TOWARDS A SAFER FITNESS TO DRIVE AND DRIVING ABILITY
ASSESSMENT PROCEDURE WITH JOYSTICK

Juan F. Dols
Assistant Professor, PhD.
Universitat Politècnica Valencia, Camino de Vera, s/n. 46022 Valencia, Spain
Phone: + 34-963877625 E-mail: jdols@mcm.upv.es

ABSTRACT

This paper presents a new fitness to drive and driving ability assessment procedure developed by the University Polytechnic of Valencia (Spain) for evaluating severely drivers with impairments who cannot drive a motor vehicle with standard car control adaptations. The objective of this new assessment approach was based on performing a series of practical tests divided into two main phases.

The first phase of the assessment utilizes a simulator that allows a safe measurement of all the necessary parameters needed to determine the residual capacities (e.g. forces, torques, displacements, reaction time, etc.) of the driver that can be used for driving a joystick controlled vehicle. Furthermore, driving maneuvers are performed in a controlled way to determine required movement coordination, response times, etc. The SERCO simulator was designed and developed for this purpose as a modular, portable and adaptive experimental tool that allows assessing driver candidates with or without leaving their wheelchair using all types of technical aids including joystick controls. The result of this first assessment phase determines the more appropriate joystick device and space location as a function of the driver needs.

The second phase of the assessment procedure includes a series of driving ability tests on a closed circuit. From the information obtained during the assessment in the simulator, the most suitable type of joystick device is determined for driving safely and the restraint system needed both by the user and the wheelchair. At this stage it will also be possible to assess the accessibility requirements needed for the adapted vehicle. Moreover, at this stage a battery of practical tests is performed in a closed circuit with the vehicle in motion, which follows the recommendations and requirements defined by the EU current legislation for obtaining a driving license (EC, 2006), reproducing vehicle maneuvers as close to reality as possible.

As a result of the described procedure it is possible to ensure that the driver is able to fulfill the minimum requirements for obtaining a driving license. Furthermore, it is possible to determine required driving restrictions or limitations, corrective conditions and coding of adaptations according to EU legislation.

1. INTRODUCTION

Driving motor vehicles by People with Reduced Mobility (PRM) has always been regarded by authorities as an anomaly that from the technical and legal environment, has led to the emergence of a number of restrictive barriers in the legislative framework on industrial safety, and especially as it affects the design and type approval of vehicles, and legislation relating to the driver in the process for obtaining the driving license (Dols, 2009).
Since its origin, the European Union (EU) has been setting standards to be followed by member states in the form of directives. Each new directive has a settling time to be adapted by each member country, which also, in turn, uses their own legal pathways for introduction into their national legislation. The policy reference in the field of driving license in the EU is currently the 2006/126/EC Directive (EC, 2006), so-called 3rd Directive, which consolidates the previous directives on the subject. Article 7 of this Directive stipulates that driving licenses shall be issued only to those who have passed a test of driving skills and behavior and also meet medical standards, in accordance with Annexes II and III. Annex I of this directive describes a list of EU harmonized codes and sub-codes that must be written in the driving license card. These codes clearly state driving limitations and/or adaptations needed on the vehicle to be driven by a driver with disabilities or impairments. Annex II is dedicated to establishing minimum criteria for driving tests based on the knowledge, skills and behaviors required to drive a motor vehicle. Furthermore, Annex III lists the minimum standards of physical and mental fitness for driving a power-driven vehicle based on sight, hearing, persons with functional disability, neurological diseases, mental disorders, cardiovascular diseases, diabetes, alcohol, drugs, medications, etc. Finally, the Directive 2009/113/EC has amended Annex III of Directive 2006/126/EC on driving licenses in sections that refer to the visual capacity, diabetes mellitus and epilepsy.

Regarding drivers with physical disability, the Annex III of 2006/126/EC Directive states that driving licenses shall not be issued or renewed to driving license candidates or drivers suffering from complaints or abnormalities of the locomotor system who make it dangerous to drive motor vehicles. Specifically, for Group 1 drivers the directive states that Driving license may be issued to physically disabled applicants - or drivers - following the opinion by a competent medical authority, based on a medical assessment and, where necessary, on a practical test. This assessment must also indicate what type of vehicle modification is required and whether the driver needs to be fitted with an adaptation device, demonstrating that with such a device the disability should be compensated for. In case of an applicant suffering from a progressive complaint, the driving license may be issued to or renewed on the condition that disabled person is regularly examined to check that is still capable of driving the vehicle completely safely. For Group 2 drivers (professional), a competent medical authority shall give due consideration to the additional risks and dangers involved in the type of vehicles covered by this group.

In 2008 different Spanish government organizations conducted the EDAD survey which highlights that the total number of people with disabilities were about 4,12 million, considering people living at home and people living in centers for the elderly, disabled facilities, psychiatric and geriatric hospitals (9% of the population living in Spain at 2008) (INE, 2008). Regarding transportation the EDAD survey determines that the private car and public transport are the most used ways and means for mobility of persons with disabilities (58.3% and 42.5% respectively). Also the special transport service –ambulances, buses or minibuses for this group- accounts for 9.2%. Disabled people surveyed -about 1% (448,000)-, were considered disabled regarding the task of driving motor vehicles.

According to a study by Ramirez and Azor (2015), the number of drivers with disabilities in Spain with at least one adaptation installed in their car is 56940 in total - representing 0.2% of total number of drivers-. Within this group, 70% are men and 30% women, a percentage that differs from other drivers without adaptations, which is represented by 59% and 41% respectively. In relation to age, the highest number of drivers with vehicle adaptations corresponds to the margin 55-59 years (13.75%), followed by group 50-54 (12.88%), and 60-64 (10.95%). Above 70 years, drivers with disabilities traveling with adapted vehicles in Spain are 13.71%. In short, more than 60% of drivers with
impairments who drive adapted vehicles in Spain have more than 50 years, specifically, two out of three drivers obtained permission 20 or more years ago, with only 13% having a driving license antiquity lesser than 10 years.

1.1. Joystick steering driving ability assessments

The results obtained in previous research (Hogan and Szeto, 1982; Östlund and Peters, 1999; Clemo, 2005) show that with the wide range of technical aids currently offered in the market, it is very difficult to reproduce objective tests to predict the driving ability of severely disabled people. However in case of drivers with impairments that are able to use Joysticks as the only solution for driving a motor vehicle, the use of experimental tools as simulators or special vehicles would help to pay special attention along the assessment to several actions for driving, as for example: the range and direction of control movements, operating response and feedback, muscle strength by the driver to perform a safe operation, fine adjustment of controls, comfortable operating range, etc.

Clearly, a simulator will never be able to replace an assessment procedure performed on a real vehicle, but nevertheless can be a valid tool to measure the ability of driving from candidates in certain operating conditions, and at the same time allowing assessment centers savings far greater costs in relation to the acquisition of real vehicles equipped with sophisticated servo-controlled aids. Some of the research held in this field shows the importance of doing these practical tests.

A new assessment procedure have been developed by the University Polytechnic of Valencia (Spain) for evaluating severely drivers with impairments who cannot drive a motor vehicle with standard car control adaptations. This assessment is based on performing a series of practical tests divided into two main phases. The first phase utilize a simulator that allows a safe measurement of all the necessary parameters needed to determine the residual capabilities (e.g. forces, torques, displacements, reaction time, etc.). The second phase includes a series of driving ability tests on a closed circuit. This paper will only be focused in the description of the first assessment phase based on the simulator tool experience.

2. THE NEW ASSESSMENT PROCEDURE FOR SEVERELY DRIVERS WITH IMPAIRMENTS IN SPAIN.

The difficulties encountered by people with severe disabilities in obtaining the driving license in Spain, jointly with the technical barriers related to the process of legalizing adapted vehicles and the selection of vehicle control adaptations motivates the promotion of this new assessment procedure. This new assessment was defined taking into account experiences carried out in recent years in different European and non-European countries. Studies such as those conducted by the MAVIS (1998), European projects as AGILE (Sommer et al., 2003) and IDEA (Dols et al., 2005) or more recently the CAPI initiative (2010), have shown that the assessment of a disabled driver requires the performance of two types of evaluation procedures: a fitness to drive assessment test in a stationary vehicle, and a driving ability assessment developed in a real circuit with a special adapted vehicle.

Given the nature and type of assessment that must be done to evaluate the fitness to drive inside the stationary vehicle to determine the residual capacities of a driver with severe disabilities, and taking into account that the disabled driver must be fitted with the Joystick devices most suitable for his handicap, it was decided to develop an experimental tool to replace the initial evaluation procedure held in a stationary real vehicle. By using this tools it is possible to select the best choice of technical aids and the measurement of any driver skills without design restrictions, safer for the user and with the inherent economic cost savings for the driver as not to have to purchase a real vehicle -cost
prohibitive in most cases, depending on the type of adaptations needed, to perform a practical fitness to drive assessment in a driving passenger compartment.

The assessment procedure developed in this project was conceived for evaluating severely drivers with impairments suffering from illness who impaired them to drive a motor vehicle due to severe disability – as neurological disorders, quadriplegic, lower limb amputations and reduced mobility in upper members, etc. The assessment was based on performing a series of practical tests divided into two main stages (see Figure 1). In the first phase is evaluated the fitness to drive capacity of applicants while in the second phase is being checked the driving ability to drive a special adapted vehicle with Joystick technical aids.

The second stage of the assessment procedure includes a series of practical driving tests on a closed circuit. From the information obtained during the assessment held in the simulator-experimental tool, it is possible to determine the type of Joystick control devices most suitable for driving safely, the restraint systems needed both by the user and the wheelchair, etc. At this stage we would be able to assess the technical aids requirements that guarantee accessibility to the adapted vehicle by the applicant, the safety conditions and driving typology of driving controls. But the most important issue at this stage is the implementation, with the vehicle in motion, of a battery of practical tests in closed circuit that follows the recommendations and requirements established by the current legislation for obtaining a driving license, reproducing the vehicle movement maneuver as close to reality as possible. The result of this phase of the assessment ensures that the driver is able to do the minimum number of driving requirements needed for obtaining the driving license.

Figure 1: Assessment procedure for severely drivers with impairments intended for evaluate its driving ability in powered Joystick steering vehicles

Finally, after completing these two assessment stages it would be possible to certificate the adequacy of the driving aids selected and the possible driving restrictions, limitations, corrective actions and Joystick adaptation needs for the control devices or technical aids installed in the vehicle. After
passing this assessment procedure the driver would be able to follow the standard theoretical and practical exam to get the driving license in accordance with EU legislation (EC, 2006).

2.1. Fitness to drive in the experimental simulation tool
The first stage of the assessment procedure requires the use of an experimental tool, consisting of a simulator allowing the measurement in a controlled and safe way to all the necessary parameters needed to determine the residual capacities for driving in a Joystick adapted vehicle, as i.e. the definition of the clamping ability of Joystick controls, strength capacity for acting onto the driving aids and the ability for performing driving maneuvers in a controlled way, movement coordination, response times, etc. The result of this first phase of evaluation will determine the more appropriate Joystick device as a function to the driver needs, and the best location that should have these technical aids in the driving position. This initial process allows the trainer to "filter" the tasks of driving that needs to be improved by the applicant in the process of further learning and training in a driving school, and in the worst cases, the situations in which users does not have enough residual capacity to drive these types of adapted vehicles.

2.1.1. The SERCO experimental tool.
The simulator for evaluation, training and rehabilitation of drivers (SERCO) is the result of the research project "Design and development of an experimental evaluation for the assessment of physical and sensory abilities of drivers," developed by the Institute of Design and Manufacturing (UPV) and the IDF Association and sponsored by the IMPIVA (Valencian Region Administration) in the 2009 call. The experimental tool consists on modular, portable and adaptive equipment that allows evaluation and assessment, both physical and sensory, of all types of drivers. Its design is based on an interactive fixed-base driving simulator (see figure 2). It is composed of a simulation computer, which provides the graphics required for the implementation of the simulation software; data collection in real time; wireless router; three-screen-display monitors 1.80x0.34 m with 120° of the field of view; Matrox TripleHead2Go graphics card; sound stereo system; steering wheel, pedals and gear shift of a Citroen Saxo and generic adjustable seat. All this provides a view of the road and the environment very close to the real conditions. The equipment of the simulator allows collect many variables, such as speed, location, azimuth or lateral speed, with a frequency of 10 Hz. In addition, the simulator has been instrumented by load cell to measure forces at brake pedal; potentiometers for measuring displacement in the three pedals; micro-switch for detected the gear-box lever position; encoder for measuring the steering wheel angle; and torque sensor for measuring torques on the steering wheel.

![Figure 2: SERCO experimental tool views](image)

Initially the SERCO simulator was used for assessing drivers with impairments who drive with different standard technical aids, e.g. hand controls for acceleration and braking. But recently, the
simulator has been updated by installing different special devices and tools to facilitate driving through electronic technical aids -Joystick type-, to introduce the new assessment procedure for users with severe disabilities.

2.2. Fitness to drive in the experimental simulation tool
The procedure used in this first stage with the experimental simulation tool is divided into different sequential phases (see Figure 3), whose characteristics and objectives are described below.

![Figure 3: Fitness to drive assessment applied with the aim of the SERCO experimental tool.](image)

2.2.1. Driver's background
In this first step all the basic information of the driver is collected, and its content is grouped into the following datasets: personal information -name, age, sex, etc.-; assessment objectives -applicant, renewal driving license-; medical background -disease, anatomical and functional limitations-; experience in driving vehicles (if applicable) -permission type, number of years holding the license, km/year, percentage km. in urban or suburban area-; type of adaptations used for driving, accidents, withdrawal of license or loss of driving license points, use the vehicle for commuting in-job, etc. The possibility of fixing the seat belt occupant himself and the capacity to tighten their belts is also being checked. The last verification is the need for an armrest for operating the Joystick controls, and adjustments to the driver's arm in a stable and comfortable way.

2.2.2. Evaluation of clamping ability for the Joystick devices
In this step it is measured the user capacity for gripping and holding of the different type of joysticks, so in this way it is possible to determine the most appropriate device with respect to the driver’s upper limbs mobility and residual force. In the experimental tool it is possible to install different technical aids or orthotic products available at the market in order to determine the ranges of mobility that is possible for the driver to use. To do this test it has been designed and manufactured a special tool allowing to mounting different Joystick and clamping knobs at both sides of the cockpit. This auxiliary
device is designed so that it can change its spatial position and orientation reaching 6 degrees of freedom (see figure 2).

2.2.3. Evaluation of drive-ability for acting onto the technical aids

The objective of this step is to determine the functional capacity for driving with the Joystick controls already selected. The measurement of these capabilities should be performed under conditions and circumstances as close to reality as possible. In this project it has been used the simulation software SoftGesCo 3.0 and SoftSimCo 3.0, developed and licensed by the Polytechnic University of Valencia, adapted for assessing the Joystick-type driving devices. During these practical exercises it could be possible to measure, at least, the following driving maneuvers:

- **Braking Behavior**

This test consists on performing a sudden braking in a driving simulation closed-circuit. The test is conducted launching the vehicle by a straight line, which will increase speed until it reached a constant value of 40, 50 (the maximum legally permitted in urban environments) and 60 km/h. Once the vehicle has reached the reference speed (40, 50 and 60 km/h), the driver has to brake in the shortest time, measuring the distance traveled during the maneuver, while the vehicle passes during braking a corridor bounded by cones on both sides of the road (see figure 4 left). The test result should show the driver control while maneuvering to prevent the vehicle to become straight linear path during braking.

![Figure 4](image)

*Figure 4: Left- Scenario for testing braking behavior. Right - Scenario for testing movement coordination behavior in slopes.*

- **Driving Among Obstacles**

The slalom test (zigzag) or driving among obstacles consist onto circulate the vehicle among five cones placed at a distance of 15 meters. The speed rate for driving among the cones is 25 Km/h (see figure 5). The test is carried out in both directions. The objective of the test is to show how the driver maneuvers the vehicle avoiding the cones, without touching any of them in a continuous path. Depending on the joystick-type, is possible to repeat the test at higher speeds (up to 50 km/h.).

- **Turning Behavior**

In this exercise the driver follows a circular path, similar to passing a roundabout (see figure 6). The test is based on different reference standards, such as the SAE J266 (1996). In this case, the driver must turn the Joystick steering device, until it stops, providing a turning radius between 15 and 20 m.
The maximum speed to be reached in the trial will be between 20 and 25 km/h. The result of the test is intended for showing how the driver maneuvers the vehicle traveling in a controlled way along the curve, without reducing the turning radius and the constant vehicle speed.

![Diagram of a controlled curve](image)

**Figure 5: Scenario for testing driving among obstacles.**

- **AVOIDING OBSTACLES AT HIGH SPEED**
  This test takes place on a stage with high-speed running on a highway. The vehicle must achieve a constant speed of 100, 110 and 120 km/h in a straight line and stand behind a heavy goods vehicle. At one point, from the heavier transport vehicle an object (box, coil, etc.) dropped on to the road and the vehicle driven must avoid the obstacle without hitting it. The testing objective is to show how the driver maneuvers the vehicle so quickly to avoid the obstacle in a controlled manner without losing control and without colliding with the object in the road.

- **STATIC REACTION TIME**
  In this test the static reaction time of the driver is measured. A visual stimuli on the front screen is used as a trigger for braking. The stimulus may be a red light that comes on suddenly, and asked the driver to stop suddenly the vehicle. The exercise can be repeated as many times as needed to obtain an average reaction time.

- **MOVEMENT COORDINATION**
  This tests includes a series of coordination movements, which are intended for measuring not only the drive capability of a given primary controls -steering, throttle or brake-, but also the coordination action with another secondary controls. Different testing for movement combination is suggested in this evaluation step as described below:

  **MC.1 - Braking or accelerating during circulation in constant radius curve:** In this test the vehicle follows a circular path, similar to passing a roundabout. In this case, the driver must operate the joystick interface to provide a path of constant radius (15 to 20 meters). In the first part of the exercise the driver must entry into the roundabout accelerating up to the reference speed, which can be placed
at intervals of 25-50 km/h, while in the second part of the exercise, must reduce the speed until the vehicle stops completely, without leaving the curve of constant radius. The testing purpose is to ensure that the driver can safely follow the circular path (constant radius) accelerating and braking to a stop, with full control of the Joystick without deviating (blue line in figure 6 left side).

Figure 6: Left side- Scenario for testing turning behavior during circulation in a constant radius/speed roundabout. Right side - Scenario for testing turning behavior during circulation in a variable radius/speed roundabout.

MC.2- Turning in a curve of constant radius and variable speed: This test will reproduce a circular path, similar to passing a roundabout. In this case, the driver must operate the joystick interface to provide a path of constant radius (15 to 20 meters) (see blue line in figure 6 left sides). Once located the vehicle in the path of constant radius the driver must increase the speed up to a value of 25 km/h, and once reached it, he must accelerate without leaving the curved path until a reference speed of 50 km/h., and stay on the path at least one full turn. The test can be repeated for different speeds at the roundabout. The purpose of the test is to ensure that the driver can safely follow the curve (constant radius) accelerating to the reference speed.

MC.3- Turning in a variable radius curve and constant speed: This test will reproduce a circular path, similar to passing a roundabout. In this case, the system should be operated by the joystick interface to provide a path of variable radius at constant speed. Once located the vehicle in the inner path of the roundabout (see green line in figure 6 right side), must reach a reference speed of 25 km/h. From this reference speed the driver must vary the circular trajectory to reach a top radius of 20-25 meters (outer path) without changing speed. The driver should perform this maneuver completely around the roundabout (360 degrees). The purpose of this test is to ensure that driver can safely follow the curve (variable radius) and keep it at least one lap, with full control of the Joystick controls.

MC.4- Slopes: This coordination test is scheduled to be performed in an upward slope with a maximum gradient of 12-15%. The simulated scenarios pay attention to driving behavior in the
mountains, tunnels or parking basement. The driver must place the vehicle in the middle of the slope and completely stop with the parking brake engaged. Once there, the driver must initiate a controlled exit ramp without lose control of the vehicle (see figure 4 right).

**MC.5- Parking maneuver:** This tests pay attention to both cars parking in battery and reversing maneuvers. Special attention must be taken to the driver skills for operating the controls to perform all maneuvers. The purpose of the test consists of verifying that the driver can safely follow a reverse parking maneuver. Figure 7 shows different parking scenarios.

![Parking maneuver](image)

**Figure 7: Scenario for testing parking maneuver.**

### 2.2.4. Evaluation of driving behaviour in simulated scenarios

Finally, the drivers ability to drive is tested in practical exercises during which the driver has to drive with the Joystick in both urban and sub-urban environments. The main testing that could be performed can be highlighted as follows:

**TEST FOR DRIVING IN URBAN AND SUBURBAN SIMULATED SCENARIOS**

Simulation tests takes place in urban and interurban (see figure 8), reproducing normal traffic conditions – heavy traffic, turning roundabouts, sudden stops, bridges, tunnels, crossing tram tracks, etc.-. Throughout these simulated exercises the trainer must observe different driver behaviour and tasks: proper use of primary and secondary controls, controlled speed during manoeuver in a straight line and cornering, etc. During the simulated driving exercises it can be recorded the number of times the driver leaves the road, collisions with other vehicles or obstacles, mean and maximum driving speeds, violations of traffic signalling, etc.

**TEST FOR MEASURING THE DYNAMIC REACTION TIME.**

The objective of this test is to measure the driver reaction time under certain types of stimuli generated during simulated driving. The scenario will replicate a series of stimuli on the screen to which the driver has to react, and eg: in urban driving –moving objects, sudden appearance of children in the driveway, a vehicle door suddenly opened, etc.-, in highway driving –an animal that crosses the road, a
vehicle suddenly braking, an object falling from a transport vehicle that precedes us, etc.-. When the stimulus appears, the driver must stop the vehicle, operating the joystick until the stopped position. The exercise can be repeated as necessary to finally obtain an average reaction time. The driver must also stop the vehicle in a safe and controlled manner without losing its manoeuvrability.

Figure 8: Scenario for testing driving behaviour in simulated urban and suburban roads.

2.3. Final simulator assessment report
As a result of the different assessment steps held during the simulator phase will be generated a final report that summarizes the results obtained. To quantify the results from the practical tests carried out it has been established a scoring system for each test on a scale of 1-4, which a qualification criteria defined as follows:

• A score of 1 indicates a totally unsafe driving ability
• A score of 2 indicates a capacity for unsafe driving
• A score of 3 indicates a fairly safe driving ability
• A score of 4 indicates a full capacity for safe driving

All practical tests must be scored by the assessor and recorded in the computer program immediately after each test, once the trainer has been ascertained by observation of applicant driving skills. If the score on a practical exercise is 1, 2 or 3, the trainer analyse the circumstances that have caused such a score. Further comments will define the needs of the disabled driver for future corrections.

3. CONCLUSION
To conclude this paper it can be said that the new assessment procedure developed in this project was conceived for evaluating severely drivers with impairments suffering from illness who impaired them to drive a motor vehicle due to sever disability in Spain. The objective of this new assessment approach was based on performing a series of practical tests divided into two main stages. The first phase of the assessment procedure it requires the use of a new experimental tool, consisting of a simulator that allows the measurement in a safety way to all the necessary parameters needed to determine the residual capacities for driving in a Joystick adapted vehicle. The result of this first phase
of evaluation will determine the more appropriate Joystick device as a function to the driver needs, and the best location that should have these technical aids in the driving position. From the information obtained during the first assessment phase it will be possible to define the most suitable Joystick controls for driving safely. The result of this two-phase assessment ensures that the driver is able to do the minimum number of driving requirements needed for obtaining the driving license.

After passing this assessment procedure the disabled driver would be able to start the process of learning and training in the driving school, and follow the standard procedure doing their theoretical and practical exam following the legal procedure established to get the driving license. Nowadays this new assessment approach it is being analyzed by the Spanish National Traffic authority to be implemented in the next years for solving all the problems generated along the last decades with the severely drivers with impairments in the process for obtaining a driving license.

REFERENCES


