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Bus Stop Design and Automated Guidance for Low-Floor Buses

Evaluation of Prototypes with Investigation of Human Factors

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Low-floor vehicle design improves the accessibility of urban buses to people with reduced mobility. In France, on the basis of the experience gained from low-floor tramways, a system approach soon appeared necessary and the low-floor bus within the urban environment was considered. Described are the results of the research and development project initiated by the Grenoble network to reach efficient guidance solutions that would ensure minimal gaps at bus stops. Operating conditions of accessibility equipment on the vehicle (kneeling, access ramp) as well as driver capability to dock at the bus stop have been investigated. From the results, an improved bus stop was designed and two prototype systems—GIBUS visual aid and VISÉE guidance system—were conceived and tested. Evaluation of these during operation on a bus route in the city of Grenoble concentrated on assessing system performance and human factors so that recommendations could be drawn before implementation.

French local authorities and network operators started buying low-floor buses later than those in Germany. However, the importance of a system approach has been highlighted. Indeed it would be a pity if bus riders were obliged to step down to the street asphalt before climbing up to reach the bus floor, because the too-large gap at the bus stop. The Grenoble tramway provided useful references both for the street-pavement environment and for the vehicle equipment.

LOW-FLOOR BUS SYSTEM APPROACH

The bus stop design and the low-floor bus equipment must be considered as a whole to fulfill the requirements on horizontal and vertical gaps between the curb and the bus floor and thus accommodate people with reduced mobility; these include elderly people, people with walking difficulties, parents with children in pushchairs, and wheelchair users. From laboratory tests (1) the horizontal gap should be shorter than 30 cm to be overcome by the frail population. The French advisory committee Colitrah (2), as well as the European Transport Research action COST 322, issued recommendations for the gap dimensions necessary to accommodate wheelchair users. These are illustrated in Figure 1.

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These recommendations for gaps that are manageable by wheelchair users take into account the fact that they concern people able to move autonomously within the city as well as the technical constraints of such a nonguided transport system.

Decision makers must choose which combination of accessibility vehicle equipment and infrastructure design is the more suitable to their objectives relating to traveler needs and operating conditions (3). The implementation of the low-floor bus system has grown rapidly in France. The most common amenities are as follows:

- Low-floor buses with a door sill height at 32 cm above the ground;
- Kneeling system (gain of 8 to 10 cm), which only a few operators choose to activate at every stop;
- Access ramp installed at the mid-door; French bus manufacturers have worked with a supplier, Bode, to integrate a short ramp into the bus floor (650 mm, providing a maximum slope of 16 percent)—it is electrically operated on request with a push button and is under control of the driver;
- Elevated bus stops, the height of which are 20 to 21 cm most of the time. Attention must be paid to sweeping over the pavement when docking.

A survey performed during 1996 among the network operators indicated that 38 percent acknowledged willingness to improve the quality of service toward all passengers. Accessibility for persons with reduced mobility was the primary motivation of only 25 percent of operators and local authorities. This explains why a few buses are equipped with an access ramp. Do these facts reflect some lack of willingness to admit wheelchair users onboard mainstream buses and the choice to facilitate only the travel of elderly and ambulant impaired people?

Some network operators, together with town planners, became convinced that introducing low-floor buses would be an opportunity to strengthen the presence of the network, making visible that it is part of the urban travel facilities. This system approach then would be considered as an urban development aid (4).

The first issue is the configuration of the bus stop. It has been demonstrated that drivers often are prevented from docking near the curb at bay bus stops (or are reluctant to do so for easier and quicker maneuver), and so automobile traffic is disturbed during the stop. It is now more common to implement a bus stop “on-line” (with restricted traffic or not) or as an “extended-bay,” as shown in Figure 2.

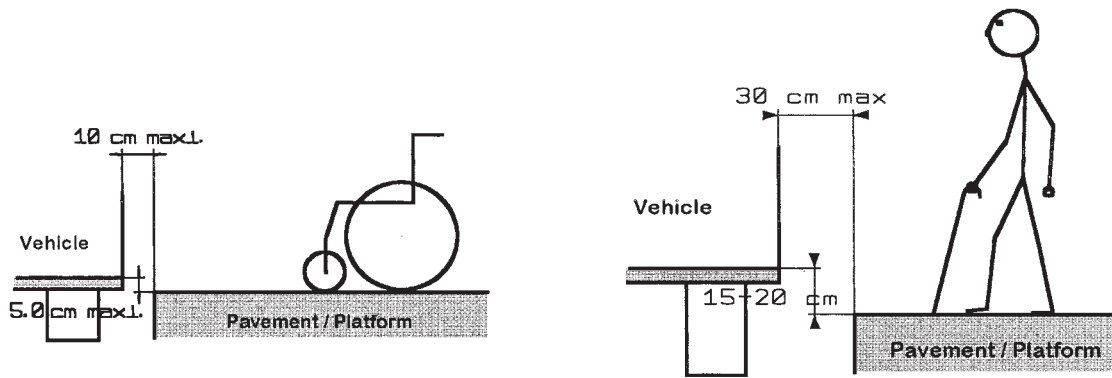


FIGURE 1 Gap dimensions to accommodate people with reduced mobility.

Of course, strict enforcement of car parking restrictions at bus stops is all the more crucial. Quality of service is improved because of shorter dwelling times, a smoother ride, and, in the case of an extended bay, a wider waiting area for public transport users and more car parking lots.

DEVELOPMENT AND EVALUATION OF GIBUS DOCKING AID SYSTEM

Facilitating the driver's task of docking close to the bus stop has been an issue for some network operators (among them CTAC in Caen, Semitag in Grenoble, Semitag in Nantes, and CTS in Strasbourg).

The Grenoble transport authorities and the operator of Semitag worked on a research and development project in view of developing a fully accessible low-floor bus system. INRETS, Transcet (a mass-transit transport engineering company), and Renault V.I. were partners of this project. Called GIBUS, the project included a thorough ergonomic study, the design of bus stops, and the development of a docking aid device.

Ergonomic Study of Docking at Bus Stop

Through direct observation of drivers when docking on a commercial route, as well as interviews of the drivers, the ergonomic study (performed by ERGONOMOS, a consulting firm) led to creation of a tree description of the drivers' activities. It distinguished the approach phase from the docking phase (5,6). An example for an on-line stop is given in Figure 3, identifying driver action, reasoning,

or choices as well as environmental factors. This study revealed that docking at a bay bus stop was much more demanding for the driver and ended with much larger gaps than the two other designs: on-line and extended-bay.

As a result, the ergonomists recommended improvement of the design of the bus stop and, most important, to reach a uniform design all along the bus route (and in time the whole network). The driver should identify the bus stop with landmarks that are highly visible ahead of the stop. Road markings were suggested to indicate the ideal path from 40 m upstream of the bus stop. However, because the driver must keep his or her attention on traffic, such a visual aid should mobilize the peripheral field of view so that the driver is not obliged to focus on some feature in front of him.

Bus Stop Design

The network operator and the local authority worked on the design of the bus stop. They involved the bus drivers as well as the bus manufacturers. After analyses and experimental tests, it appeared important that the design make the driver confident with steering the bus close to the curb (without fear of damage). In April 1996, a new bus route was opened that featured 18 bus stops of the new design. After few further improvements, the finalized bus stop design includes the following:

- An extended bay with a shelter, seats, information map, and time schedules;
- A pavement raised up to 21 cm;
- An oblique curb (the "Kassel curb" in Germany) made of white concrete; and



FIGURE 2 (a) Bus stop configuration, on-line; (b) Bus stop configuration, extended bay.

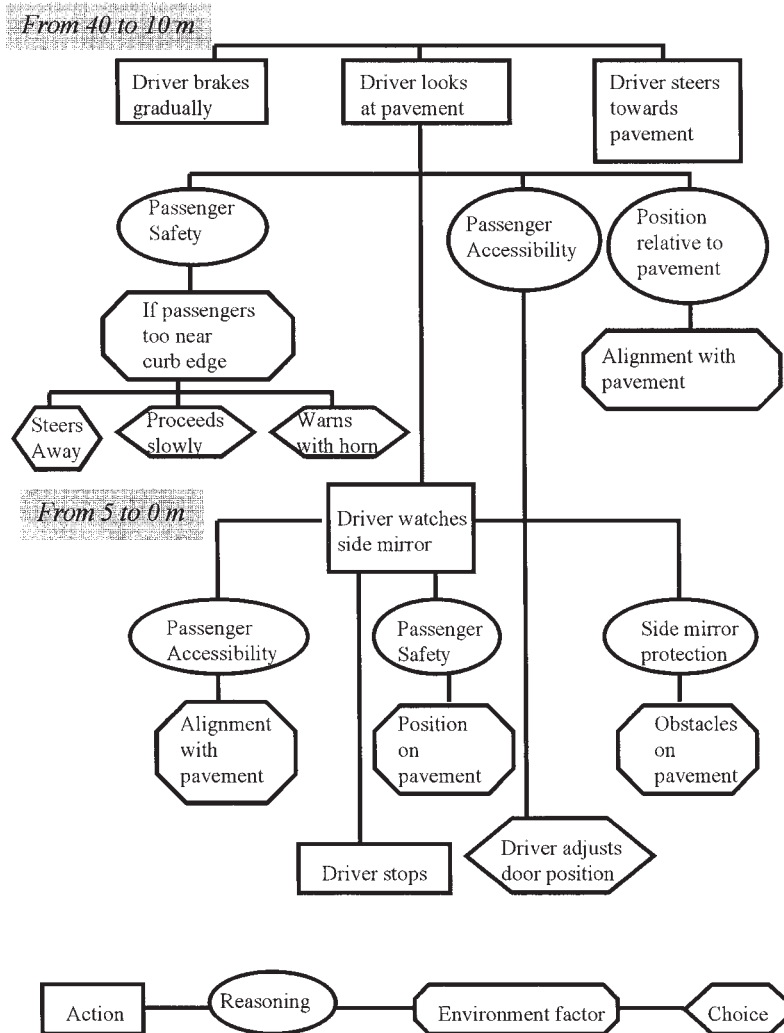


FIGURE 3 Tree description of driver's activities for docking at on-line bus stop.

- A rugged strip of contrasted color with the pavement, 60 cm wide from the curb (to prevent pedestrians from standing too close) and ending with a striped stone (so that sight-impaired people can identify the bus stop and curb).

More than 100 other bus stops have been redesigned in accordance with these specifications (Figure 4). The second "fully accessible" route was inaugurated on June 1998; it was operated with low-floor articulated buses equipped with a kneeling system and a powered access ramp. The kneeling system should be activated only in case of a bus stop at a standard level pavement of 15 cm (in case of disturbances).

GIBUS Docking Aid Device

Description

A literature survey of guiding systems allowed an examination of various technologies developed for passenger transport in cities,

within restricted areas (leisure parks), or for freight transport (as in industrial plants). Apart from the requirements issued from the general objectives and from the results of the ergonomic study, the operator Semitag added two requirements: (a) avoid the burden of electrical wires in the soil (owing to frequent road works), and (b) enhance the driver's environment (the bus is considered "crude" as compared to a tramway or auto).

It was then envisioned to develop an electronic device that would display the real position of the bus relative to the curb. Such a device would include a telemeter, a microprocessor, and a visual display. A preliminary experiment tested three candidate systems:

- A painted line on the pavement (as a road marking),
- An electronic aid with a screen display implemented at the right end of the dashboard, and
- An electronic aid with an LED display (two amber and two red lights), implemented on the right A-pillar under the side-view mirror.

A fourth system delivering an audible signal has been abandoned because the driver cockpit environment already was quite noisy.



FIGURE 4 Accessible bus stop in Grenoble.

Tests performed with three drivers on a restricted road showed that the drivers preferred the electronic aid with a screen display. They also appreciated the capability of this system to show when the target position was overtaken (warning of the risk of sweeping over the pavement). They may have lacked training to take advantage of the painted line.

The development of a prototype device was then launched. As shown in Figure 5, it included the following:

- An ultrasonic telemeter located under the bus body behind the front wheel;
- A microprocessor that, in time, could be connected to the management control system; and
- A visual display using LED technology that lights up progressively when the distance to the curb decreases and shows the target gap with two bars corresponding to 10 and 6 cm from the curb.

Performance Assessment

An experiment was conducted with field trials on the new bus route during commercial operation (7). An ergonomist observed driver

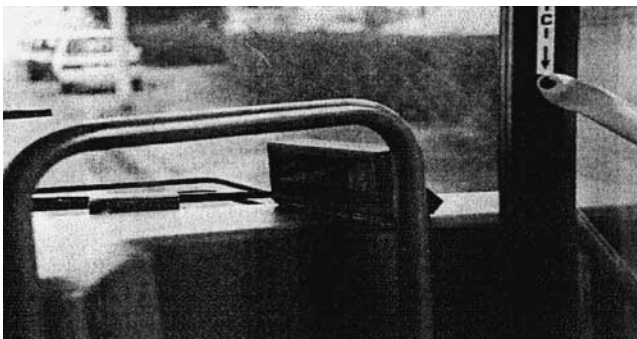


FIGURE 5 GIBUS docking aid device.

behavior, noted his opinions at the scene, and interviewed the driver after each trip. Two surveyors collected the parameters relevant to the bus operation and docking (traffic disturbances, gap at stop, longitudinal position at stop, pedestrians near the curb, etc.).

The drivers were instructed to dock at the bus stop when required (by the passengers or by the surveyors) and to reach a small gap by using the GIBUS display. Moreover, they were asked to stop the bus at the designated longitudinal position, so that the front door could be found easily by sight-impaired people. For training purpose, two trips were made without GIBUS display.

Eight drivers participated in the experiment, but unfortunately only one was familiar with the bus route and the low-floor bus, despite the selection criteria suggested to the staff manager. It must also be pointed out that the bus route was not very busy (newly opened in the suburbs), and some bus stops were not yet enhanced according to the accessibility specifications. More than 380 docking maneuvers were recorded and analyzed.

The results for the bus position at stop were as follows:

- The mean gap from the curb was 8 cm, with a standard deviation of 7 cm. This can be considered a very good performance; nearly all the bus positions would have allowed ambulant-impaired people to board or exit the bus without difficulty (the access ramp would be unfolded for wheelchair users). Moreover, the bus was parallel to the curb (mid-door as near the curb as the front door).
- The longitudinal position was always farther than the designated position (mean value 50 cm). However, these positions were much less widespread than those encountered during the first ergonomic study.
- The GIBUS device appeared to help drivers dock close to the curb; the gap at stop was significantly smaller when the display was on, whether or not the bus stops were enhanced.

Driver Behavior and Opinions

The drivers rapidly adopted strategies for docking with the new system of bus stop design and the GIBUS docking aid. Their opinions varied about the help provided by the visual aid, but the opinions sometimes did not correspond to what the drivers had been able to perform:

- Three drivers had favorable opinions and thought that they had improved their docking performance.
- Three others did not determine that it helped them. In fact, they considered the target gap too small and not necessary for their customers, and they were afraid to come close.
- Three drivers felt that their visual load was increased by the usage of GIBUS. They decided to ignore the visual display after a number of stops. However, another driver acknowledged that his feelings of a greater visual load and stress disappeared over time.
- The drivers pointed out that safety was their priority and so estimated that they could not use the visual display in tough situations.

Recommendations

Provided the limits of this experiment highlighted earlier, the results show that the target gap of 10 cm at the bus stop can be reached with both the new accessible bus stop and the GIBUS docking aid. Several improvements were recommended:

- The bus stop design certainly has a highly positive influence on the docking performance; however, some difficult situations were identified, such as the stop immediately after a roundabout or a right turn.

- The GIBUS docking aid provides distance information at the end of the docking maneuver. It is used as a control means of the final docking, not as an aid during the dynamic phase (located from 40 to 20 m ahead of the stop).

- The visual display should be better positioned, so that the driver can pick up the information rapidly and can avoid eye movements between the sideview mirror and the display.

- Information and training of the drivers is a very important issue. Drivers must adopt the operator policy toward persons with reduced mobility.

DEVELOPMENT AND EVALUATION OF VISÉE GUIDING SYSTEM

In the process of the project, Renault V.I. took the lead for the development of a more ambitious system. This system aims at guiding the bus on a predefined trajectory that limits driving uncertainties. The system is based on image processing and detects the position of the vehicle on the traffic lane in relation to the horizontal beaconing of the carriageway (straight or broken lines) by means of an onboard video camera. On the basis of this information, the central unit can calculate the ideal trajectory of the vehicle and act directly on the steering system via an electric motor. This system uses the earlier lane keeping demonstrator developed by Renault and Matra Cap Systèmes within the framework of a PROMETHEUS project (8,9).

The guidance system is not an automatic pilot but remains a driving assistance device that leaves the responsibility to the driver. At this stage, the development focuses on the docking at bus stop and is entitled VISÉE (10,11).

Description of VISÉE Guiding System

Localizing the bus calls for only minor implementation on the road infrastructure. As shown in Figure 6, the VISÉE guiding system includes

- A lozenge marking the next stop,
- Two parallel broken lines painted in a pastel color localizing the bus on its way,

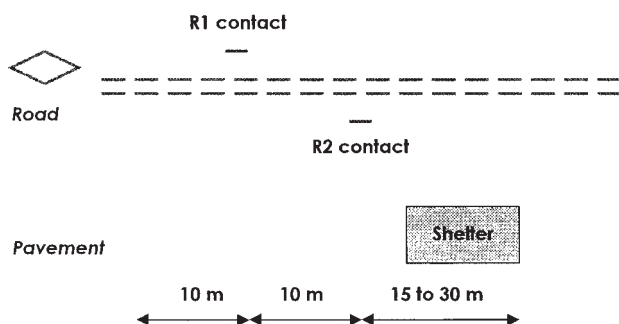


FIGURE 6 Localization system relative to bus stop.

- A first marker (R1 contact) identifying the type of bus stop and activating the docking procedure, and
- A second marker (R2 contact) used for security.

These markers are encoded with parameters that define the ideal trajectory—distance between lines, distance to the stop position, length of the bus stop platform.

The steering control is integrated on the steering column. It starts at the first marker and stops at the bus stop. The driver can let him- or herself be guided or can take another trajectory if the one suggested by VISÉE is not appropriate to the situation. The system automatically detects what the driver is trying to do and adjusts its action so as not to interfere with the driver's maneuver.

The man-machine interface (MMI) informs the driver about the guiding system state. It has been conceived with redundancy in the information display:

- Kinesthetic information: a vibration appears in the steering wheel when the guidance starts, then the driver can feel a torque in the steering wheel during the whole docking;
- Audible information: this warns the driver when he or she overrides the system; and
- Visual information: a series of three LEDs is located on the dashboard and gives the state of the system—yellow, ready to run; amber, system on action; red, failure and system is deactivated.

Experimental Assessment of VISÉE system

Apart from tests on reliability, safety, and other industrial issues, an experiment has been settled in order to assess the precision and repeatability of the system and to check the acceptability for the driver. Field trials were performed by bus drivers on a real site (with urban traffic but without passengers). The method used various scenarios devised with an ergonomic approach so that the driver's behavior could be studied in standard operating situations as well as with voluntary incidents.

The assessment is based on direct observation of the driver's activity by an ergonomist from ERGONOMOS, the recording of the driver's opinion (on scene and after each trial), the physiologic measurement of stress, and the recording of vehicle parameters (speed, gap during docking, system action on steering).

Performance Assessment

Bus docking with manual driving served as a reference, the drivers being instructed to come as close to the curb as possible. The VISÉE system was calibrated for a lateral gap of 10 cm. The results of about 700 dockings on a part of the new Grenoble route (equipped with the new bus stop design) with 10 drivers are summarized in Table 1. It is clear that the VISÉE system improves the performance measured by the mean gap. It also shows a good repeatability and a much lower discrepancy in the distance from the curb.

Human Factors Assessment

Twelve scenarios were added to validate the behavior of the drivers in downgraded modes, including loss of the reference line by the video camera during the guiding period and failure of the MMI although the system is active.

TABLE 1 Docking Performance from Field Trials on Real Site

	Mean Gap	Std Dev.	Min/max Gap
Manual docking	16 cm	6.5 cm	2/29 cm
Docking with VISÉE	11 cm	2.5 cm	3/18 cm

Analysis of all the trials must be used carefully because of the limited number of drivers involved in the experiment. However, it appears that the VISÉE guiding system simplifies the docking task. After apprenticeship, the driver's attention was not focused on the system and he or she was able to pay more attention to the surroundings (traffic, pedestrians, etc.). The driver's kinesthetic perception became keener with training so that he or she could detect more rapidly an anomaly or failure of the system. The visual information remained useful for the driver as confirmation via another sensorial channel.

The main results were as follows:

- The bus drivers appreciated the guiding system because it relieved them from managing the short gap at a stop and let them concentrate on traffic and pedestrian supervision;
- After an apprenticeship period, the docking task became quite automatic and so was a lessened burden for the driver;
- The guiding system was flexible, and the driver could easily override the system as desired; and
- The drivers rapidly detected failures or anomalies in the system by using the MMI information and recovered control without difficulty.

RECOMMENDATIONS

The experiment on real sites demonstrated the feasibility of the VISÉE guiding system, which improves the docking performance at bus stops and decreases the driver's work load. It gave very useful information on driver behavior and enabled recommendation of improvements. The following recommendations were suggested:

- The MMI should be improved, mainly the visual display should be better located on the dashboard.
- It remains necessary to implement the bus stop so that no disturbances would oblige the driver to swerve with an uncomfortable action on the steering wheel.
- Training of the drivers is important, and the passengers should be informed about the accessibility objective and the docking guidance system.

CONCLUSION

Implementation of low-floor buses is growing rapidly in France, and many local authorities and network operators are becoming more concerned about accessibility of their bus services for people with reduced mobility. The interest of a system approach, linking the bus and the infrastructure mostly for docking purposes, has been highlighted. Efforts have been made to enhance the bus stop design in accordance with the low-floor bus and its accessibility equipment

depending on the choice of each city. The primary feature should be the extended-bay or on-line configuration of the bus stop.

Through the partnership of different competencies within the GIBUS project—bus operator, town technical services, bus manufacturer, transportation research institute, and ergonomist—two innovative guiding systems as well as a new bus stop design have been developed and evaluated. The authors acknowledge the importance of considering the human factors all during the project's progress, the results of which will be added value for the drivers' acceptability during the period of introduction on the bus fleet.

The GIBUS docking aid device, which displays the distance to curb in the final approach, together with a new bus stop design, enables the driver to reach the target gap of 10 cm. It would be a very useful tool for training the drivers for the docking objective.

The VISÉE guiding system, with automated steering for docking, proved to be a feasible technology and reached the expected performances for the gap objective at bus stops and for the driver's work load with a high level of safety.

The assessment of both systems in the city of Grenoble have demonstrated how each of them could help the driver in his or her docking task. It is clear that the VISÉE guiding system provides better performances with low discrepancy as well as a lower driver work load. However, such a system certainly will be more expensive than the GIBUS docking aid device.

GIBUS and the bus stop design will be evaluated on route 8, recently made accessible with surveys on operating performance (dwelling times, gap at stop) and on quality of service for passengers, including people with reduced mobility and wheelchair users.

Renault V.I. and Matra Transport International are further developing the VISÉE system, which will be part of the future intermediate transport system on dedicated rights of way called CIVIS.

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