Engineering Design Solutions:
Future Considerations

BUS DRIVER'S CAB

A COMPILATION OF SEVERAL RESOURCES

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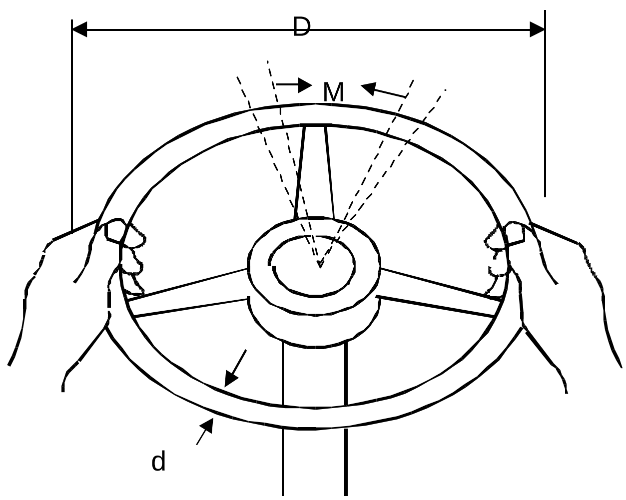
The measurements of the driver's cabin and the adjustments that can be made to the seat and steering wheel must fall within a range that accommodates 95% of the working population. Special proportions, such as being overweight and having long or short limbs, should be taken into account in the design.

1. ENTRANCE TO DRIVING CAB

Anything that can be stumbled on should be avoided. Steps in the entrance area must be of equal height and have adequate step depth.

2. STEERING WHEEL

Figure 1 shows the recommended ranges of dimensions (hand wheel diameter, D, and rim diameter, d, and displacement, M) for hand wheels designed for operation by two hands are given. Minimum-to-maximum tangential forces needed to operate them, with one or both hands, are also shown.



Parameter	Recommended Design Value (Minimum – Maximum)	
Hand wheel diameter (D)	18-53 cm	7-21 in.
Rim diameter (d)	20-50 mm	0.8-2.0 in.
Displacement (M), from neutral	60^o	
Resistance at rim (tangential force)		
One-hand operation	20-130 N	4-29 lbf
Two-hand operation	20-220 N	4-49 lbf

Figure 1: Criteria for Hand wheel Design
Adapted from Department of Defense, 1974; Ely, Thomson, and Orlansky, 1963; Kellermann, van Wely, and Willems, 1963 Eastman Kodak, 2003.

3. SEATING

Seat position and design should be such as to eliminate or minimize all windscreen reflections from the vehicle interior. Windscreen reflections are a known potential hazard when buses are operating in service and good design practice should be employed to eliminate this problem.

Ensure the length of the seat rail accommodates greater than 95% of the population. This will eliminate smaller persons having to stretch when reaching for controls. At the same time, this will ensure that taller persons have sufficient leg room.

The driver’s seat should also have the following adjustments: seat length and height settings, seat back angle, seat bottom angle, seat depth and lumbar support. It is also recommended that the driver’s seat be equipped with a three-point seat-belt and head rest. The optimal seat placement has a back incline about 20º.Manually adjusting the seat to the ergonomically right position is time-consuming. Therefore, some way of electronically storing the adjustment functions listed in Table 1 should be investigated. This would allow for quick and easy re-finding of individual seating adjustments (e.g. by entering it onto an electronic card).

<u>Table 1</u>: Bus driver seat measurements and seat adjustment ranges.

Adapted from Ch. 102 Transport Industry and Warehousing. Ergonomics of Bus Driving In Encyclopaedia of Occupational Health and Safety / edited by Janne Mager Stellman. 4th ed. Geneva: International Labour Office, 1998. Vol. 3, pt. XVII.

Component	Measurement	Standard value (mm)	Adjustment range (mm)	Memorized
ENTIRE SEAT	Horizontal	—	≥ 200	Yes
	Vertical	—	≥ 100	Yes
SEAT SURFACE	Seat surface depth	—	390–450	Yes
	Seat surface width (total)	Min. 495	—	—
	Seat surface width (flat part, in pelvic area)	430	—	—
	Depth of seat recess	10–20	—	—
	Seat surface slope	—	0–10° (rising toward front)	Yes
SEATBACK	Seatback height			
	Min. height	495	—	—
	Max. height	640	—	—
	Seatback width (total)*	Min. 475	—	—
	Seatback width (flat part)			
	Lumbar area (lower)	340	—	—
	Shoulder area (upper)	385	—	—
	Side upholstering* (side depth)			
	Lumbar area (lower)	50	—	—
	Shoulder area (upper)	25	—	—
	Seatback slope (to vertical)	—	0°–25°	Yes
HEADREST	Height of headrest upper edge above seat surface	—	Min. 840	—
	Height of headrest itself	Min. 120	—	—
	Width of headrest	Min. 250	—	—
LUMBAR PAD	Forward arch of lumbar support from lumbar surface	—	10–50	—
	Height of lumbar support lower edge over seat surface	—	180–250	—

– Not applicable

* The width of the lower part of the backrest should correspond approximately to the width of the seat surface and grow narrower as it goes up.

The adjustability of the driver's seat and steering wheel should be coordinated so that all drivers within the design range can find positions for their arms and legs that are ergonomically friendly.

4. CONTROLS

All controls should be positioned in such a way as to avoid water damage from the driver's signalling window.

4.1 Foot-Operated Controls

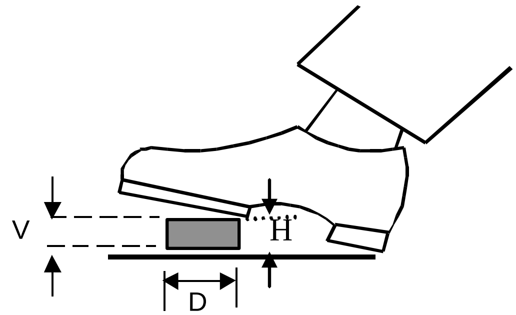
Foot controls are to be such to ensure fatigue-free driving, sensitive operation, avoidance of "wrong footing" and rapid transfers of foot from accelerator to brake. There are two main types of foot-operated controls, i.e. foot-operated push buttons / switching pedals and the operating pedals. In a push button / switching pedal, the pedal stroke is usually applied with the front of the foot, and small forces and strokes are required. In most buses, the left / right signalling controls are foot-operated push buttons. In an operating pedal, the force is applied by the whole foot, and the force that can be exerted is dependent on the holding time. Foot brakes are considered to be operating pedals.

Figure 2 shows the recommended minimum diameter (D) for foot-operated pushbutton. Figure 3 shows the minimum length (L) and width (W) of an operating pedal, which vary with the frequency of use of the pedal. The figures also show the range of pedal displacement distances (V) for pedals activated by either ankle or whole leg movement, as well as the maximum height (H) above the heel rest for a pushbutton, and the recommended range of ankle motion from the neutral position for any foot-operated control. The minimum and maximum forces, or counter pressures, needed to activate foot controls are given. Minimum forces will increase to 40 N (0.9 lbf) if the foot rests on the pedal. Maximum forces depend on which muscles can be used to activate the pedal; the large muscles of the leg are able to deliver more force than the smaller muscles controlling ankle motion.

Also, note the following:

- Pedals that result in overstretching of the ankle joint (more than 25º around the resting position of the foot) are not recommended.
- The more frequently a foot pedal is operated, the nearer it should be to its minimum force limit.
- If the operation of a foot pedal requires very high counter-pressures, the pedal should be placed to allow the leg muscles, not just the ankle, to exert the force.
- Counter-pressures greater than 400N (90 lbf) should not be required on a frequent basis even when the leg is involved, as in operating a brake (Motimer, 1974 in Eastman Kodak, 2003).

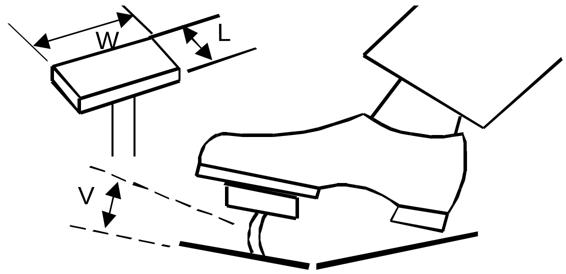
The design of accelerator and brake pedal control locations is subject to a number of conditions: vehicle structure, cost, comfortable reach, optimum force exertion, etc. Control via the accelerator pedal is almost a continuous task. Therefore, this pedal should be located so that the driver can comfortably operate it for extended periods. Braking, on the other hand, is applied intermittently. It involves basically a leg movement and requires the exertion of maximum leg force under certain emergency conditions, hence the force criteria is more important than the comfort criteria for the brake compared to the accelerator.



Switching Pedal or Push Button Parameter	Recommended Design Value	
Diameter (D)		
Minimum	12 mm	0.5 in.
Preferred	50-80 mm	2-3 in.
Displacement range (V)		
For ankle flexion	12-65 mm	0.5-2.5 in.
For whole leg movement	25-180 mm	1-7 in.
Maximum height of pedal above heel rest (H), lower leg vertical	8 cm	3 cm
Angle of ankle from neutral position, recommended minimum - maximum range, operator seated	20^{o} up, 30^{o} down	
Counter pressures, recommended minimum-maximum	15-75 Nm	3.3-16.5 lbf

<u>Figure 2</u>: Foot-Operated Push Buttons (or Switching Pedals) Dimensions and Counter-pressures

Adapted from Department of Defense, 1974; Ely, Thomson, and Orlansky, 1963; Kellermann, Van Wely, and Willems, 1963; Murrell, 1965 in Eastman Kodak, 2003.



Operating Pedal Parameter	Recommended Design Value	
Minimum Length (L)		
Occasional use	8 cm	3 in.
Constant use	25 cm	10 in.
Minimum Width (W)	9 cm	3.5 in.
Displacement Range (V)		
For ankle flexion	12-65 mm	0.5-2.5 in.
For whole leg movement	25-180 mm	1.7 in.
Angle of ankle from neutral position, recommended minimum-maximum range, operator seated.	20^{o} up, 30^{o} down	
Counter-pressures, recommended minimum-maximum	15-90 N	3.3-19.8 lbf

Figure 3: Operating Pedals Dimensions and Counter-pressures
Adapted from Department of Defense, 1974; Ely, Thomson, and Orlansky, 1963; Kellermann, Van Wely, and Willems, 1963; Murrell, 1965 in Eastman Kodak, 2003.

4.2 Hand-Operated Controls & Equipment

All controls in the driver's workstation should be arranged for comfortable access. A large number of controls are often required due to the amount of equipment added to the vehicle. For this reason, controls should be grouped and consolidated according to use. Frequently used controls such as door openers, bus stop brakes, and windshield wipers should be placed in the main access area. These controls should be able to be reached without stretching and/or twisting the body. Less frequently used controls can be located outside the main access area (e.g. on the side console). Controls should also be designed for simplicity and consistency so that ideally they are positioned in the same areas on different types of vehicle to avoid confusion.

An important part of the bus driver's activity consists of selling tickets, operating devices to provide information to passengers and communicating with the company. Until now, separate devices (e.g. radio headset), located in the available work space and often hard for the driver to reach, have been used for these activities. An integrated design should be sought from the start that arranges the devices in an ergonomically convenient manner in the driver's area, especially the input keys and display panels.

The driver's signalling window should be simple to operate when the driver is seated in the normal position.

Cash-collecting Equipment

As the driver could have to process thousands of transactions per week, it is vital that the electronic ticket machine is mounted within easy reach of the driver and also in such a position that sunlight does not adversely affect viewing the machine's display. These displays should be back-lit wherever possible.

Cash collection equipment should be designed to suit the individual operator's requirements and be free from sharp edges or obstructions that might injure the driver during ticket transactions. The equipment needs to be in some form of housing to allow it to be adjusted to suit various sizes of driver and driving positions.

Cash collection equipment should be located, where practical, to minimize constant twisting of the spine during operation. The option of utilizing driver seats with a swivel feature could be explored. The units should not obstruct, or interfere with the operation of any driving controls or gauges. The cash collection area should be adequately lit by a light source under the driver's control, and should ensure secure cash transactions.

5. INSTRUMENT PANEL

All visual warning systems should be in the driver's field of vision and be unobstructed by the steering wheel. Clear simple analogue dials which are properly illuminated are necessary.

Analyses of visual movements have shown that driving the vehicle in traffic and observing the loading and unloading of passengers at the stops is a serious burden on the driver's attention. Thus, the information conveyed by instruments and indicator lights in the vehicle should be limited to those absolutely necessary. Vehicle computerized electronics offer the possibility of eliminating numerous instruments and indicator lights, and instead installing a liquid crystal display (LCD) in a central location to convey information, as shown in the instrument panel in Figures 4 and 5.

With the exception of the speedometer and a few legally required indicator lights, the functions of the instrument and indicator displays have been assumed by a central LCD display. With the proper computer software, the display will show only a selection of information that is needed for the particular situation. In the case of malfunction, a description of the problem and brief instructions in clear text, rather than in difficult-to- understand pictograms, can provide the driver with important assistance. A hierarchy of malfunction notifications can also be established (e.g., "advisory" for less significant malfunctions, "alarm" when the vehicle must be stopped immediately).

Furthermore, the instrument panel should also be adjustable to allow for easy access to adjustment levers and good visibility of the instruments. In this case, adjustments to the instrument panel should be coordinated with the steering wheel adjustment. Using a smaller steering wheel would prove beneficial.

5.1 Color Coding for Indicator Lights

- Use green for satisfactory operation, test ok, ready, etc.
- Use white for status, selection mode, test in progress or items that do not imply success or failure.
- Use yellow for alert, caution, recheck or delay.
- Use red for system inoperative, error, no-go, failure or malfunction.
- Blue is seldom used and also presents a problem for the color deficient observer who might have trouble distinguishing it from the green light.
- Flashing red would be used for extreme danger where life or machine is at stake. On-off periods should be 3 to 5 seconds.
- Flashing white light is used for alert to communications.

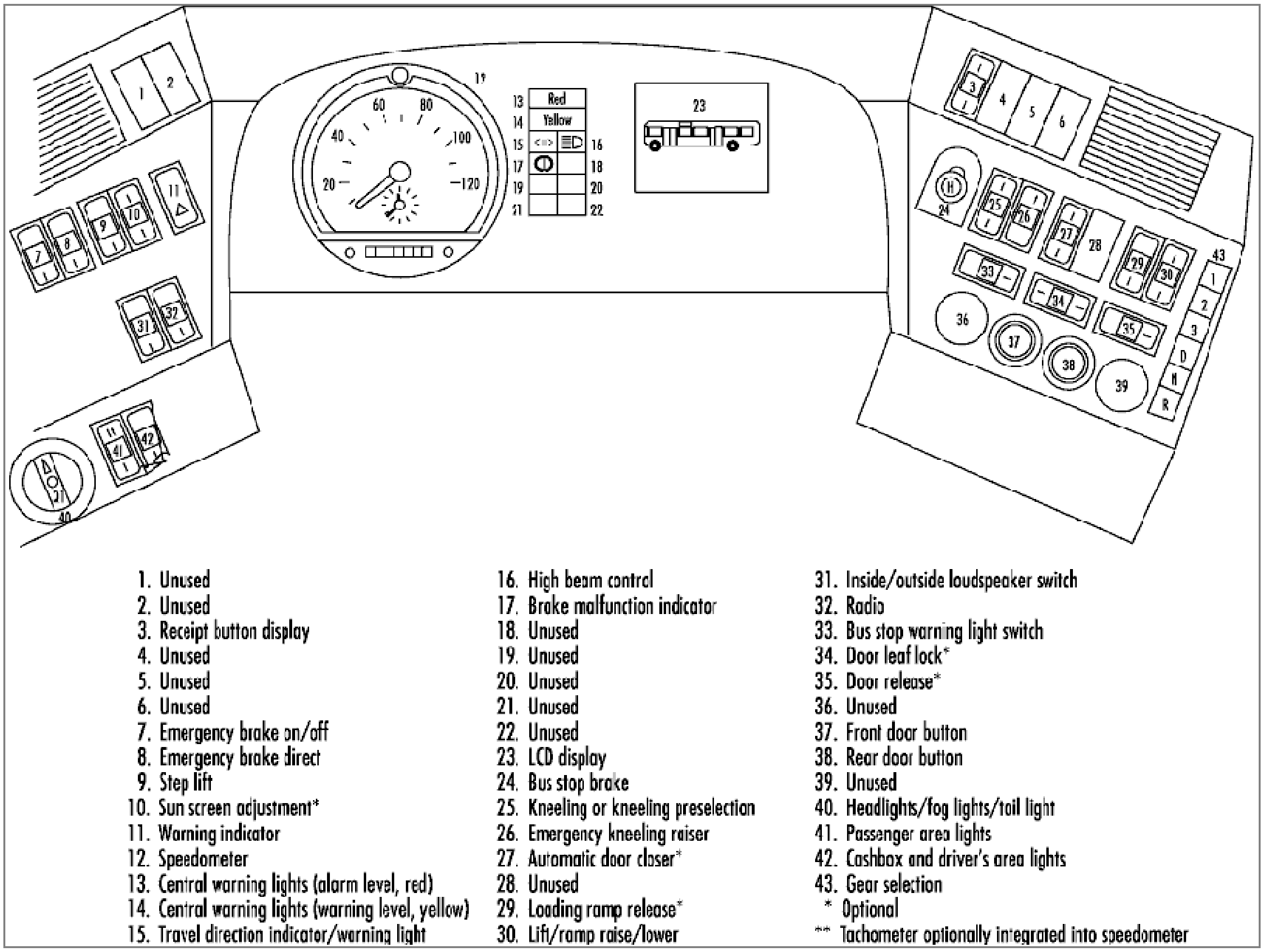
Figure 4: View of an instrument panel
Adapted from Erobus GmbH, Mannheim, Germany in Grosbrink & Mahr, 1988.

6. VIBRATION

Driving a vehicle causes vibration that could originate from internal sources such as the motor, the transmission components and other mechanical accessories, as well as vibration from external sources resulting from irregularities in the road or other obstacles (e.g. gutters) over which the vehicle has to travel. Added to these vibrations are transient excitations related to the motion of the vehicle, namely start-up, braking, turns, etc.

Seat suspension is, therefore, a desirable feature to reduce the effects of repetitive shock loads induced by deteriorating road surface, speed tables and “road humps”. However, this is a complex area which requires careful attention as the damping on the seat must be matched to the damping on the vehicle, so that the driver is not inconvenienced by large vertical seat movements when negotiating such potential road hazards.

Also, since the vibration environment could be affected by factors such as the driving speed, the road characteristics, the type of bus, and the load in the bus, their influence must be known so as to identify the seat suspension that could have the best performance under the greatest number of operating conditions. Efforts should also be directed toward a seat suspension mechanism which automatically adjusts itself at mid-ride position and has a height adjustment independent of the suspension.



<u>Figure 5</u>: Illustration of an instrument panel with legend
Adapted from Erobus GmbH, Mannheim, Germany in Grosbrink & Mahr, 1988.

7. NOISE

High frequency noise can be irritating and should be eliminated because it could interfere with the drivers' concentration. It should be noted that there is a problem of low frequency noise (infra sound) which can be amplified by large flat plain windows. This problem can be avoided by careful design and thoughtful construction. For example, curved windows do not vibrate as much as flat windows.

8. ENVIRONMENTAL FACTORS

Suitable sun visors should be provided that provide adequate protection to drivers of all stature and should also be capable of adjustment to give shade from the side.

Heating systems in buses often heat the interior with warm air only. For real comfort, however, a higher proportion of radiant heat is desirable (e.g., by heating the side walls, whose surface temperature often lies significantly below the interior air temperature). This, for example, can be achieved by circulating warm air through perforated wall surfaces, which thereby will also have the right temperature. Large window surfaces are used in the driver's area in buses to improve visibility and also for appearance. These can lead to a significant warming of the inside by sun rays. The use of air conditioning is thus advisable.

The air quality of the driver's cabin depends heavily on the quality of the outside air. Depending on the traffic, high concentrations of harmful substances, such as carbon monoxide and diesel motor emissions, can briefly occur. Providing fresh air from less-used areas, such as the roof instead of the vehicle front, lessens the problem significantly. Fine-particle filters should also be used.

9. PERSONAL FACTORS

Where anti-assault screens are necessary they should be fully integrated into the overall cab design to ensure that the driver is adequately protected, but that the nearside driving mirror can be easily viewed and reflections from the interior lighting system are eliminated. Care should be taken to ensure that the driver can communicate adequately with the customer with the screen in place.

Finally, the assessment of the driver's area by the drivers, whose personal interests should be taken into account, is of great importance. Supposedly minor details, such as placement of the driver's bag or storage lockers for personal effects, are important for driver satisfaction.

10.CONSIDERATIONS FOR LOW-FLOOR BUSES

10.1 Fare Box

As a result of raising the operator's position, the ergonomic relationship of the fare box to the operator and passengers will need to be adjusted to assist the operator in operating the unit and monitoring fare payment. Operation of the fare box is particularly important where manual or mechanical fare boxes are employed. With electronic fare boxes remote activation switches can be used. These are encouraged and their location could be determined by the individual transit system.

One approach is to adjust the height of the fare box by placing it on a platform to elevate it. This would be based on both the design of the fare box itself (i.e. is it floor or stanchion-mounted), the driver's platform height and a balance between convenient customer access (particularly for children and those carrying parcels, etc.) and driver access. The top of the fare box should be between 1194 to 1245 mm (47 to 49 inches) from the floor assuming a driver's platform height of 330 to 432 mm (13 to 17 inches). A fare box platform could be integrated with the intermediate step for the driver's platform. However, any design should not restrict passenger movement in the front entrance area and, in particular, should permit passage by wheelchairs and scooters of normal design, typically meaning an envelope of 762 by 1219 mm (30 by 48 inches). The impact of this approach on ease of use by customers should be evaluated.

10.2 Driver's Platform Height

It is generally accepted that the driver's position on a low-floor bus relative to the road surface, should continue to be the same as that with a high-floor bus. Since this height is between 737 and 813 mm (29 and 32 inches), the driver's platform would need to be between 330 and 432 mm (13 and 17 inches) from the floor on a low-floor bus. This height range allows for individual variations between manufacturers to accommodate different windshield sizes and designs to minimize reflection of interior lighting, among other considerations.

With a platform height of 330 to 432 mm (13 to 17 inches), the question of a need for an intermediate step arises because this measurement exceeds the norm for a single step 165 to 178 mm (6.5 to 7.0 inches). Some transit systems have experimented with an intermediate step but removed it because it was not found to be useful and was even a potential tripping hazard, while others view it as necessary for safety reasons. Manufacturers should design the driver's platform area to accommodate an intermediate step but leave the choice of specifying a step to the individual transit system.

10.3 Vehicle Noise

There is some concern that interior and exterior vehicle noise and/or vibration is accentuated in low-floor buses due to the greater proximity of the passenger compartment to the road, and to the greater tire pressure in the smaller tires used by low-floor buses. Although it would be useful to measure actual noise and vibration levels, the overall issue of unacceptable vehicle noise levels is gaining prominence and many transit systems are specifying noise levels that are substantially lower (as low as 75-76 dba) than current levels (82-83 dba) to merit attention. This should also help to enhance passenger and bus driver comfort.

10.4 Visibility to Right Front Exterior Mirror

The height of the driver's seat in a low-floor bus compared to a high-floor bus should be relatively similar if the specifications discussed earlier are followed. However, some variation in the height of the front windshield can occur. Some systems have found that the tinted top portion of the windshield can obscure the driver's view of the exterior right hand mirror. This situation should be reviewed by the transit systems in any new vehicle models. If this appears to be a problem, systems may wish to consider excluding the tinting from the top portion of the right-hand windshield.

10.5 Destination Sign Control

Another minor concern in low-floor bus models is accessibility to the destination sign control switch for drivers. The destination sign and its controls are somewhat further from the driver compared to high-floor buses with the result that it is difficult for the driver to reach the controls without leaving the seat. Where possible, install an extension of about 152 mm (6 inches) to the handle or lever used to change the destination sign. For digital route signs, the controls could be relocated to either the driver's front or side instrument panels.

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