1. Introduction
Driving vehicles becomes difficult and dangerous when fog is present. The user loses information, both in terms of number of items and content: under these conditions, it becomes hard to estimate speed and distance due to the lack of visual references.

Driving safety diminishes and accident risks increase. Accidents caused by fog are generally very serious; in terms of numbers they are not many nation-wide, since foggy days as a whole are not many, but unfortunately they make up an important share in special areas, such as the Po valley. The kind of accident changes, depending on the kind of road. On single-carriageway roads, designed for basically slow speeds, accidents are generally less serious and involve going off the road, collisions at cross roads, interference between various components of the traffic. Roads with separate carriageways - such as motorways - is where the most serious accidents take place, consisting generally of simple or chain telescoping due to the fact that vehicles are driven at high speed. In any case, the main reason for accidents seems to be driving at a speed which is not suited to the visibility distance. Other reasons are insufficient distance between cars, poor signals on the vehicles or on the road, the capability of the drivers. Looking at the way the latter behave, we notice a general reduction of speed, but - the density of the fog being the same - increased speed when traffic increases.

In this note, we introduce driving safety problems when fog is present. First, the two basic elements - fog and visual perception - are taken into consideration. The physical constitution and the predictability of fog are taken into consideration, in order to get to know the route followed by light and by sight through it. Regarding visual perception, phenomena associated with eye mechanisms are considered.

Hence, the features of vision in the presence of fog and relevant simulation models are taken into account. Then the practical problem of how to convert visibility measurements provided by meteorology stations is dealt with, together with the determination of the most suitable safety speed depending on ambient lighting. Then, the behaviour of drivers is investigated. The issues analysed here must then be made the subject matter of further research in order to lay down rules for road planning in foggy areas, as well as driver assistance systems.

2. The physical constitution of fog
Fog is due to the suspension in the atmosphere of particles of various origin: dust, smoke, water drops or ice. What interests us most here is fog made up of water drops.

Different kinds of fog arise under different conditions of formation. Formation of fog, in any case, requires the simultaneous presence of condensation nuclei and of hyper-saturation conditions of air in steam. The excess steam, contained in the lower layers of the atmosphere, can condense around the nuclei due both to cooling of the ground and of the base of the air mass, and to increased specific humidity.

Fog may be classified according to the following definitions, depending on its formation process (Shepard, 1999).

Radiation fog
Fog is produced by the cooling of the soil by radiative transfer. This takes place at night, with a clear sky, when a layer of humid air close to the soil is covered by a layer of dry air. The low, humid layer cooled by the ground quickly becomes saturated, and fog develops. This process generally takes place in autumn and in winter, towards dawn. The fog only dissipates when the sun heats the atmosphere. Under
high pressure conditions, this kind of fog can stay around even for several days in a row. Radiative transfer fog is also known as valley fog, since the cool and heavy air goes downward and then stays in the valleys.

Advection fog
This kind of fog is created by the movement of humid air over a cold surface. This often takes place in summer, near the coast, when the hot and humid air, coming from the land, touches the cold water of the sea.

Upslope fog
This kind of fog develops when the air flows along the slopes of hills and mountains and hence is cooled below the dew point. This mainly happens in winter and in spring, and may go on without any interruption, day and night, even for long periods of time.

Evaporation fog
This develops when cold air moves over warm water, or over very damp and warm terrain. This often happens in summer, when a perturbation coming from the North (hence cold) precipitates onto a terrain heated by summer temperatures. It is generally short lived and stops as soon as the sun comes out.

Whatever the manner of formation may be, fog always consists of a collection of water drops small enough to stay suspended in the atmosphere. It features three parameters: particle size distribution of the drops, their concentration and their content in condensed water (Paulmier et al., 1992). These parameters mainly depend on the formation process, and also on temperature, altitude, duration. Different opinions exist as to the characteristic parameters of water drops. In any case, the average radius is believed to be between 0.5 and 5 μm, concentration 10–100 and 30–100 m−3 and content in water between 0.10 and 0.30 g·m−3.

Various physical and/or statistical methods have been studied to forecast and locate fog, but without good results. Physical type forecasts are based on the fact that fog is small-scale meteorological event. Its formation threshold is very sensitive: a variation of a few degrees is enough to decide whether fog will develop or not. Several experimental physical studies have been carried out. Some were carried out on the field, studying the atmosphere in different situations of humidity saturation (Gazzi et al., 1997) (Bergot and Guedalia, 1994). Others were carried out inside a laboratory, in a continuous flow isothermic chamber, so as to lead the condensation nuclei to growing degrees of humidity until formation of fog of different density (Dumont and Zouboff, 1996). The conclusion was that - although there is considerable uncertainty about the characteristic features of local situations - it is possible to draw up simulation models like those used, in this case too with limited success, in hail forecasting. In any case, physics of the atmosphere is constantly developing, and the problem of fog forecasting is expected to find more reliable solutions; this is a very important, so that safety systems against fog (Villa and Vivaldi, 1999, 2000) can be made to work before fog develops, in order to improve traffic safety.

3. The human system for receiving images
Visual perception is a complex phenomenon made up of various concurrent functions, each of which is useful for acquiring various aspects of the image: size, shape, position in space, colour, contrast, movement.

The main components of vision are (Zinggian et al., 1992):
- visual acuteness: discriminating capacity under maximum contrast conditions;
- visual field: capacity for perceiving the environment surrounding the object being viewed;
- sensitivity to contrast: the capacity to discriminate under conditions of reduced contrast;
- colour sense: the capacity for recognising the colour of images;
- luminous sense: capacity to adapt to different conditions of environmental lighting;
- binocularity: capacity of perceiving the depth of space.

All these components of sight are associated with physical, optical and refractive factors which condition the formation of the image on the photoreceptors. These are neuro-physiological elements which make it possible to acquire the stimulus and to deliver it along the nervous paths responsible for sight. Finally, there are perceptive and psychological factors which enable recognition and interpretation of images. Visual acuteness includes three main functions: discrimination of light and colours, spatial discrimination (i.e. the capacity for making out shapes and correlating them in space), and time discrimination which comes into play when stimuli vary through time. This component of vision is used on the road to identify distant objects. The greater the acuteness, the more time is available to react to visual sensations (Legrand, 1977).

Together with acuteness, the field of vision is certainly one of the most important components of the visual function. The field of vision affords the driver a panoramic perception of the environment within which he is moving, proper location in space of the objects and an evaluation of his own movements compared to the surrounding figures. It is constantly being solicited by unexpected items appearing on scene, and is the attention component of vision.

Due to the number of factors involved, sensitivity to contrast, that is the capacity of perceiving changes of luminosity between different regions of the field of vision, is one of the most complex transfer functions of the retina. The differential luminous threshold contains information on the discriminating capacity of the eye, both in the field of spatial and temporal definition. In the case of fog, stimuli become weaker both in amplitude and in time of appearance, and their perception therefore depends on the capacity of the eye to resolve differences of luminosity for that amount of stimulation and that time of exposure (Doré, 1991).
The ergonomic requirements of car driving, in case of fog, imply quick adaptation to changing conditions of environmental lighting and image colour recognition. A good quality of vision, therefore, requires a suitable capacity for adapting to the environment when this is not luminous. Without such an adaptation, the driver may suffer from lack of spatial orientation, and this will not allow him to evaluate the exact distances from fixed elements.

Finally the capacity for perceiving depth of space and hence the distance of obstacles - i.e., binocularity and stereopsis - depend entirely on the performance of the user’s eye.

Speaking generally, therefore, we can define vision as the physiological and psychological process whereby the subject develops a representation of the real world which presents itself before his eyes. The physiological aspects are well known, but not so well known or taken into account are the psychological aspects which can condition a driver strongly.

The visual function, in fact, is an adaptive function which aims at achieving a specific goal; the implementation of this function depends on the ability of the eyes - not only from an ophthalmological and functional point of view - to look, identify, evaluate an object in space. Psychology comes into the vision process by putting a person in the condition of knowing how to look. Some folk expressions, such as “I am so angry I cannot see anything” or “I am so hungry I cannot see anything”, are significant examples of how certain situations of emotional balance/imbalance can affect the quality of vision in a more or less subjective manner. Changes of mood, even temporary and transient, are clinically proven to affect visual perception.

When driving in the presence of fog, a situation of visual deficit always creates, at first, a state of deep anguish, although often latent, which may express itself in various ways, from vague anxiety to general depression, a feeling of omnipresent insecurity and a feeling of personal inadequacy. When people enter a fog bank on a car, they generally stop talking, take on sad expressions and express feelings of unease. This situation may lead psychologically to a feeling of further reduction of vision, besides the physical reduction due to the presence of fog. This first phase may be followed by other phases in which the driver behaves in the opposite manner. Features typical of deprivation may foster the development of psychological motivations leading certain individuals to deal with the most serious problems with an enthusiasm entirely out of proportion, overestimating their own personal capacities. This situation is certainly dangerous, since overestimation also involves visual capacity and this therefore means an increase of speed in unsafe conditions.

This situation is often typical of young people, or of people in general with an enterprising and proactive spirit. On the other hand, certain individuals - already depressed by the reduction of their efficiency - may tend to pour out their existential malaise onto their own disability, reducing their operative capacity still further and hence their visual capacity. As a consequence, they tend to reduce their speed considerably, sometimes slowing down suddenly, and this means creating unexpected obstacles on the carriageway which are dangerous for the vehicles behind. This situation often takes place among individuals without motivations - such as the elderly - and in general among people who tend to give up in their lives.

The people whose reactions we may call ‘normal’ are to be found between these two extremes. As a consequence, drivers speeds are very diversified in case of fog, apart from their ophthalmological visual capacity, and this leads to an unsafe traffic situation which leads to the probability of accidents taking place. As a matter of fact, accidents during fog are not generally due to lack of safety of the infrastructure - such as driving off the road - but more often to the presence of obstacles on the carriageway, as is the case with telescoping.

To conclude, the reception of an image in case of fog is a very complex process which involves a degree of uncertainty in theories connected to human vision, and hence to simulation models, which needs to be taken into account with due caution.

4. Visibility with presence of fog

As can be seen from the description of the constitution of fog, in order to ensure vision, light must move in a medium containing a considerable amount of water drops having a diameter of a few microns. Along its path, the light flow is attenuated for two reasons, absorption and diffusion, which allow fog to be characterised by an extinction coefficient, the sum of the absorption and diffusion coefficients. Absorption is negligible compared to diffusion: it can be shown that in a water drop having a 10 mm diameter, subject to 1 lux illumination, the absorbed flow is 10⁻⁷ times the diffused flow.

Therefore, the prevailing phenomenon in light attenuation is diffusion, which deviates the rays from their initial, direction. Fog therefore features an extinction coefficient which practically coincides with the diffusion coefficient (Paulmier et al. 1998).

Fog interferes with the propagation of light in the atmosphere, leading to diffusion so the water drops diffuse the incident ray in every direction. This way, luminous energy reaches the retina after being diffused many times along its route. This phenomenon modifies the spatial distribution of the luminosity used by the vision system, and these modifications are the reason fog affects visibility, for example by causing wrong estimates of distances and speed (Dumont, 1999).

In any case, we can say that if k is the extinction coefficient, F₀ the light flow emitted by a source, F the flow transmitted at the distance d, then:

$$F = F₀ e^{-k d}$$

The extinction coefficient, of course, is associated with the diameter and concentration of the water drops. If nₙ is the number of drops having radius rₙ, then (because of the theory of Lorenz-Mie):

$$k = \frac{2\pi}{\lambda} \sum nₙ rₙ^2$$

The distance of visibility in fog does not only depend on the path of the light through the medium, but also on the photometric features of the object being viewed and on the background, i.e. the contrast behind it. The theories dealing with these matters are very old, but they are still held to be valid.
Koschmieder (1925) proposed a theory about the distance of visibility of objects seen against the sky at the horizon. Noticing that a far-away object ends up by being confused with the sky, and on the basis of certain hypotheses, the author established a simple relationship between the visibility distance and the apparent luminosity. The apparent luminosity is calculated on the basis of the intrinsic luminosity of the object and the luminosity of the atmosphere. Basing himself on these results, Duntley (1948) established a contrast attenuation law which can also be applied to fog. This law does not take the dimensions of the object or the time of observation into account.

Allard (1876) suggested a law associating the illumination produced by a point-shaped source with the transparency of the atmosphere. To establish the distance of visibility, one needs therefore to know the conventional limit of sensitivity to contrast on the eye, which depends on its capacity for adaptation (Heiss, 1976) (Theeuwes and Alferdink, 1997) (ICAO, 1986).

The theories expounded here are quite simple, but have important gaps in terms of visibility on the road. Especially, they do not take into account the background luminosity created both by the object itself and by an source, such as vehicle lamps.

It became necessary to establish visibility models (Serres, 1991) especially in order to define driving aid systems (Nilsson and Hakan, 1996).

Recently, mathematical models and calculating programmes have been developed (Dumont, 1998) with the specific purpose of pointing out the relationship between background luminosity and contrast, since ophthalmologists concur in saying that it contrast sensitivity is the most discriminating function for viewing objects. Whatever the system used to develop the model, the parameters employed are validated by gauge experiments which take into account the real circumstances of driving through fog.

To sum up, vision simulation is clearly of interest when we wish to evaluate comparatively the visibility of objects under different conditions, when fog is present. One can therefore compare the efficiency of passive driving aids such as road signs of various kinds. In the case of active devices, such as lighting in its many applications, one can check their functional validity in terms of whether they ensure sufficient contrast on the road, for example making a foot-passenger visible at sufficient distance in a city area, or a slowly moving vehicle outside town.

The main limits to vision simulation models in the presence of fog lie in the difficulty of forecasting the luminosity of the objects in the relevant scenario when there are multiple light sources, when objects have very different sizes and when the reflection features are hard to classify.

5. Visibility index in fog

Recently in Italy, in order to improve the quality of the service and traffic safety, some motorway companies (e.g. Autostrade del Brennero (Villa and Vivaldi, 1999, 2000) and Autostrade Centro-Padane) have provided themselves with special road paving and meteorological detection systems. These stations make it possible to collect many data, including visibility distance and state of the paving over time. The density of the fog measured indirectly using a transmission metre however is not directly correlated to the actual visibility distance for stopping, since the latter depends on the lighting of the environment and on the specific conditions. In order to convert the readings from the meteorological stations into working visibility distance for safety purposes, one must consider at least three different environmental situations:

1. daytime-natural lighting, car lights off;
2. night time-car lights on;
3. daytime(with three different kinds of luminosity)-car lights on.

![Figure 1: Visibility Index in Fog (Predicted visual range), depending on the photo-metric visibility distance for four conditions of illumination](image)

In order to solve the problem, one can use suitable analytical models (Heiss, 1976) specially developed for motorways, or else one can apply the instructions provided for airports by the ICAO (ICAO, 1986) to motorways.

To define a Visibility Index in Fog allowing one to "weigh" the visibility distance on the basis of the lighting of the surrounding environment and to establish the most suitable speed limit depending on the conditions of visibility and on the state of the paving, we based ourselves on the ICAO regulations.

Conversion of the readings of the transmission metre (in terms of photo-metric visibility distance $V_p$) into the visibility distance $V$ to be found on the road is based either on Koschmieder's law or on Allard's law. If we suppose that the driver obtains more visual information from horizontal signs or from objects present on the road, we apply Koschmieder's law, whereas if the information comes from lights on the track, we use Allard's law. Therefore, we shall use Koschmieder's law when the drivers first see the shapes of the vehicles (situation 1) and Allard's law when the visual
information is provided by the lights of the vehicles (situations 2 and 3). ICAO regulations provide the Illumination Threshold values depending on the Background luminance, and hence allow us to build curves correlating the photo-metric visibility distance to the actual visibility distance (figure 1).

The straight dotted curve shows situation 1, which is also the least likely one. Starting from the expression of the stopping distance provided for by Italian rules on situations with wet road surfaces, we were able to build the curve linking the visibility distance to the maximum permitted speed under safe conditions (figure 2).

![Figure 2 - Safe stopping speed depending on the actual visibility for a wet road surface](image)

We were thus able to build diagrams relating the photo-metric visibility distance, obtained by the local meteorological stations to the maximum safe stopping speed for different conditions of environmental illumination and for different paving conditions (different explicable adhesion) (figure 3).

This way, we can "enrich" the data coming in real time from the meteorological stations providing useful information to those who have to manage the infrastructures. Besides data on visibility and the conditions of the road, variable message signs can provide the users with instructions on the maximum permissible speed under safe conditions.

6. Behaviour of the users

Driving is a complex system where a man/vehicle/environment interaction develops. The environment is considered in its widest context, and includes the infrastructure with its associated elements, traffic and such environmental conditions as fog and rain. The behaviour of the user consists of effecting a movement in a constantly evolving environment. This movement has a purpose and is subject to explicit rules - such as the features of the road and the signs - and implicit rules such as traffic safety. The activity of the user consists of carrying out a definite path along the carriageway and choosing a speed under steady moving conditions.

The function of the person responsible for driving a vehicle, therefore, is a complex dynamic operation, subject to constant correction stress depending on the environment. The user must identify current and potential reasons, in space and time, which could be harmful to the safety of his movements; he must take decisions which depend on the parameters of the current situation and on hypotheses as to the future state of the system, and must know when and how to take steps to correct his behaviour. Generally, the simplest and most rational solution is chosen out of all the available ones, and this comes from an intrinsic cultural factor in the individual. Also, human perception - psychologically and naturally - follows the general law according to which we seek to minimise the quantity of information to handle.

If we consider the human organism as an information-processing machine, one has to admit that it has a limited capacity, like every machine; no more than a certain quantity of information can be handled within a certain span of time. Therefore, a more frequent stimulus is coded more quickly than a less frequent one, and the perception of a situation becomes easier the more probable the stimulus (Baker, 2000).

On the other hand, one must also note that when a visual stimulus presents itself which is below the identification threshold, the individual will certainly be in a condition to provide partial or wrong answers.

All of this means that, when driving a vehicle, one must identify the privileged sources of information and organise the consultation of these sources in space and time in order to set up the most suitable strategy. The stimuli which reach the user's receptive system - sight and hearing - determine a decision which turns into an action. For example, one sees a fog bank decides to slow down, takes one's foot off the accelerator and brakes. During such a process, it is fundamental to select and sort the information associated with the forecasting mechanism. Selection of the information may be of two kinds: information not actively sought for by the user, such as very strong stimuli, for example a flashing light;
and information sought for, associated with the complex of probable hypotheses for the user.
The first consequence of fog is a reduction in the user's visual information, in a manner which is correlated to its density. Spatial points of reference are lost, and this affects distal information. The information which the user receives is limited to the central part of the visual field and refers mainly to the central part of the carriageway. This quantitative impoverishment of the references used is also qualitative, insofar as their information value is cut down. The most heavily modified references are associated with problems of speed and distance. This is a consequence of the fact that the perception of movement is hindered by the general reduction of illumination, and especially, of contrast which is the decisive element of vision. The perception of movement will be delayed and this will negatively affect the estimate of the speed of the driver and of other vehicles. Therefore the presence of fog modifies the capacity for perception of the driver and disturbs his behaviour.
Various experimental investigations have been carried out on the road and with simulated driving in order to evaluate the behaviour of users in the presence of fog (Van der Hulst et al., 1998) (Edwards, 1998, 1999). During these investigations, reference has generally been made to two indexes used during safety verification of the movement of vehicles in a current of traffic: the TH (Time Head-ways), the distance from the vehicle ahead of us divided by the speed of the vehicle following, and the TTC (Time to Collision), distance between two vehicles divided by the difference of speed.
The following results were obtained from the studies:
- When starting to drive in the presence of fog, the driver is affected by a general disorientation which induces a certain differentiation of speed among the vehicles.
- Later, drivers tend to take as their point of reference the cars ahead of them, without overtaking them, and this leads to a situation where people drive in groups and the average speed is reduced.
- TH and TTC increase, and drivers tend to keep a greater distance between the vehicles.
- The TH and TTC indexes are very different, depending on the kind of road. They are lower in roads with separate carriageways, since in this situation, traffic appears to be safer, and higher roads with a single carriageway where traffic appears more unpredictable.
- There are no strong variations in speed, i.e. accelerations and decelerations are limited, so TH and TTC are practically constant for every kind of driving.
- The TH and TTC indexes, which are tactical choices of behaviour, are associated with the general expectations and the possibility of forecasting the environment and the road.

7. Objectives and conclusions
The introductory notes to the study on traffic issues in presence of fog have highlighted the fact that the behaviour of the driver is complex and involves several different disciplines. Internationally, various experiments have been performed on the road and with simulated driving. These experiments failed to give satisfactory results, regarding the psychological approach of drivers in their behaviour when driving in fog, and in the conclusions which were reached concerning the actual conditions of driving, in terms of the volume and kind of traffic. Regarding psychology, one needs to investigate - according to the methods developed by this discipline - using interviews and question sheets made out by the users. Regarding real traffic conditions, image acquisition systems must be used, offering complete knowledge of traffic make-up and speed distribution.
Once the behaviour of the user is known, the goals the road designer must put himself involve making projects which ensure safety under fog conditions and the identification of driving aid systems. Here only some guidelines can be given, which will be developed in future studies. Regarding the infrastructure in areas subject to the presence of fog, greater attention must be paid to the safety rules normally used during planning, and they must be applied more strictly. Mainly, the road - with its appurtenances and its individual points - must be predictable. This means that a person driving along the road perceives the continuity of its geometrical and physical features, such as the geometry of the track, the cross-section, adhesion of the paving, and is induced to manoeuvre consequently, in an almost automatic fashion. This means that the sequence of curves and straight lines must be homogeneous, the radii of the curves must differ little among each other, longitudinal slopes should be similar, the width of the road and the number of lanes constant, the exit devices the same, paving should have the same surface features in terms of adhesion, drain-ability, colouring. No item should lead to the user making a mistake (for example a lay-by near an exit, the components of the traffic in a mixed area, discontinuous safety barriers). Signs must not impose themselves at individual points such as exits, but must indicate a situation which does not come about unexpectedly and suddenly, but is part of the natural sequence of what happens along the track.
No experimentation has yet made it possible to lay down a scale of merits for driving aid systems. The most interesting are those which try to give the driver back his perception of visibility in case of fog, as if he were driving under normal conditions. Electricity is used to this end. Methods range from traditional, uniform lighting - white or yellow - to point signals which create a kind of luminous path. Point signals may be constant or flashing, static or dynamic with a 'whip' pattern. Choices have not yet been made in this matter based on certain experimental investigation. Indeed, a lot of doubt exists about luminous paths, and some suspect that it may even increase the level of danger. In fact, the user tends to increase speed when he is shown the track of the road, but obstacles on the carriageway remain undetected. Besides these active systems, there are other passive kinds, consisting of references on the carriageway which should suggest safe driving speed; such systems are generally not very effective. Finally, a vehicle can be equipped with two kinds of driving
aids in case of fog: old-style fog guard lamps, which are not very effective, and radar obstacle detection systems. The latter refer to individual points on the road, such as crossings or more generally obstacles on the carriageway; in any case, such devices are currently being studied and have not yet given satisfying results.

As a conclusion, we can say that research must mainly follow three guidelines: the behaviour of the user, the design of infrastructures, driver aid systems. Such research must be dealt with theoretically and experimentally with multidisciplinary qualifications.

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