EXTERNAL AND INTERNAL RISK OF THE USER IN ROAD SAFETY AND THE NECESSITY FOR A CONTROL PROCESS

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ABSTRACT

The aim of the paper is to explain a new interpretation of road safety based on the idea that the road risk consists of two components: internal risk and external risk.
When a road user is driving, he or she perceives the benefit of moving from an origin to a destination more comfortably and faster than other modes of transport. At the same time, the user perceives that while travelling he takes a risk related to the interaction with other road users, to high travel speed and to the different perception time of boundary conditions. It is possible to define the risk, with a deterministic or probabilistic approach, as the unwanted consequence of a specific activity related to its probability of occurring. Considering the definition of risk that depends on the probability P that an event occurs and on the related intensity of the consequences I, it can be defined as: $R = f(P,I)$. Accident behavioural theory has been developed since the 1970s and it is clear that user behaviour represents a central issue to be investigated in risk analysis in order to reduce risk and improve road safety. In fact, most accidents happen because of an underestimated perceived risk linked to an event.
Introducing the concept of external and internal risk of the user in road safety, this paper explores the possibility of splitting the perceived risk into two factors: the perceived internal risk (due to user's internal factors) and the perceived external risk (due to user's external factors). This subdivision permits better explanation of some contents of the homeostatic theory and completion of the concept of risk compensation. The complexity of risk analysis due to the non-homogeneous behaviour of users, their different perceptions of external risk and their physical and psychological condition leads the concept of "control process" to be considered as a possible solution to reduce road risk, improving safety.
The topic of this paper is not to measure the internal risk, not even to prove mathematically how to use it in a practical manner but to underline the necessity of a control process in road safety and to study and improve upon factors that give rise to risks in order to consider them in engineering models, tools and regulations as well as in human behavioural assessment and in social education.

1. SUMMARY

After describing the scientific background on the topic and considering typical definitions of risk and accidents, two different user behaviour are defined: "strategy behaviour" and "reaction behaviour". The first depends on user expectations of the risk components and the second on the real environmental conditions encountered by the user.
Then a risk economic analysis is carried out, introducing the meaning of Safety Budget [1] intended as the money that a person is willing to spend to avoid or reduce the risk. At the same time, the risk economic analysis depends on the total travel disutility, defined as the sum of three components, the subjective costs of travel time, the perceived risk of accident and its potential consequences, and the perception of speed limit control [2]. Therefore it is

easy to understand that there are some system components that could be predictable well in advance but others that remain unexpected. These components are different for regular and non regular users and could change the single user Perceived Risk. It seems reasonable to assume that most accidents happen because of an underestimated Perceived Risk linked to an event. In these cases the problem is not in the Safety Budget, but in the Perceived Risk, which is underestimated compared to the External Real Risk.

In the fifth section the concept of external and internal risk as components of the total risk is introduced. The External Risk determines the driver's immediate reactions when an unexpected event occurs and it represents the difference between the External Real Risk and the perceived risk. The internal risk determines driver behaviour in the medium and long term and represents the difference between the perceived risk and the Safety Budget, depending on the driver's condition and his aversion to risk. The expressed considerations necessarily lead to consider a Perceived Risk related to an external risk and a Perceived Risk related to an internal risk in order to better analyse human behaviour in road safety.

Starting from the conclusion of the fifth paragraph, the sixth attempts to define the risk factors that could be modified by technical and engineering solutions.

The seventh paragraph refers to the concept of risk compensation and to the associated theory - known as risk homeostasis [1,3,4]. In ethology, risk compensation is an effect whereby individual people may tend to adjust their behaviour in response to perceived changes in risk. It is seen as self-evident that individuals will tend to behave in a more cautious manner if their perception of risk or danger increases. Another way of stating this is that individuals will behave less cautiously in situations where they feel "safer" or more protected. There is evidence that suggests that such an effect is seen in humans, associated with the use of safety features such as car seat belts, bicycle helmets and antilock braking systems. The analysis carried out leads to consider that Risk Homoeostatic theory is based just on Internal Risk.

In the eighth and ninth paragraphs, non-homogenous drivers' behaviour and combined risk are analysed in order to better understand the complexity of risk analysis.

The paper concludes with the need to explore the concept of "control process" in order to reduce the road risk and improve safety. Firstly the genesis of a correct control process is carried out; secondly the modes of transport are distinguished according to the control system that governs them. The complexity of the system, the non-homogenous drivers' behaviour and the combined risk in road risk analysis lead to transfer, in some cases, of the control process from users to a higher level.

2. BACKGROUND

The typical definition of risk [5] leads to considering the actions for risk reduction. Firstly, actions for probability or frequency reduction, (named prevention), which consist of activities to eliminate the causes of accidents or their intensity. Secondly, actions for magnitude reduction, (named protection), which consist of activities to reduce the damage related to an accident.

At the same time, a road accident depends on users' behaviour, especially in the case of unforeseen events. Consequently, a proper analysis of road risk cannot be separated from human behaviour and the interactions between user behaviour and all external components (including the behaviour of other users).

Several accident theories have been developed in the last 100 years. At the beginning, accidents were considered as random events. The following theories were the accident proneness theory (from 1910 to 1955), the casual accident theory (from 1930 to 1970) and system theory (from 1945 to 1990) [6].Since the 1970s behavioural theory has virtually replaced all the others. Recent developments in behaviourally-oriented accident theory have focused on individual road user behaviour as a critical determinant of accident occurrence. The latter theory fits the risk homeostasis theory of driving behaviour. The first formulation of this model was probably Taylor's [7] "risk-speed compensation model" which postulated that drivers adjust their speeds in accordance with the perceived risk. More recently the model was expanded by Wilde [3, 4] to include and account for a host of driver behaviours. Despite its intuitive appeal, the theory has been challenged by many researchers in the field [8, 9, 10, 11, 12, 13] but the fact remains that we do adapt ourselves to our state and to the external environment. Risk is probably only one motivational (or deterring) factor to be considered in road safety. The motivational approach to understanding driver behaviour does not begin and end with risk. But the question is what kind of risk do we have to consider in developing future models of accident behavioural theory?

3. THE ROAD RISK

A traffic accident is an unexpected event on a road, involving at least one user of the same road and producing a significant negative impact on users and/or on society. The definition itself shows that the accident depends on user behaviour, especially because of unforeseen events.
It seems very useful to consider, from the point of view of the user, the conditions that interact while he is driving and that can cause a traffic accident and, especially, which type of behaviour he uses in different situations.

3.1 The strategic behaviour

Each user has a driving behaviour which depends on their physical or psychological condition, experience, vehicle, the road they are driving on and what they meet during their journey (traffic, weather conditions, etc.).
Indeed, if the user is not experienced or does not know the road he is driving on, his behaviour will surely be different from that of an experienced or regular user one. For example when a non-regular user leaves a well-known highway and takes a rural road that he has never traveled on, he knows that it is better to reduce speed in order to maintain his safety level. He changes his driving considering his past experience and the foreseen boundary conditions. In the same situation a regular user of that rural road will decrease speed but probably not as much as the non-regular user.
Different driving behaviour can be described even among experienced and inexperienced drivers. An experienced user who travels on a highway, even if for the first time, will behave differently from a novice user. The acceleration and speed that he selects will be somewhat different from those of the inexperienced user. Many other similar examples can be given between tired or rested users, between people who are physically well and others who feel bad, people who have experienced traumatic events both while and not while driving. In practice, it is possible to deduce that each user adopts a driving attitude that differs from his own driving behaviour in ideal and limit conditions (e.g. an expert driver, regular user of the road that he is travelling on to reach a hospital for an emergency), on the basis of several factors: his physical or psychological condition, knowledge of the road he is driving on, of road type, his past experience and boundary conditions that he knows or plans to meet on the journey. This behavioural difference corresponds to a *safety*

margin that the user keeps from his driving limit condition, hereinafter referred to as *δi*. This *safety margin* depends on the difference between a real situation and limit conditions but also on the uncertainty that the user has about this difference. Each driver chooses its own *δi* according both to his physical and psychological conditions and how he perceives the external components. The main effect of this *safety margin δi* is a reduction of speed ΔVi that the user decides to select referred to the speed *Vlim* that he could select in limit conditions. This behaviour is characterized by a generally medium-long time of definition (about ten minutes or more) and by a normally unconscious level of awareness and can be defined as the strategic behaviour of the driver. Therefore the way the user selects the speed in the medium-long time term, forecasting the boundary condition of the road to follow, can be defined as the main characteristics of the strategic behaviour.

3.2 The attention behaviour

Another type of behaviour has to be considered when the user's attention is being urged. In this case the user feels that external conditions are changing (e.g. it starts raining, there is a curve at the end of the straight, etc.), because he changes his driving style trying to maintain his *δi* constant. At this point, the question arises as to how he changes his driving style, certainly by modifying the speed (deceleration or acceleration). This variation of behaviour is characterized by a generally medium time of definition (about one minute or less, however significantly more that the reaction time of the user) and by a level of consciousness normally conscious but that evolves rapidly in unconscious when external conditions become stable and the user returns to have a strategic behaviour. Therefore the way the user accelerates and decelerates in medium-short time can be defined as the main characteristics of the attention behaviour.

3.3 The reaction behaviour

However, when an unexpected event happens while driving (for example, there is a hole that it is not possible to avoid, an animal crossing the road, a car runs through a red light, etc.) it is possible to define another type of user behaviour: reaction behaviour. It depends on the actual environmental conditions the user meets when he has not foreseen them and, at the same time, it depends closely on the driver reaction time and also on his physical or psychological condition. This behaviour is characterized by a very short (about one second) definition time (absolutely conscious). The lack of knowledge of possible unexpected events generates a *safety margin* that the user keeps from his driving limit condition, hereinafter referred to as *δe*. Each driver chooses its own *δe* (risk proneness) according both to his condition and how he perceives the probability of a unexpected event. The main effect of this *safety margin δe* is a reduction of speed *ΔVe* that the user decides to select referred to the speed (*Vlim – ΔVi*) that he could select if the probability of an unexpected event is 0. At this point, the question arises as to how the user changes his driving style when an unexpected event happens, certainly by braking and/or suddenly changing the trajectory of the vehicle. Therefore braking and changing trajectory, both in a short time, are the main characteristics of reaction behaviour.

3.4 The risk

Considering that Risk “*R*” is defined as:

$$R = P \times I \qquad \text{(Eq. 1)}$$

where
p is the probability that the negative event happens,
I is the intensity of the consequences that the event would cause,
the "strategy behaviour" depends on user expectations on the probability *p* and the intensity *I* during the journey and on the higher or lower safety threshold *δi* (risk aversion for the uncertainty of boundary conditions) which the driver uses in order to take into account the difference between a real situation and limit conditions and the uncertainty that he has about this difference.
Whereas the "reaction behaviour" depends on the higher or lower safety threshold *δe* (risk aversion for unexpected events) which the driver uses in order to take into account possible unexpected events.
Of course the user cannot distinguish between the safety margins defined above (*δi* and *δe)*. Their identification, however, it is essential to understand the concepts of compensation and control introduced in the rest of the paper.
To summarise, the different types of behaviour and their main characteristics can be represented in the following table.

	Strategic Behaviour	Attention Behaviour	Reaction Behaviour
Depends on	estimate of the difference between real situation and limit conditions	mutation of external conditions	unexpected events
Main characteristics	speed selection	acceleration and deceleration	braking and changing trajectory
Time of definition	medium-long	medium-short	short
Level of perception of the risk	perceived	perceived	unperceived
Level of consciousness of the user	unconscious	conscious	conscious
Safety margin	*δi* (risk aversion for the uncertainty of boundary conditions)	*δi* (risk aversion for the uncertainty of boundary conditions)	*δe* (risk aversion for unexpected events)
Speed selected	Vlim – ΔVi – ΔVe	Vlim – ΔVi – ΔVe	Vlim – ΔVi – ΔVe

Table 1 – strategic, attention and reaction behaviour

4. ECONOMIC RISK

The unit of measurement of (Eq 1) is money, or better, the cost of the damage provoked by the accident multiplied by its probability. Therefore, each time we drive a car on a Km of a route, it is like we know we are willing to spend a quantity of money equal to p*I [12]. Of course we hope fervently that the accident does not happen, but we know in reality that sooner or later it will happen. In that circumstance we will spend, all in one time, the money we have saved during the previous journeys in which the accident did not happen.

Therefore, talking about risk R is equivalent to speaking about the money that a person is willing to spend to avoid or reduce the risk (i.e. for safety). In this paper we call this quantity of money the Safety Budget.
When we travel, we plan our behaviour (more or less risky in relation to road safety) on the basis of how much we are willing to spend for that specific trip. Since each travelled kilometre entails a travel cost *cu* for the user, it is also possible to calculate - for each behaviour and therefore for each velocity v - the total cost *Cu(v)* for the user, sum of the monetary travel cost cu(v) and the risk related costs:

$$Cu(v) = cu(v) + p(v) \times Iu(v) \quad \text{(Eq. 2)}$$

where *p(v)* and *Iu(v)* represent – per Km – the probability of an accident at speed v and the intensity of consequences for the user, in case of an accident at speed *v*.

Actually *Cu(v)* consists of several addends:
cost *c1* related to the vehicle (fuel, amortization, insurance, maintenance, etc.)
cost *c2* related to the user (value of used time)
cost *c3* related to the road (toll)
cost *c4* related to any penalty for transgressing rules
cost *c5* related to a possible accident.
It is necessary to take into account that *c1*, *c2* and *c3* are spread over time, while *c4* and *c5* are concentrated.
Obviously, the same relation can be found considering the costs for the whole society and not only those for the single user, that is the monetary travel cost *cs(v)* and the total cost *Cs(v)*. In this case, it is necessary to take into account a cost *c6*, related to the environmental impact of mobility, and a cost *c7*, related to the prevention of and punishment for road accidents. It would be:

$$Cs(v) = cs(v) + pa(v) \times Ia(v) + ps(v) \times Is(v) \quad \text{(Eq. 3)}$$

where
pa(v) and *Ia(v)* are the probabilities (per km) of a sanction and its consequences for society, at speed *v*.
ps(v) and *Is(v)* are the probability of an accident and its consequences for society, corresponding to the speed *v*.
Users who give importance only to their own utility and are sure of not suffering an accident travel at a speed *v* that minimizes *cu(v)*. On the contrary, users who take into account the possibility of suffering an accident choose v minimizing *Cu(v)*.

Finally, "social" users – taking into account the needs of the whole society - choose v minimizing *Cs(v)*[*].

Our behaviour (in relation to the unit length of road to travel) naturally takes into account the boundary conditions in order to ensure that the risk remains constant. For example, if our psychological and physical conditions are not good, as this would increase the probability of an accident, we are forced to reduce speed, bringing the probability of an accident back to the originally accepted value. The same mechanism could be triggered by the vehicle (e.g. if tyres are worn), the environment (e.g. if the weather gets worse), the traffic (e.g. if it increases).

The speed reduction required by our behaviour to maintain a constant level of risk inevitably produces an increase in travel time and therefore higher travel costs. In this way, we have decided to spend money to reduce the risk of accident and we can also theoretically quantify the cost of this reduction. Reducing speed is a decision to pay more for the ticket of the journey itself and to spend less money on charges and insurance against the risk of accidents and possible sanctions. Increasing speed is a decision to pay less for the ticket for the journey itself, but to spend more money on charges and insurance against the risk of accidents and possible sanctions.

The curve below (taken from Tarko AP, "Estimating Subjective Risk Revealed Through Driver Speed Choice" in a talk given to the "Road Safety and Simulation International Conference RSS 2007 7,8,9th November 2007 Rome, Italy) represents the disutility due to the time wasted travelling against speed.

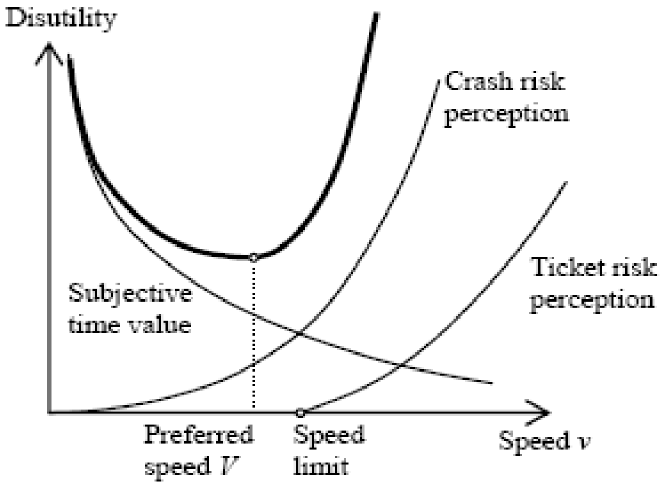

Figure 1 – speed deterrent and enticement curves in speed selection

[*] In (Eq. 2), we assumed *c1, c2, c3* incorporated in *Cu(v)*, but clearly there are other possible interpretations. For example they or a portion of they may be part of *Cs.*

According to the Author, the total travel disutility is the sum of three components, the subjective costs of travel time, the perceived risk of accident and its potential consequences, and the perception of speed limit control:

trip disutility = *time value* + *perceived risk* + *perceived enforcement*

Actually, the value of time is not only subjective (it depends on your income), but it is a function of the user conditions (e.g. the value of time on Sunday or during a holiday is different from the value that the same subjects give to their time on a workday). As a consequence the curve can be very flat during non-working periods. In these cases the speed selection is dominated by other factors rather than by the time wasted. The most significant factors should be found in the main motivations for a trip. For example, in the case of a tourist trip, low speed can be determined by the pleasure of enjoying the day talking with the passenger, enjoying the landscape with a greater intensity, etc. Therefore a function of variability for the value of time should be sought that is able to take into account all these factors. The same is true for the curve relative to sanction and probably also for the risk related curve.
However, the driver psycho-physical conditions, the vehicle conditions, weather and traffic are generally predictable well in advance, with some exceptions.
If the driver is not a regular user, the road conditions are valued at the moment. In any case the user is aware that there is an uncertainty about the conditions he will effectively encounter. Therefore this uncertainty is transformed into less risky behaviour (e.g. with a slightly lower speed), than would have been adopted perfectly knowing all the boundary conditions a priori. This means that the monetary risk that the driver actually spends on the route will be less than the risk corresponding to the perfect knowledge of the boundary conditions. The difference between the two risk values represents a δ of money which is not spent. On the contrary, this is held to be spent in unforeseen scenarios that will certainly occur because of the above described uncertainties.

5. EXTERNAL AND INTERNAL RISK

The following theoretical treatment is supported by a practical example in order to give substance to the formulas. The case examined is that of a tunnel with regular lighting at the entrance, located after a curve, along a road in a cutting.
The case history shows that some accidents happen due to sudden events, in which the equilibrium conditions are quickly or very quickly lost [14]. On the other hand, it is obvious that, apart from accidents caused deliberately (e.g. suicide) or totally unforeseeable, with no detectable risk (e.g. a billboard falling on a moving vehicle), all other accidents happen because of an underestimated perceived risk linked to an event. In fact, if the driver had been able to perceive and predict what happened, he certainly would have done everything to avoid the accident. In these cases, obviously, the problem is not in the Safety Budget, but in the Perceived Risk, which is underestimated compared to the External Real Risk.
The previous remarks lead to considering the hypothesis that, in a potentially risky event, human behaviour is linked to a "subjective equilibrium". This equilibrium is updated by the subject if the Perceived Risk changes. This may happen for two reasons: a sudden change in boundary conditions, perceived in the short term and not characterized by steadiness, or a structural change of the risk itself, which tends to persist with a certain stability and influences the subject in the medium or long term, affecting his driving attitude.

To explain this in a better way, we can assume that the risk R consists of two components, Re and Ri.

$$R = Re + Ri \qquad \text{(Eq. 4)}$$

Re (External Risk) determines the driver's immediate reactions (e.g. there is an unexpected fault in the lighting system that causes a sudden change in luminosity, the driver suddenly reduces speed). It corresponds to the equilibrium between a driver's perception (e.g. he unexpectedly perceives the complete absence of light) and external reality (e.g. the light is less than outside), so in general it will be:

$$Re = Rre - Rp \qquad \text{(Eq. 5)}$$

where Rre is the External Real Risk and Rp is the Perceived Risk.
When the equilibrium exists (e.g. the failure of the lighting system is indicated by the variable message signs along the road, before entering the tunnel: the driver perceives the danger, reduces speed and increases attention while approaching the tunnel), reality corresponds to what has been perceived:

$$Re = 0 \qquad \text{(Eq. 6)}$$

Therefore, it is Re that acts when, after sudden changes in boundary conditions, Rre (External Real Risk) changes, becoming very different from Rp (perceived risk). Critical situations arise when Rre is subject to large increases in a very short time (e.g. if there are no warning signs approaching the tunnel, the user will be in the dark in an unexpected situation and he will be subject to hazardous reactions):

$$Re > 0 \quad \text{(Eq. 7)} \quad \Rightarrow \quad Re = \delta e \quad \text{(Eq. 8)}$$

Where δe represents the value of the risk that a driver suddenly has to face (e.g. the driver continues to travel despite not seeing well). From Eq. 5 and Eq. 8

$$\delta e = Rre - Rp \qquad \text{(Eq. 9)}$$

In other words, the lack of knowledge of unexpected events (e.g. the failure of the lighting system) creates a safety margin that the user keeps from his driving limit condition. Ri (the subject's Internal Risk) determines a driver's behaviour in the medium and long term, it depends on the past experience of the driver in similar boundary conditions and on his psycho-physical conditions. It corresponds to the equilibrium between a driver's perception and his unconscious reality, using the unconscious" with Freud's meaning, it stands for all psychological contents that do not appear in the current horizon of consciousness [15,16]. In general:

$$Ri = Rp - bS \qquad \text{(Eq. 10)}$$

Where Rp is the Perceived Risk and bS the Safety Budget.
When the subject has to decide his "average driving attitude" according to the boundary conditions which can be predicted on average for a potential risk, he evaluates Ri. Obviously it depends on the driver's condition and his aversion to risk. Returning to the

previous example, assuming that the driver goes on that road every day and that the lighting system often fails, he will take into account the possibility to meet the failure and will adopt more cautious driving behaviour.
If we hypothesize that the driver pursues the safety condition, Ri has to be null or, in case of high risk aversion, negative [17]. So:

$Ri \leq 0$ (Eq. 11) => $Ri = -\delta i$ (Eq. 12)

Where δi is a generally positive term, expressing subject's risk aversion; that is to say how much the driver is willing to invest in the Safety Budget in order to exceed Perceived Risk, as shown in Eq. 10 and Eq. 12:

$$\delta i = bS - Rp \qquad \text{(Eq. 13)}$$

As previously defined δi represents a safety margin that the user keeps from his driving limit condition taking into account his past experience in similar boundary conditions and his psycho-physical condition.

Considering Eq. 4, Eq. 5, Eq. 9, Eq. 10 and Eq. 13:

$$R = Re + Ri = Rre - Rp + Rp - bS = Rre - bS \qquad \text{(Eq. 14)}$$

$$R = Re + Ri = \delta e - \delta i \qquad \text{(Eq. 15)}$$

Eq. 14 gives the Risk as the difference between the External Real Risk and the Safety Budget; Eq. 15 shows that it is also equal to the difference between the Sudden Risk (that is "the value of the risk that a driver could suddenly face") and the driver's risk aversion.
The first impression from observing Eq. 14 and Eq. 15 is that the total Risk does not depend on the Perceived Risk, but only on the External Real Risk and on the Safety Budget (i.e. on the sudden risk and the risk aversion).
This would lead to the conclusion that, in order to reduce risk, we should work only on factors which can give rise to sudden risks (road geometry, road signs, vehicle maintenance, driver's health) or on those influencing driver's personality.
This would be true if we supposed that human behaviour is "algebraic", i.e. that summing Re and Ri were correct. Actually, Re and Ri act independently of human behaviour: Re acts on immediate reactions in a very short time, Ri influences unconscious reality. So, the total behaviour is the sum of different actions which can hardly influence each other.
It is necessary to consider Re and Ri separately in order to analyse human behaviour in road safety, also assessing the influence of the Perceived Risk.
Therefore, we can assume that Perceived Risk in Eq. 5 and Eq. 9, relating to external risk, is different from Perceived risk in Eq. 10 and Eq. 13, relating to the internal risk. From this:

$$Re = Rre - Rpe \qquad \text{(Eq. 5')}$$
$$\delta e = Rre - Rpe \qquad \text{(Eq. 9')}$$
$$Ri = Rpi - bS \qquad \text{(Eq. 10')}$$
$$\delta i = bS - Rpi \qquad \text{(Eq. 13')}$$

but, above all (Eq. 14) becomes

$$R = Re + Ri = Rre - Rpe + Rpi - bS \qquad \text{(Eq. 14')}$$

It is interesting to notice that the external Risk changes with the External Real Risk in the same way as the pupil changes its dimension with environmental brightness (dazzling effect):
if *Rre* suddenly increases (e.g. a sudden change in light due to the a fault in the lighting system), *Rpe* also increases immediately (e.g. the driver suddenly perceives a change of boundary conditions);
if *Rpe* goes on being high, the driver’s attitude in the short-term changes (e.g. the driver reduces speed);
if *Rre* decreases, before adjusting *Rp*, the driver “verifies reality”: if real conditions tend to confirm the decreasing of *Rre* for a significant period of time, after this period *Rpe* actually decreases, with a consequent modification of subject’s behaviour and driving attitude (e.g. the driver increases speed).
Rpe is modified by the boundary conditions while driving (short-term changes); it represents the natural consequence that is perceived by the user when an external factor changes. *Rpi* depends on the specific user, his situation and his experience (medium and long term change).
In the case of failure of the lighting system at the entrance of a tunnel, all the users perceive the change of light, which influences *Rpe*, more or less rapidly. On the contrary, the factors that can greatly change the overall risk perception are the user's psycho physical condition, history, experience and so way of relating to the road. Human diversity can only be represented by a subjective magnitude. This also happens in the case of road safety with *Rpi*.

6. FACTORS INFLUENCING ROAD SAFETY

The equation we have to consider in order to study factors influencing road safety is Eq. 14. The equation shows that there are four factors that affect the total risk: the External Real Risk *Rre*, the external perceived risk *Rpe*, the internal perceived risk *Rpi* and the Safety Budget *bS.* It is therefore important to identify factors that may be affected by technical and engineering solutions. Engineering can certainly mitigate some sources of External Real Risk (e.g. illuminating the entrance of a tunnel, increasing the radius of a curve, etc.). Likewise, engineering may modify the external perceived risk. For example, the road signs need to anticipate a situation of External Real Risk in time and space. The driver, through the signs, gets ready to face the risk and change his driving behavior.
Generally engineering actions tend to eliminate the "reaction behavior" in order to bring it to the attention behavior (for example with road signs) or to the strategic behavior (with more complex design interventions), therefore having the effect of internalizing the external risk.
Concerning other two factors, it seems reasonable to think that, being influenced by the experience and psycho-physical conditions of individual drivers, these two factors cannot easily be governed by technical or engineering solutions. However, some management, behavioral and social rules may affect the two factors. For example, public means of transport are driven by specialized personnel characterized by considerable experience and training, therefore with a different *Rpi* from that of a generic driver. Similarly, it is possible that income level can influence the Safety Budget.

7. COMPENSATION

Considering the premises carried out in the previous sections it is possible to consider that Homoeostatic theory of Risk is based just on Internal Risk. In fact, according to this theory, if a driver is involved in a risky situation, his behaviour does not only depend on the total Risk (*R*), but on the difference between *Rpi* (perceived risk – internal) and *bS* (Safety Budget). Thus, if boundary conditions change so that *Rpi* changes, the driver unconsciously modifies his attitude and his *bS* in order to maintain the difference between them constant.
As an example, if we rectify a curve or we light a crossroads, obviously *Rpi* will decrease. The driver, with a constant aversion to risk, will be inclined to invest a smaller safety budget, keeping the difference respect to the Perceived Risk constant. A smaller investment in safety probably means a higher speed. In fact, our behaviour unconsciously considers boundary conditions, in order to guarantee a constant economic risk.
The higher speed, unconsciously determined by our driving attitude to maintain our Risk level constant, reduces travel time and, consequently, travel cost: we have decided to spend the money saved to correct higher risks linked to accidents and possible sanctions.
In this sense Homoeostatic theory of Risk influences the risk factors not always induced by technical and engineering solutions.

8. REGULAR AND NON-REGULAR USERS: NON-HOMOGENOUS DRIVER BEHAVIOUR

It is interesting to note that the table in section 3 applies to all users, but it may happen that in a road section different users have different behaviours (defined by the columns of the table). This is the case of regular and non-regular users, as the firsts (in absence of unexpected special events) have almost internalized all the risks, while the seconds obviously not.
If a driver knows a road very well, obviously External Risk (*Re*) will approach zero, also near potential pitfalls representing a big external risk for drivers who are not regular users. Therefore, consciousness (or sub consciousness) determinates a different driving attitude and, unavoidably, non homogeneous behaviour.
In any case, the regular driver is essentially subject to the internal Risk (*Ri*) that depends on his aversion to risk [18] at the precise moment he drives along that precise road.
Aversion to risk depends on factors such as psychological and physical conditions, sex, age, driving experience, characteristics of the vehicle, so if these factors change, we will have different driving behaviour for different subjects.

9. COMBINED RISK

Generally users do not drive alone along a road, so the accident risk is linked not only to their behaviour, but also to the influence of others. In particular, the more the interactions with other users, i.e. the heavier the traffic, the more the driver's behaviour depends on them.
The risk of an accident between two or several vehicles is compound and also depends on not homogeneous behaviour of the different drivers. From the point of view of a single user, the differences in driving behaviour of the others can be considered similar to external situations, not completely predictable and can be evaluated as additional external risks,

not due to road pitfalls. External Risk, which only seems to be important for non regular users when we consider the isolated vehicle, has an increasing relevance when a vehicle is not isolated.

10. GENESIS OF THE CONTROL PROCESS

It is not easy to predict user behaviour based on external factors, including the behaviour of other users. The development of a behaviourally-oriented accident theory model including risk compensation and the differentiation between internal perceived risk and external perceived risk will be a goal of future research. A variety of applications will need to be conducted to determine the influence of perceived internal and external risk on road user behaviour (for example the differentiation of behaviour between regular users and non-regular users).

At the same time, in order to reduce road risk and improve safety in the near future, it is necessary to consider the concept of "control process" of a person's behaviour within the system considered [19]. Of course, another variable to be clarified is the size limit of a problem: below the limit, we face a "problem without significant conflict" that only requires the intervention of the individual (the user), and, beyond the limit, we face a "potentially conflictual issue" that requires the intervention of a rule to share. For example, if I really like chocolate, I can eat it a lot, before driving: there are no rules that forbid me doing so (below the limit example). If I drink alcohol before driving the situation changes dramatically: the potential risk to which I am exposed must be governed by a rule (and then by a process control) because it conflicts with not only my health but also the safety of other road users (beyond the limit example). In particular it has to be verified whether the process is internal or external with respect to the person.

For each behavioural problem, it is necessary to determine:

the system;

the relational level of the problem (personal or interpersonal);

the possible consequences of improper behavior not controlled by the components of the system;

who controls the behavior of people belonging to the system (the individual, the institution formally recognized immediately above, another institution on the 2nd, or the nth level or at the highest level possible);

the highest possible level to control the behavior of users within the system you are considering;

whether the level of the control process of the system is suitable for the level of relation of the problem (personal or interpersonal);

whether the control rules are adequate;

The problem of road safety is incorporated within this context. Therefore, before proceeding, it is necessary to answer each of the questions above. Until now, efforts have generally been made to solve the problem starting from the last issue, trying to adjust the enforcement rules.

1. What is the system? The system is made up of all the users of mobility which potentially interferes with the generic driver, i.e. pedestrians, motorcycle and cycle users, private car users, road public transport users and professional users. Essentially it includes people potentially interacting, excluding those forced to remain in confined areas with no road (hospitals, prisons, etc.).

2. What is the level of relation of the problem (personal or interpersonal)? The level of relation is generally interpersonal, except in the (very rare) case of people travelling with the certainty of being alone throughout the trip.
3. What are the consequences of improper behaviour not controlled by the components of the system? The consequences can be very serious, because they can determine PDO (property damage only), but also the severe disability or death of the transgressor or of other involved users.
4. Who manages the control process of the behaviour of people belonging to the system (the individual, the institution formally recognized immediately above, another institution on the 2nd, or the nth level or at the highest level possible)? The control process of the behaviour of people belonging to the system is usually managed by an individual (mobility or private transport), but in some cases by a professional who works for third parties (lorry or public transport drivers). In the case of an individual, this is true for position along the cross section, speed of maneuvering, and also for travel departure time, origins, destinations, itineraries and stops. These parameters are controlled by a higher level in case of professionals working for others. However, position along the cross section, speed and maneuvering are subject to general rules. These rules can be violated, since the enforcement system, belonging to a higher level (usually the Government), only regards a limited sample of users. In the case of negative consequences associated with improper behaviour (accidents), there are organizations (insurance companies) at a lower level that can act a posteriori to compensate at least a part of the financial costs caused by the individual responsible for an accident.
5. What is the highest possible level of control of user behaviour within the system you are considering? The Government.
6. Is the level of the control process of the system suitable for the level of correlation of the problem (personal or interpersonal)? No, because the severity of the consequences does not allow the control process to be managed by the person himself, particularly in cases where the risk is generally considered too high.
7. Are the control rules adequate? It is necessary to adjust the rules, particularly to take into account the cases in which the level of the behaviour control process should be adjusted first.

In accidents in which the risk is generally considered very high and not acceptable, the problem is the lack of adequacy of the level of the user behaviour control process. In fact, at the moment it is delegated within the system, (i.e. the user himself). In such cases, it seems appropriate to consider seriously the possibility of transferring this control process from the system (user) to a higher level.

11. CONTROL IN TRANSPORT MODES

Having explained the control process that should be conducted in order to reduce risk and improve road safety, it is convenient to provide some practical examples to support the theory.

Currently, it is possible to distinguish between modes of transport according to the control system that governs them. The control systems can be either infrastructural or managerial. The following describes the methods of transport in descending order of effectiveness of the control system that governs them.

Public transportation modes are primarily controlled because the driver is a specialist, he does it for a living. In these cases the driver is characterized by a low *Rpi* and a high *Sb.* There are some public transport modes that are also physically constrained in movement.

In these cases, the control system is also infrastructural and the influence of *Rpi*, *Rpe* and *Sb* is almost zero. Going into detail, it is possible to put together the metro and train modes because they are governed by a both infrastructural and management system of control. These modes of transport may move only along the railroad. All the main manoeuvres are also constrained by the infrastructure (turning, overtaking, changing direction, etc.). At the same time, management control systems govern the speed, braking, acceleration: the driver must only comply with the rules and can intervene with his free will only in case of emergency or necessity. For these modes, the type of accident occurs only if the system fails or if the driver does not follow the management rules. Generally for these modes the only factors affecting the total risk are the External Real Risk connected to unexpected events (e.g. a stone on the railroad) or a human failure (e.g. an unseen rail signal).

Going down to the second degree of variability there are the air and sea transport modes. In this case, there is not a physical constraint of the trajectory and so the system of management control seeks to intervene in the path by establishing additional rules that determine the route of travel. Even in this case the driver is a specialist. If he follows the navigation rules (and therefore the rules of the management control system) he lowers the probability of a collision incident. In this case the driver has a greater degree of freedom: in case of need he may act on the speed, acceleration, deceleration, but also on the route. The influence of *Rpi* and *Sb* is almost zero due to the experience of the driver, *Rpe* is almost zero due to the management control system.

Going down to the third degree of freedom there is public transport by road. In this case, similarly to the case of air and sea transport, the driver is able to act on both the speed and acceleration of the trajectory of the vehicle. The main difference is that while for air and sea transport the vehicle position is continuously monitored through GPS and radar systems managed by a control authority that operates at a higher level (able to request a change or correction of the route) for public transport by road there is not this kind of control. The free will of the driver in this case has an additional degree of freedom. The influence of *Rpi* and *Sb* is almost zero due to the experience of the driver so, total risk is influenced mainly by *Rre* and *Rpe.*

At the fourth degree of freedom it is possible to consider the private mode of transport by road. The main difference with the previous public modes is that the driver, in this case, is not a specialist, he drives a car if he has a driver's license. In this case it is important to analyze the relevance of the reference system. If the driver of a public means makes a mistake the consequences are paid by all the passengers, and so by the community. If a car driver makes a mistake, he surely pays the consequences firsthand. However, his mistake may mean a loss for others. Probably a single car accident involves fewer people than an accident involving a public means of transport. However, almost everywhere almost all individuals have a driver's license, the number of accidents involving private vehicles is very high, so the cumulated social consequences are certainly higher than those related to accidents involving public transport. It therefore seems inevitable that, in addition to increasing road safety, it is socially useful and necessary to assign the control of private transport mode to a higher level. Currently, the control process of the private road transport is widely left to the individual driver and the total risk is affected by *Rre, Rpe, Rpi* and *Sb*. Control is only exercised by a higher level at a few points within in the network, through checks of law enforcement, the penalties for exceeding the speed limit, etc.. There are some cases in which control is extended to entire road network sections. This is the case of the Italian motorway, where the “Tutor” system, measuring the precise speed and average speed of travel of vehicles, ensures widespread control of the means of transport. If the control is only limited on some links of the network it is possible to observe a

compensation phenomenon: violations and accidents decrease on the controlled link but increase on the rest of the network. It would be desirable for the control system to be implemented on the entire network. Nowadays, the technology allowing overall control already exists. It would possible to use GPS sensors (or using tachographs, automatic car stop systems, etc.) in each car and to implement a real-time control system capable of controlling all traffic. In this case the private mode of transport by road could be considered in the same way as the metro and train modes where the only factor influencing the total risk is the External Real Risk connected to unexpected events (e.g. a stone on the lane) or a human failure (e.g. an unseen railway signal). Of course the drivers would consider the control as a severe limitation of their free will. However, the car user, if aware that his error has an impact on other people, would understand the usefulness of the control and get used to it in time. The rule of compensation should also be valid in this case: it should be important to identify areas in which the free will of the people could be truly free without prejudicing the rights or safety of others.
In order to complete the classification of transport modes considering the control system that governs them, it is possible to put the cycling as the fifth degree of freedom and the pedestrian mode as the sixth. In these modes, which are more complex to represent, the freedom of choice seems to prevail over the consequences related to lack of control. Certainly, with cycling being characterized by a faster speed than the pedestrian, it is opportune to physically separate cyclists from pedestrians. The same consideration applies to the pedestrian mode. In order to preserve cycling and pedestrian modes, which represent the native and natural part of mobility, the interaction between them and other transport modes has to be controlled (pedestrian crossings, pedestrian paths, 30 km/h zones, etc.). The cycling and pedestrian free choice of speed, deceleration, acceleration and trajectory should be possible in all places precluded by other means of transport.

CONCLUSIONS

Behaviourally-oriented accident theory has become an essential issue in recent decades. The theory of risk compensation grew largely out of investigations of road safety interventions. It was noted that some interventions had failed to achieve the forecast savings in lives and injuries. Theorists speculated that while the studies demonstrated that the probability of injury given a crash had reduced, the fact that the overall probability of injury was unchanged indicated that there must have been some change in the probability of crashing. Probably the answer to the dilemma is the size of the reference system: considering a system close to the area of an implemented safety measure, the reduction of accidents predicted by the studies will be correct; expanding the reference system it will fail. This is the case of the introduction of speed limits on Italian Highways: this safety measure, which guarantees the speed limit on controlled sections, has reduced accidents on Highways, but at the same time there are more accidents on freeways where the level of control is lower. [20]. This is one of many examples that can be made to support risk compensation theory and to demonstrate the effectiveness of a control process external to the user.
Risk compensation is now widely accepted, but risk homeostasis, which goes much further, has many fewer followers. Certainly it is necessary to conduct studies and tests that justify and prove the homeostatic theory; probably it is not the solution to road safety but is an important component to consider in order to formulate future models of accident behavioural theory. In this context, models should consider the various risk components to conform more to reality. Homoeostatic theory of Risk is based just on Internal Perceived

Risk. The paper investigates the meaning of the Perceived Risk and indicates the necessity to consider Internal Perceived Risk and External Perceived Risk in order to correctly consider human behavior in road safety.
It is necessary to study and improve factors which can give rise to sudden risks (road geometry, road signs, vehicle maintenance, driver health) and factors influencing driver personality (education) in order to reduce risk. At the same time, it is also important to assess the influence of the Perceived Risk (in the short and medium-long term). The complexity of the system leads to considering the transfer of the “control process” from the single user to a higher level (The Government). In some cases this transfer of the control system has already been carried out (fixing distancing from vehicles in tunnels, monitoring average and current speed on important highways, limiting lane access in risky segments, etc.). Further study and data analysis have to be conducted in order to determine when and where the transfer of the control process is appropriate, with respect to social equity and at the same time of the user benefit.

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