# PROPOSITION OF A MAETHOD TO EVALUATE ACTIVE SAFETY HANDLING QUALITIES

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## ABSTRACT

Primary safety is briefly defined using an accident model.
The difficulties to evaluate the efficiency of active safety devices using only accidents statistics are recalled and a method based on accident *causation* statistics is proposed.
It is explained how main accident scenarios are used to defined handling test procedures. Examples are given , some of them are adaptation of ISO test procedures with specific initial conditions.
It is then explained why during emergency situations the vehicle should be stable and should not scare the driver. A method to derive metrics to evaluate objectively these former qualities is shown. The improvement introduced by specific safety devices can be measured and the qualities of a car considered as a system as well.
Some idea to improve this method in the future (new tests procedures and/or new metrics) are listed.

## 1 DEFINITION OF PRIMARY SAFETY.

To define active or primary safety, the model of figure 1 will be used [1] . It gives the detailed phases of an accident

Definition of the 3 pre – impact phases could be :
•**Phase 1, "Normal Driving" –** The risk of accident is minimal, the driver is carrying out routine driving tasks.
•**Phase 2, "Danger Phase" –** The risk of accident is increased but can be avoided if a good decision and/or action is taken by the driver or if he is assisted by devices on the car.
•**Phase 3, "Crash Unavoidable" –** The crash is now unavoidable but the car can be "prepared" for the crash by reducing the crash severity (and pre-arming the passive safety systems).
With this model it is easy to understand the sequences of the different phases that may lead to an accident. However separation between the phases is too simple. To better understand this let's take an every day example :
In a lane, a driver follows another car, at a distance corresponding between to 1 second. This situation will be classified as phase 1.

- If one car in the lane brakes, a crash is then unavoidable. The situation was in fact a hidden phase 2.
- If all the cars travel without braking, the situation will revert to phase one. Fortunately all phase 2 situations do not result in a crash.

## 2 VEHICLE QUALITIES INVOLVED WITH PRIMARY SAFETY.

Figure 2 gives a model of the vehicle – driver system during a driving task. The different numbers given to the driver are here only to underline the diversity of control actions to be implemented :

*For task one* , visibility and lighting are the most important factors. They condition the driver's perception of the environment and therefore his decisions.
Concerning visibility the lowest occultation of the useful zone is recommended i.e. to the front, to the rear and also above (signs)
Concerning lighting, the selected light intensity and distribution shall :
- enable the driver to see as far ahead as possible
- provide a good beam width at 50 m (regulation limit) in order to anticipate change of direction
- provide a good close distance openness for manoeuvres

*For task two*, braking and handling are the most important. On a day to day use of the car, the driver builds up a knowledge of the dynamics of his car and learns the laws of control. Here are some characteristics of this learning.

1) If the laws of control are linear (no pure delay or friction) and the phase lag (for instance between steering wheel angle and yaw speed) small the learning will be easy and the performance of driving loop will be good.
2) The laws of control acquired in normal driving conditions shall enable the driver to control the car in emergency situations. Day to day driving is carried out with moderate accelerations : frequently up to 2 m/s² in longitudinal and up to 4 m/s² in lateral. The car behaviour is linear in this domain. During emergency situations acceleration may be very high (up to 7 or 8 m/s² or even higher with modern ABS and EBA).Because of physical phenomena the car behaviour is no longer linear.

The driver faces two difficulties

a) The stress of an emergency situation
b) Control the vehicle in a situation where he has no knowledge of the laws of control.

In the following paragraphs we shall see how the car can help the driver in such situations.

[1] In the following primary safety will be used

*For task 3* the driver has to fell the motion of the car. This point is very interesting and is developed in paragraph 3.

Ergonomics are always present for all the tasks. If comfort devices, an HMI (Human Machine Interface) that is easy to learn and simple to use will leave the driver free for driving tasks. In addition, controls designed to ease the changeover from gas pedal to brake pedal and to keep driver's hand on the steering wheel will make it easier to obtain a better performance in the driving loop.

## 3 HANDLING AND PERCEPTION

### 3.1 Handling and primary safety

For primary safety, important variables are those related to trajectory definition and car's attitude related to the trajectory. The different variables of interest are vehicle speed, yaw rate, longitudinal and lateral acceleration and side slip angle. An other interesting value is the error between actual and desired trajectory.

### 3.2 Human perception and driving loop.

The human body has sensors for these different variables and to fell the driving instruments (steering wheel, brake pedal) see table 1.
For the explanation of the driving process the task will be detailed as a sequence but in the real world this is a continuous process.

**Table 1.**
**Human sensors**

| Variable | Human sensor |
|---|---|
| Lateral acceleration | Vestibular apparatus |
| Longitudinal acceleration | |
| Vehicle speed | eyes |
| Side slip angle | |
| Yaw rate | |
| Path error | |
| Steering wheel torque and angle | hands |
| Brake pedal force and displacement | foot |

#### 3.2.1 Lateral driving

The driver gives a command using the steering-wheel. The effort perceived by the driver must be a reflection of the tyre forces. Via the relationship between these two variables, the vehicle informs the driver that he is executing the command and that the trajectory will be modified. A decrease of effort on a slippery road is a warning before the manifestation of path error.
If we go back to the model in figure 1, a good steering feedback will be a warning of a transition between normal driving and the danger phase. This information is useful as all the drivers will have a good perception of effort variations.
In the following of the manoeuvre, the driver checks the execution of his command. Lateral acceleration is the first sign. Normal driver very often have a poor perception of this variable, on the contrary professional drivers will use this information.
After that, as a consequence of acceleration, speed parameters ( side slip angle, yaw rate) are modified. These modifications occur later. During an accident situation, they occur when the danger is already happening. These variables are well perceived by a normal driver.
Finally the driver sees the difference between the desired and the actual trajectory. This difference is very well perceived by a normal driver.

#### 3.2.2 Longitudinal driving

The command is given using the brake pedal. To initiate a fast motion (as in the case of an emergency braking) the driver decides to apply a displacement or speed. This first phase lasts between 100 to 500 ms and is called ballistic phase [1]. After that the driver will perform a regulation loop. Once again, if the pedal force and displacement reflect the steady state deceleration, the driver will be informed that his command will be executed. Here also the quality of information will avoid transition into the danger phase.
In the following, the driver checks the execution of his command. Longitudinal acceleration is the first sign. For a normal driver the perception is only qualitative.
After that, as a consequence of acceleration, the speed is modified, this variable is well perceived by a normal driver. For a normal driver the most intuitive information is processed from speed, it is the Time To Obstacle [2].

#### 3.2.3 Consequence

Some points have to be highlighted :
1) Quality of braking and handling are very important for

- Anticipation and avoidance of dangerous situations
- Completion of driving tasks in normal and dangerous situations

2) The quantity of visual information used by the driver in order for him to

- Understand his environment
- Complete the driving tasks

Highlights the importance of visibility and lighting qualities.

The role of these qualities in relation with the different phases of an accident is shown in figure 1.

## 4 PRIMARY SAFETY ASSESSMENT

In the following only handling and braking will be treated.
In order to improve primary safety it is necessary to define repeatable measurement procedures and the associated objective criteria.

### 4.1 Specific difficulties

For secondary safety, with a given accident configuration it is easy to analyse the consequences on a dummy.
The problem is more complex for primary safety. When an accident is avoided what is due to the behaviour of the car and what is due to the driver ? Simple comparison between accidents statistics is not the answer. Some vehicles may be over represented because of a grater use, use by a specific population (younger drivers), specific use (on secondary roads). In addition it is very difficult to obtain data about accidents which have been avoided.

In the following a methodology is proposed to select

- Test procedure
- Performance criteria

### 4.2 Evaluation situations

We have no data on accidents which have been avoided but we do have data on danger phases that have resulted in an accident. Therefore we know of some situations where an improvement to the car could lead to accident avoidance.
RENAULT and PSA PEUGEOT-CITROEN sponsor a common laboratory : the L.A.B. (Laboratoire d'Accidentologie et de Biomécanique or Laboratory for Accidentology and Biomechanics ) who produces three kinds of studies :

1) Statistics on all accidents
2) Detailed accident analysis (EDA) with trajectory and speed reconstruction of the vehicles involved, interviews of the persons involved in order to better understand the accident circumstances and measurement of coefficient of friction of the road.
3) Specific studies where an accident situation is simulated to study driver behaviour

Due to these studies, two kinds of situations appear as very important.

- Front to rear crashes are important because of their occurrence and risks of injury
- Accidents in a curve that represent 46% of fatal accidents in France.

The question is now how to evaluate the vehicles in these situations.

### 4.3 The tests to evaluate primary safety handling qualities

The desired qualities should help the driver to perform the driving tasks. The performance will be measured during an open loop manoeuvre but the criteria will indicate a good performance of the driver – vehicle system in a closed loop.

#### 4.3.1 <u>Front to rear crashes</u>

**a) General**
The main quality for the vehicle is a short stopping distance at various speed. In order to magnify the difference between cars we prefer to compare stopping distance from 130 km/h which is the top legal speed in France.
**b) Brake actuation**
One of the LAB studies was designed to observe emergency braking in real-world crashes [3]. Figure 4 is issued from this study. We see that :

- only 5% of emergency braking are made with a pedal speed smaller than 300 mm/s, and conversely 95 % of normal braking are made with a pedal speed smaller than 300 mm/s. So the speed of the braking pedal characterises very well emergency braking.
- The medium speed of emergency braking is 500 mm/s

In order to be repeatable during the steady state phase of braking, the effort on the pedal should be constant.
Finally the characteristics of the brake actuation are:

- During the first 100 ms the pedal speed shall be greater than 500 mm/s for at least 50 ms
- After the first 100 ms pedal effort shall be 400 N +/-100 N.

On the cars that were tested, those equipped with an emergency braking assistance had this feature activated.
**c) The criteria**
This is the stopping distance measured from the beginning of the brake actuation (starting when the effort becomes greater than 40 N). The elimination of the transient at the beginning is not realistic for an emergency braking in the real-world and an important part of vehicle performance can be lost.

#### 4.3.2 <u>Accident in a curve</u>

Thanks to the Detailed accident analysis EDA we can obtain the characteristics of the typical fatal accident in a curve [4]:

- Radius between 80 and 130 m
- Entry speed between 80 and 130 km/h
- Maximal lateral acceleration between 5 and 7 m/s².

In such a situation a driver can have three types of reaction :

- Power off without braking (power off in a curve)
- Power off plus braking (braking in a curve)
- Turn the steering wheel (radius change).

For all these situations RENAULT and PSA PEUGEOT CITROEN have defined the initial radius and speed to test cars. For the radius change the most sever case (radius reduction) has been chosen.

We began the work with braking in a curve. This test is detailed below.

### 4.3.3 Braking in a curve

The starting point is the ISO test procedure [5].

**a) Selection of initial conditions**

During a subjective test of a various group of different vehicles we could see that the performance of some cars were similar on small radius although very different at higher radius. The same is valid with speed. So we tested various radii and speeds in order to find the minimum values for these two parameters that enabled us to find the differences between vehicles. The selected values are : Radius 150 m and Speed 120 km/h. This corresponds to the higher limit of actual fatal accidents (we have to remember that an important part of these accidents occur on slippery roads).

**b) deceleration level**

It is well known that when ABS is active the car is stabilized. So the area of interest is for the small deceleration before ABS actuation. We found no rules to select it for all cars so we apply two level of deceleration, one must be between 2 and 3 m/s² and one must be between 3 and 4 m/s² (average deceleration is calculated between 0.5 s and 1.25 s after the beginning of the power off).

**c) precision of initial conditions**

During this test vehicle behaviour is highly non linear. So small differences of initial conditions lead to great differences between on the parameters observed.

A difficult task was to find the necessary constraints on the initial conditions in order to obtain repeatable measurements. For each variable we had to define a minimum time where it is kept constant, these conditions are given in table 2. The time is only 1.5 s thanks to a low steering wheel rate to reach the desired radius.

**d) necessary qualities**

In order to ease driving two main qualities are necessary

*Limit driver panic*

The driver is in a situation never experienced before. Under panic he can make a manoeuvre that will lead to an even worse situation. So driver panic must be avoided as far as possible. To measure the risk of panic we decided to measure the side slip angle.

**Table 2.**
**Initial conditions for brake in a turn test**

| Condition during 1.5 seconds | Mean value | Standard deviation |
|---|---|---|
| Speed | 120 +- 3 km/h | +- 2% |
| Steering wheel angle | Chosen value +- 4° | +- 5% |
| Throttle position (last second only) | Value needed +- 10% | +- 10% |
| Lateral acceleration | 7.5 m/s2 +- 0.1 m/s2 | +- 0.1 m/s2 |

*Vehicle stability*

As the driver does not know the vehicle behaviour in this situation he must not be asked to stabilize the driving loop. As a consequence the car has to be stable in open loop (without modification of the control). This stability must be clear for normal driver so we chose the yaw rate to express it.

**e) The criteria**

For a group of cars we search for a correlation between the measured variables and the subjective assessment. As stated previously the criteria will be an aggregate of yaw rate and side slip angle. Details are given below. In this section origin of time is the lift off from gas pedal (1s in figure 4).

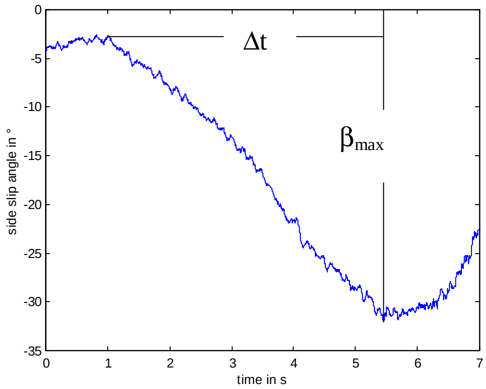


**figure 4. Illustration of side slip angle criteria**

*Side slip*

We chose the rear side slip angle (i.e. at the rear axle) as this point is not dependent on loading conditions.

Maximum side slip $\beta_{max}$ (vertical line) and time of side slip variation Δt (horizontal line) are defined in figure 4. With the correlation studies we determined that value of interest is $\frac{\beta_{max}^{2}}{\Delta t}$

*Yaw rate*

The stability criterion proposed by Otto [6]is based on the variations of yaw velocity :

- First the way the change of trajectory occurs directly after braking. This is given by a comparison between the measured yaw velocity and the ideal yaw velocity of a vehicle following the ideal trajectory (150 m radius circle) and slowing down at the same rate.

  The reference yaw speed $\dot{\psi}_0$ is defined by : $\dot{\psi}_0(t) = \dfrac{v_x(t)}{R_0}$

  where $v_x(t)$ is the instantaneous longitudinal velocity and $R_0$ is the reference radius : 150 m.

  And then first part of the criterion is

  $$\Delta \dot{\psi} ref,_m = \dot{\psi}(0.75) - \dot{\psi}_0(0.75)$$

- The way the car stabilises itself soon after braking. This is measured by the mean yaw acceleration (i.e. yaw speed variation).

  $$\ddot{\psi}_m = \frac{\dot{\psi}(1) - \dot{\psi}(0.5)}{0.5}$$

The values had to be changed because time origin is the lift off from gas pedal and to have a better description of yaw acceleration so we have :

- $\Delta \dot{\psi} ref,_m = \dot{\psi}(0.9) - \dot{\psi}_0(0.9)$
- $\ddot{\psi}_m = \dfrac{\dot{\psi}(2.9) - \dot{\psi}(0.9)}{2}$

and the yaw velocity criterion is $\left| \dfrac{\Delta \dot{\psi}_{ref,m}}{0.9} \right| + \left| \ddot{\psi}_m \right|$

*Correlation*

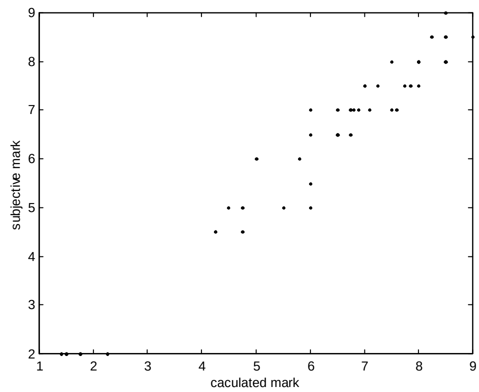


**figure 5. Comparison between calculated and subjective marks**

The correlation between the aggregate and the subjective marks is show on figure 5. The group of cars include all segments, tractions and propulsion. A point is still to be solved. Some cars are not stable at 120 km/h before the braking. We propose that these cars are tested at 110 km/h. The offset criteria to apply is undetermined at present.

#### 4.3.4 Other situations

**Power off in a curve**

Here also the starting point is the ISO test procedure [7].

As there is a smaller deceleration than in the braking in a turn, a 100 m radius is sufficient.

The correlation work is unfinished at present. It seems that the same criteria as braking in a curve can be applied.

**Radius change**

There is no ISO test procedure corresponding to this case. RENAULT and PSA PEUGEOT CITROEN propose the design shown in figure 6. The corridor is very narrow in order to avoid driver dependent trajectory. With this test it is possible to make significant subjective assessment of different cars.

The measured criteria is unknown at present.

## 5 CONCLUSION

This paper discusses the main difficulties involved in assessing the primary safety performance of cars.

General accident statistics suggest the following : stopping distance, braking in a turn, power off in a turn and radius change.

It shows how detailed analysis of real accidents and knowledge of the driver action during emergency situations can be used to specify test procedures for this purpose. The corresponding procedures are shown.

Examples of measured criteria are also given.

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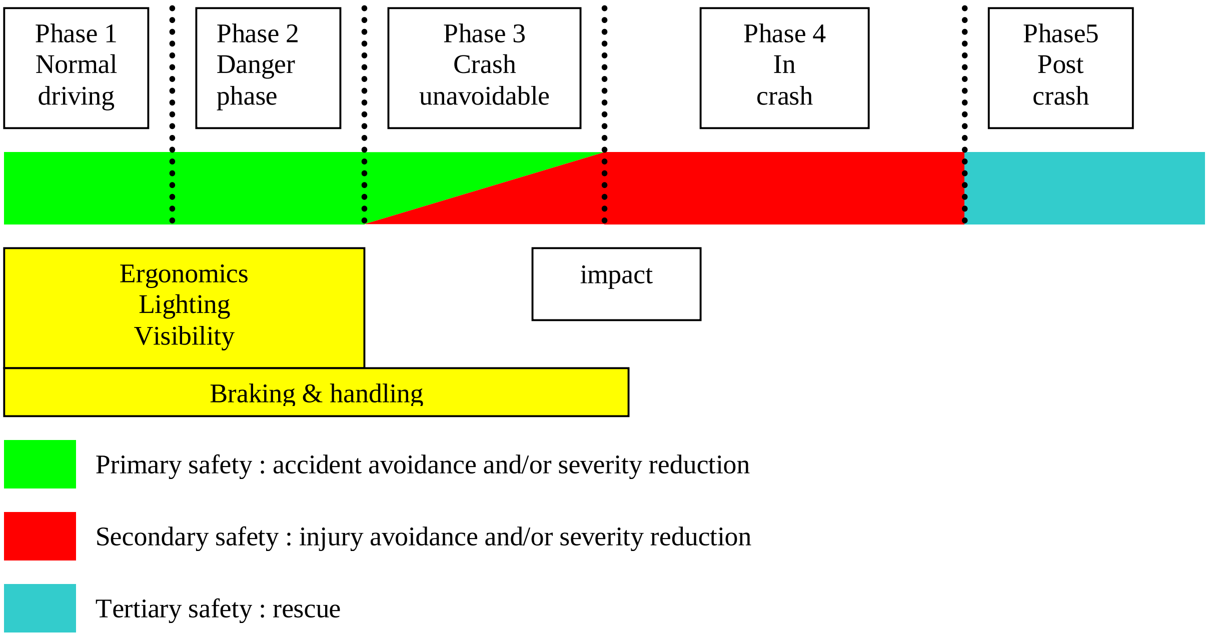



**Figure 1. Model to definie primary safety**

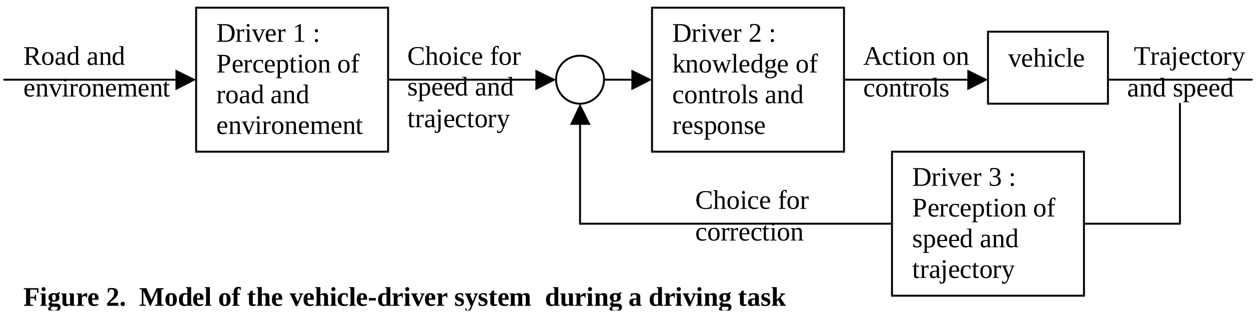



**Figure 2. Model of the vehicle-driver system during a driving task**

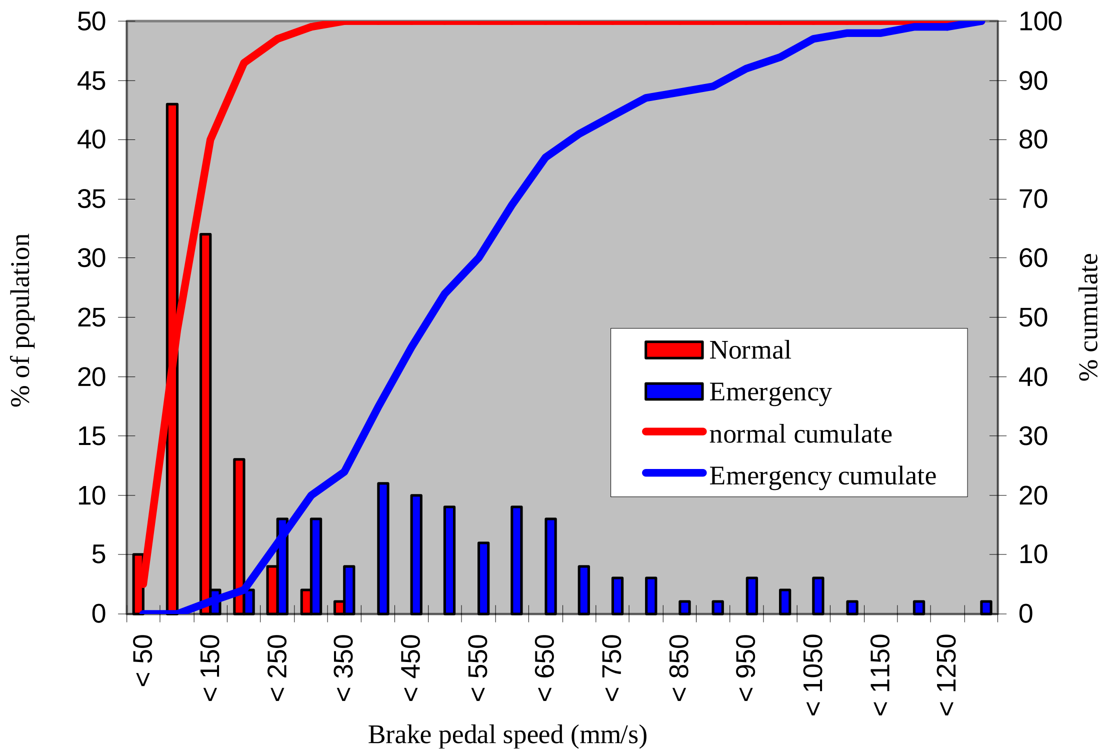
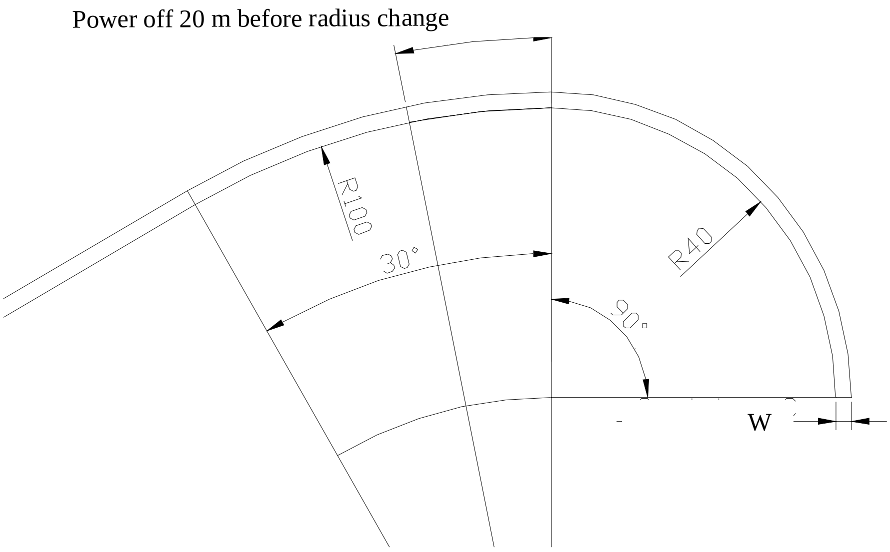



**Figure 4. Distribution of brake pedal speed**




Width of the track W : depends on vehicle dimensions (lenght and width) + 0,25m .

**Figure 6 : Proposition for the radius change**