screenshot, second sheet

4.3. The manual of infrastructural measures

The third step of this study was the creation of a manual of infrastructural measures, so that for each of the 6.700 bus stops it is possible to define which measures must be adopted to improve its LoS.

In the previous chapters, we referred to the deficiencies of the Italian legislation and to the difficulty to apply what it requires because of various environmental and economic constrains. But the relationship between geometrical deficiencies and the possible harmful events they can cause, offers a way to fill these regulatory gaps. The bus stop was then considered as a modular object, to which attach various geometric elements. Geometrical deficiencies are solved through a cyclical process, "pasting" to the bus stop the missing geometrical elements, one after the other (i.e. the creation of a waiting area, the improvement of accessibility, the improvement of road signs, etc.), until a sufficient Level of Safety is achieved. The order in which geometrical elements are "pasted" depends on their influence on road accidents, as the process begins applying elements which are statistically the cause of more frequent and harmful accidents. Then the software returns a list of measures needed to make a bus stop safer, and estimates costs in order to give also an economic indication.

5. First results and future planning

On February 2011 the algorithm was completed and the software was available: the state of the art in the Greater Area of Bologna was analyzed. First of all, it was calculated the number of bus stops with an insufficient Level of safety (that is a mark lower than 6). The result is reported in table 3.

Table 3. Level of safety in the Greater Area of Bologna

Bu stop mark	< 5	5 - 5.5	5.5 - 6	> 6
Percentage of bus stops	0,3%	1,7%	7,1%	90,9%

This tool was firstly used to make safer the 24 bus stops with the lowest Level of safety (a mark lower than 5). Given this low number, it had been possible to act in a short time and accurately, carrying out onsite inspections and defining which measures adopt to secure bus stops. Since the last February, 8 of the 24 bus stops had been secured, 2 of them were abolished because it was not possible to implement measures sufficient to make them safer, while measures needed for the remainders have to be completed yet.

This tool was also tested on some bus stops that during these last few months have been geometrically improved.

We will now present four of them, showing pictures of before and after and giving some information about their lack of safety, the adopted measures and the increase of the level of safety increased.

Example n. 1 (Figure 4) - Mark before: 5.5 *Mark after: 7.0*

Main features: urban, high traffic, high bus frequency, high number of passengers.

Safety deficiencies: troubles for the bus in approaching the sidewalk and troubles for the passenger to get on and get off the bus because of irregularly parked cars.

Solution: the sidewalk extension allowed the bus to approach it correctly and to organize parking.


Fig. 4. (a) before; (b) after

Example n. 2 (Figure 5) - Mark before: 5.5 *Mark after: 7.0*

Main features: suburban, high traffic, medium bus frequency, low number of passengers.

Safety deficiencies: no waiting area for passengers, no accessibility to bus stop.

Solution: the new pedestrian-cycle lane is used as a waiting area and to reach safely the bus stop.

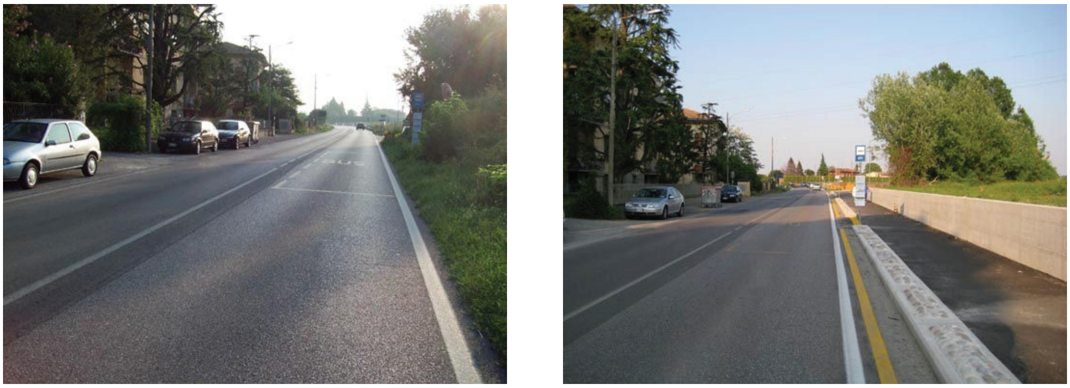

Fig. 5. (a) before; (b) after

Example n. 3 (Figure 6) - Mark before: 5.5 *Mark after: 6.5*

Main features: suburban, medium traffic, low bus frequency and number of passengers, low speed limit.

Safety deficiencies: no waiting area for passengers, no accessibility to bus stop.

Solution: the small sidewalk makes the function of waiting area, and given the characteristic of traffic, number of passenger, etc…is enough to make the bus stop safe.

Fig. 6. (a) before; (b) after

Example n. 4 (Figure 7) - Mark before: 5.5 *Mark after: 7.0*

Main features: urban, high traffic, medium bus frequency and number of passengers.

Safety deficiencies: unsafe waiting area for passengers because of the parking behind it.

Solution: the bus stop was moved in the car lane and a sidewalk was created so that now the waiting area and the parking are separated.

Fig. 7. (a) before; (b) after

5.1. Future planning

This tool allows a new approach to the work methodology. As mentioned above, until now the technicians responsible for the bus stops safety have worked "running after" users' requests. With this tool, instead, it will be possible to carry out a temporal and economic planning, to be developed in collaboration with the bus operator and the local technicians, in order to verify and define measures for the most problematic bus stops.

The work will be divided into 2 steps. During the first step the Greater Area of Bologna will be divided into some sub-areas, which will be defined taking into account local boundaries and areas with homogeneous bus service. Once these sub-areas will be defined, the bus stops included in each of them will be extracted from the software and elaborated in order to define a *criticality index* for each sub-area.

During the second step an inspections of every bus stop with low level of safety will be carried out, beginning from sub-areas with a higher criticality index, and measures and related costs proposed by the algorithm to make bus stops safer will be verified.

At the end of this second step a technical report for each sub-area will be produced, reporting all the measurers to be adopted. The bus stops that do not require expensive measures to be made safer will be quickly settled, while for other cases, the technical report will be used by local technicians for their next budget planning.

References

(a) ACI Automobil Club Italiano. Dati e statistiche. http://www.aci.it/?id=54.

(b) Comune di Bologna. http://www.comune.bologna.it/iperbole/piancont/dati_statistici/Indici/Trasporti/

(c) Nuovo Codice della Strada (Road Code) – D.Lgs 30.04.1992, n. 285

Regolamento di esecuzione e attuazione del Nuovo Codice della Strada – DPR 16.12.92, n.495

(d) Norme funzionali e geometriche per la costruzione delle strade – D.M. 05.11.2001

(e) Quaglia L. Novarin A. (May 2001). *Fermate del trasporto pubblico extraurbano, criteri di localizzazione e dimensionamento*. AIIT.

(f) Quaglia L. Novarin A. (Ottobre 2005). *Fermate del trasporto pubblico urbano, criteri di localizzazione e dimensionamento*. AIIT.

(g) Busi R. (2009). *Linee guida per la realizzazione delle fermate del trasporto pubblico locale*. EGAF.