DEFINITION OF AN INDEX OF PERFORMANCE IN ORDER TO CHARACTERIZE THE LEVEL OF DANGEROUSNESS OF ROAD INFRASTRUCTURES

Sascia Canale, Salvatore Leonardi, Francesco Nicosia.

1. INTRODUCTION

Service Level indicators of road infrastructures may be connected to safety and comfort characteristics and to transportation costs. The study of vehicle motion must to be analysed through a global analysis of road-vehicle system. Road infrastructures may be divided into elementary sections. The vehicle motion is characterized by a continuous exchange of information between driver and road environment. Information must be acquired and transformed into actions by means of the organs used by the driver. A road is dangerous if do not guarantee to the driver an exact perception of necessary stimulus. In this frame, to determine the safety level of a road layout has a relevant importance. The motion of a vehicle happens through the adoption of a series of risks undertaken from the customer. The risk analysis applied to the road allows to characterize the various elementary sections in function of their safety. The risk level of a road section is due to the type of section and to the seriousness of eventual accident. In this paper we want to propose the use of a new performance index. This index contains all the fundamental parameters necessary to study the safety level of roads: plane-altimetric characteristics, use of lanes, type and volume of traffic, existing signs. The proposed methodology permits to obtain a performance index aimed to the management of road network.

2. RUNNING OVER AN INFRASTRUCTURE

Many of the activities developed by men are characterized by a latent level of risk. Vehicular running is certainly a dangerous activity because driving may hide perils which may end into an accident. We may compare a trip along an infrastructure to a cycle of production which allows the vehicle to carry on a "work" moving on the road. If we consider the whole infrastructure divided into elementary sections (sections which are identical and perfectly operating in determined conditions at time t), (Fig. 1),we may define "accident" the non-voluntary interruption of the journey due to non-perfect working of the road-vehicle system.

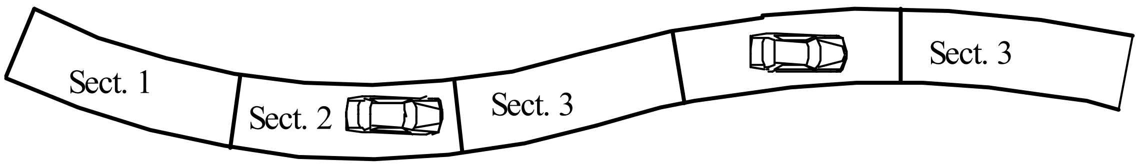


Fig. 1 - Scheme of a road infrastructure

We define security of trip S(t) at time t, with regard to the unfavourable event, the relation between the number x(t) of the sections where the passage took place without any accidents after time t, and the total number of the runned sections:

$$S(t) = \frac{x(t)}{n}$$

To analyse road conditions it is necessary to study all the aleatory phenomena which concomitance may bring to the feared event. We must analyse in detail the connections road-vehicle so to evidence all the elements which may bring to road accident or may reduce the safety of the infrastructure.

Road accident is a very complex phenomenon due to the combination of numerous factors tied to:

- users behaviour (experience, capacity, emotionality, etc.);
- vehicle characteristics (performances, maintenance, etc.);
- infrastructure (geometry, pavement, etc.);
- environment (traffic flow, meteorological conditions, etc.).

We are obliged to control the correct operation of each elementary section so to be able to analyse the global infrastructure operation; if only one section is not perfectly working, this may create problems to the whole infrastructure. A correct operation study must therefore start controlling every elementary sections to check its suitability. The elementary sections to be individuated have not a pre-established physical dimension. It is clear that the shorter the sub-division is, the best the investigation will be carried out.

3. ROAD-VEHICLE SYSTEM

Driving is a continuos succeeding of perceptions and reactions. Many driving activities are filtered by perception of safety and comfort.

The driver, closed into his car, trusts on his organs of view, hearing and touch. External stimuli, filtered by perception organs, arrive to the brain, which elaborates the best drive behaviour and makes the driver in condition to execute control actions (Fig. 2).

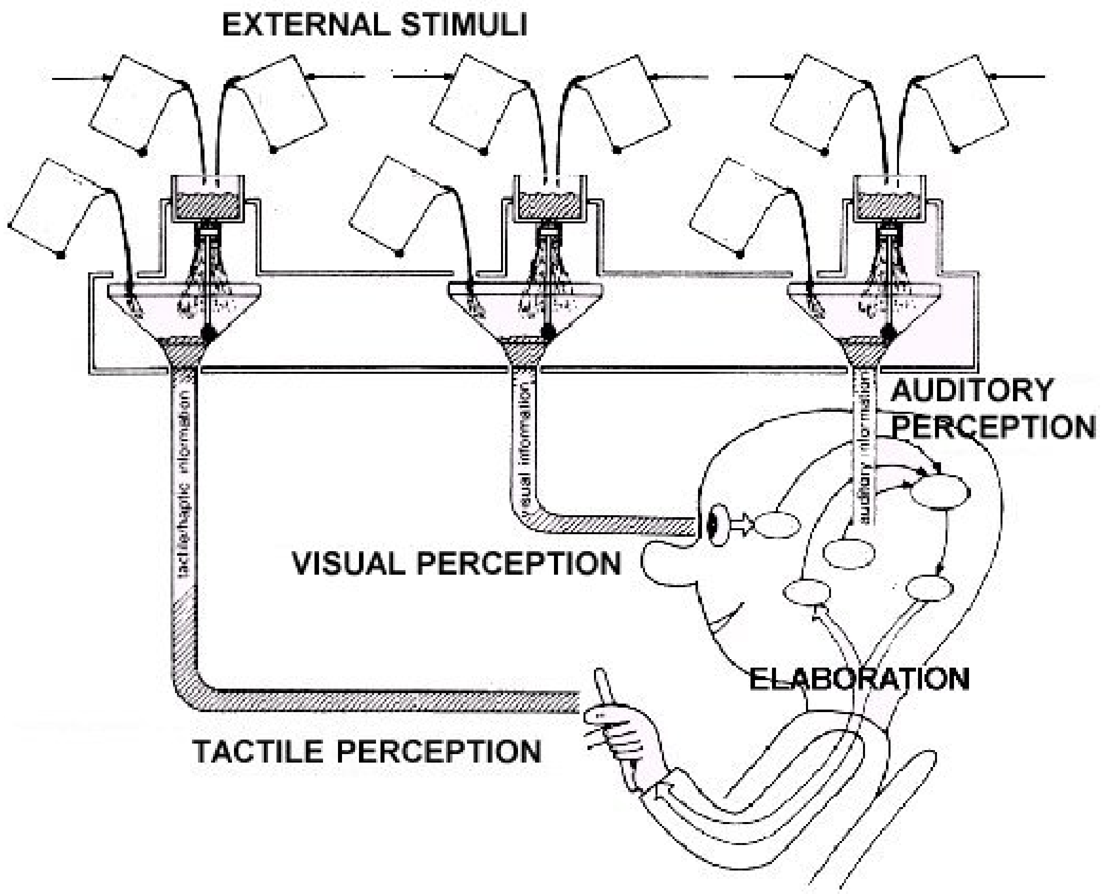


Fig. 2 - Drive activity

We may represent driver activity in the following sequence:

S→ P → R

where:

S = the stimulus constitutes by road situation,

P = the filter of personality,

R = the reply or reaction.

The efficiency and the safety of the circulation of a road infrastructure depend to the typology of information which may be given to the user. The user must receive of all the information univocally and in due time so to be able to carry on the correct drive actions.

Road design specifications foresee a direct correlation between design speed and geometric characteristics of road sections. The higher speed running is the more attention has to be given to the definition of the elements characterizing the sections. Speed running depends not only to the choices made during design phase or to the choices made by the user but it may vary if traffic varies on the section. An increase of traffic volume may produce a speed decrease, as clearly showed in Fig. 3.

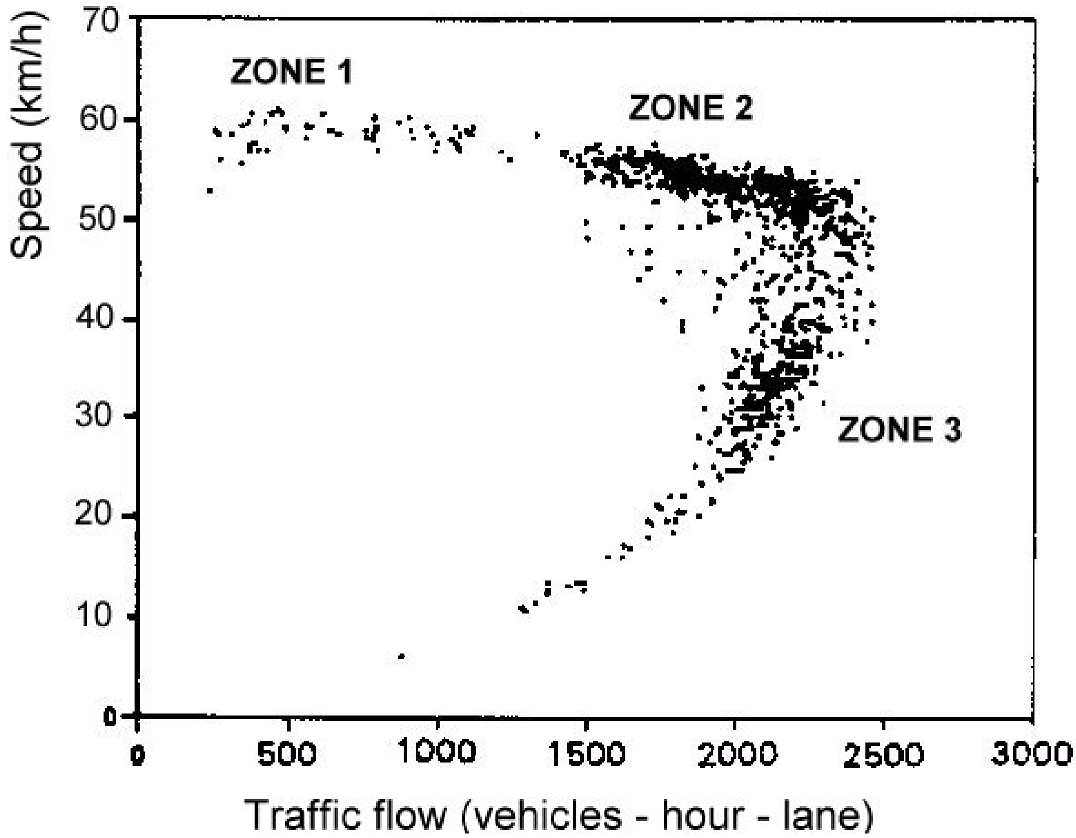


Fig. 3 - Relation between speed and traffic flow

Road infrastructures fundamental function is to guarantee high speed running and high safety. Safety may be correlated to the availability of signs, emergency and assistance systems, light systems, etc. Such elements play a primary role for the individuation of safety representative parameter and for drive comfort.

A correct drive activity must be based on a clear perception of the information coming from outside and on the capacity offered to the driver to modify his behavior according to the necessary exigencies of the road. When this is not possible, the potential causes of accident increase and subsequently safety decreases.

All the information are characterized by a determined speed running, so the user thinks he can move in every sections of the road keeping unalterable his running speed, considering that all the sections have fulfilled safety requirements. A strong connection between "memory" and "expection" is created then. This connection often brings the driver to make banal errors which may generate an accident.

4. METHODOLOGY OF RISK ANALYSIS

We may define the risk as the uncertain damage to which a certain person is exposed as consequence of the occurrence of probable events. The probability that a determinate event may occur is the element which characterises every human activities based on logical process, while uncertainty characterizes the aleatoric actions made by a person who knows that there is no certainty to obtain the expected result.

From an analytic point of view, we may define the risk, in the frame of the measurables elements, as the combination of the damages or the negative consequences and the probabilities connected to them. The aim of all human activities does not consist in finding situations without any risk but the purpose is to try and research, by means of systemic analyses, those conditions characterized by minor risks.

The quantitative definition commonly adopted for risk is:

$$R = f \cdot M$$

- f = frequency of the happened accidental event;
- M = Amplitude of the accident effects, that is effect consistency and its consequences.

To search a minor risk situation (or a bigger level of safety) means therefore minimization of the consequences seriousness or minimization of the probability for the accidental event to happen, or better, both minimizations of risk.

We may graphically represent these data by means of a curve of risk, which shows the probability of an event or accident occurrence f_e, of a certain amplitude of the consequences (Fig. 4).

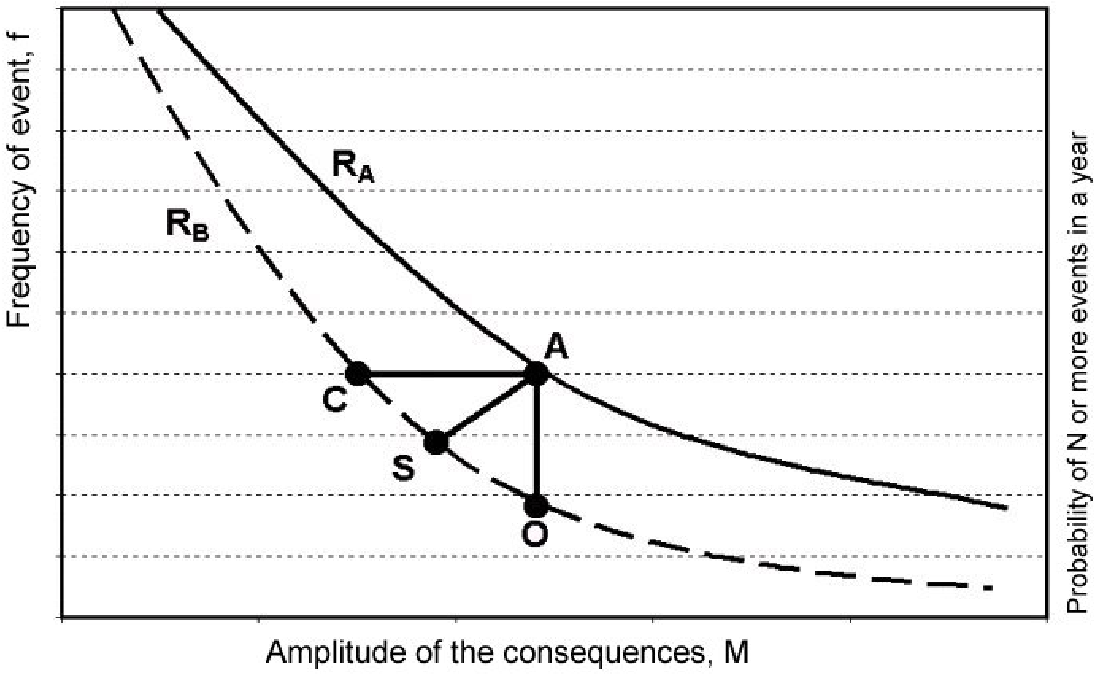


Fig. 4 - Risk curves relevant for a generic "system"

Naturally, in the frame of human actions, we may individuate an infinite series of risk curves. Each risk curve represents a condition of isorisk characterized by different values of risk.

To reduce the risk of the system from the value R_A to the value R_B, we may work in three different ways:

1) reducing the probability (C);

2) reducing the amplitude (O);

3) reducing both elements (S).

To evaluate the level of risk in each section of the road infrastructure, we must investigate on the existing connections between the road and the vehicle. Particularly, we must evaluate:

- the frequency of the accident;
- the seriousness of the event in terms of damages and victims.

Accidental frequency evaluation may be done with procedures based on a detailed analysis of the operation conditions in those sections which may be "candidate" to be the place of the accident.

For what concerns amplitude, the problem is more complicated because of the numerous factors which may influence the individuation of the possible damage. Studies and observations put in evidence that the damage of a determined type of accident is function of the surrounding environment conditions, that is the seriousness of the accidental event is tied to the place.

5. ANALYSIS OF THE RISK FOR THE EVALUATION OF ELEMENTARY SECTION OF AN INFRASTRUCTURE

It is essential to analyse all the elementary sections (the maximum possible subdivision) to evaluate the risk of the whole infrastructure. The logical investigation process may be carried out in three phases:

- identification of the elements which characterize the operation of a section;
- probabilistic operation evaluation, pondered through the disaggregation of the effetcs relevant to the dreaded event and of the effects of limitation of the consequences of the accident;
- evaluation of the operation risk of the elementary section in order to establish the acceptability or the actions which may be carried out to minimize the frequency and/or the consequences of the accidents.

We may use any disaggregation method to evaluate the probability of the dreaded event occurrence. We may use the events or damages tree, or the investigation on similar events.

The tree of the events is graphically constituted by a logical diagram which connects an event (called top event), with the events which caused the top event (called primary events). Fig. 5 simply represents, with different graphic symbolism, the basic events (ellipsis) and the intermediate events (rectangles) coming out from the combination of the basic events.

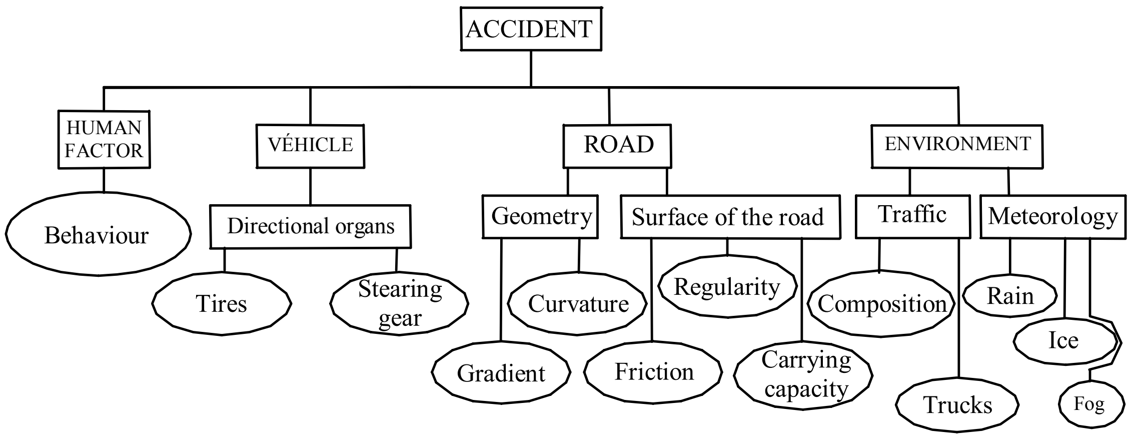


Fig. 5 - Example of simplified tree

The peculiarity of the technique of the events tree is its capacity to investigate backwards on a particular event, to individuate not only the possible relations between cause-effect and the determining effects, but also to individuate the existing connections and concatenations among these factors. The relations among the various factors may bring to complementary connections when the causing factors happen contemporaneously to produce the event, or they may be independent when only one of these factors is sufficient to cause the accident

Road infrastructure design is characterized by different plane-altimetric alignment, by different orography and also by very different conditions of the surrounding environment. Running speed is the element which characterizes driving activity and is function of what the driver is expecting from the road, sometime he maintains the same speed allover the road, not considering that the margins of safety in certain areas are very reduced.

Road sections have different characteristics also on the basis of the importance of the damage due to an eventual unfavorable event. During road construction, to minimize the consequences of the accidental event, we try to realize, in certain sections, all those implementations called “passive safety” capable to contain the seriousness of the possible damages, for example “safety barriers”, if installed on viaducts, they must have a reduction level higher than the barriers commonly installed on embankment. From what above said is clear that we may classify the typologies of road sections on the basis of the importance (seriousness) of the accident.

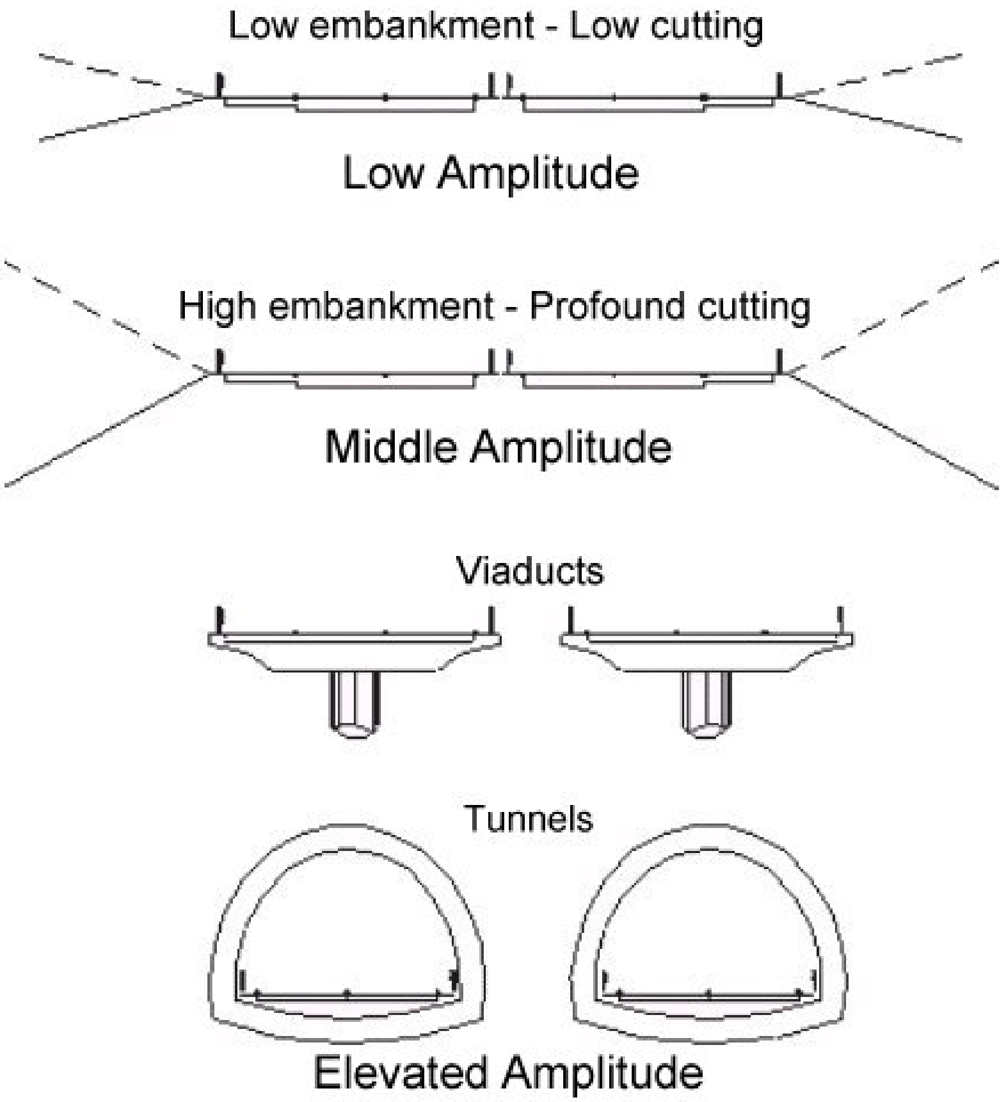


Fig. 6 - Sections classification on the basis of amplitude

As the “top event” of driving activity is the accident, it is essential to deeply analyse each elementary section and try to obtain a parameter able to characterize the suitability of the road so to carry on the operations for which it was built.

6. EVALUATION OF SUITABILITY INDEX OF THE ELEMENTARY SECTIONS

It is essential to create a check list to control the conditions of an elementary section so to be able to estimate the suitability index and to evaluate their correspondence to design standards and to theoric suitability requirements. The determination of suitability index of each elementary section has to be executed introducing some "weights" (P) able to put in evidence the role developped by the various elements during driving activity. The assignment of the value of the weights is done by the application of the procedures based on the elementary disaggregation of the operation probability, that is: the application of the event tree.

The disaggregation of the elementary sections characteristics allow the definition of the parameters characterizing the suitability of the elementary sections and exactly defined by an index (I) and by the relevant level of pondering (P). Particularly, reference will be made to:

- *Geometrical characteristics*

1. Planimetric radius (I_{rp}, P_{rp});
2. Superelevation (I_{pt}, P_{pt});
3. Longitudinal grade (I_{pl}, P_{pl});
4. Altimetric radius (I_{ra}, P_{ra});
5. Stopping sight distance (I_{da}, P_{da});
6. Overtaking sight distance (I_{dv}, P_{dv}).

The suitability coefficient of the geometrical characteristics of a determined section may be the following:

$$I_G = I_{rp} * P_{rp} + I_{pt} * P_t + I_{pl} * P_{pl} + I_{ra} * P_{ra} + I_{da} * P_{da} + I_{dv} * P_{dv}$$

In the same way it is possible to to define a suitability index of the operations of the section:

- *Conditions of operations:*

1. Coefficient of transverse friction (I_{at}, P_{at});
2. Coefficient of longitudinal friction (I_{al}, P_{al});

3. Coefficient of evenness (I_{rg}, P_{rg});
4. Coefficient of bearing capacity (I_{po}, P_{po});
5. Elimination of surface waters (I_{sa}, P_{sa}).

This coefficient may be expressed as follows:

$$I_F = I_{at} * P_{at} + I_{al} * P_{al} + I_{rg} * P_{rg} + I_{po} * P_{po} + I_{sa} * P_{sa}$$

We may also define and index on the conditions of the section:

- *Conditions of the road state*

1. Vehicular flow (vehic/h) (I_{fv}, P_{fv});
2. Vehicular composition (I_{cv}, P_{cv});
3. Typology of the users (I_{us}, P_{us}).

The coefficient of road conditions may be expressed as follows:

$$I_V = I_{fv} * P_{fv} + I_{cv} * P_{cv} + I_{ut} * P_{ut}$$

During the movement the driver receives some impulses from the signs, it is therefore necessary to define a section suitability index of the conditioning to drive

- *Conditionings to drive due to the signs*

1. Presence and type of traffic signing (I_{sv}, P_{sv});
2. Presence and type of road marking (I_{sh}, P_{sh});
3. Presence and type of integrative signing (I_{sc}, P_{sc});
4. Visibility of signs (I_{vs}, P_{vs}).

The suitability coefficient to conditioning may expressed as follows:

$$I_c = I_{sv} * P_{sv} + I_{sh} * P_{sh} + I_{sc} * P_{sc} + I_{vs} * P_{vs}$$

Also the elements at the edge of the road are very important to define section suitability so to have safety transport, we may define a suitability index as follows.

- *Conditions of containing elements*

1. Type of lateral barriers (I_{bl}, P_{bl});
2. Type of central barriers (I_{bc}, P_{bc});
3. Types of barriers in peculiar place (I_{ps}, P_{ps});
4. Places of emergency get-away (I_{pf}, P_{pf}).

The coefficient of this containing elements may expressed as follows:

$$I_R = I_{bl} * P_{bl} + I_{bc} * P_{bc} + I_{ps} * P_{ps} + I_{pf} * P_{pf}$$

The systems serving the road are often erroneously considered only operational fittings, instead they are essential instruments for a correct driving activity therefore we consider very necessary to define a suitability index of these aid instruments.

- *Condition of aid elements for driving*

1. Lighting system (I_{pl}, P_{pl});
2. Optical delineator system (I_{dl}, P_{dl});
3. Emergency (first aid) system (I_{sc}, P_{sc}).

The coefficient of suitability to aid elements is:

$$I_A = I_{pl} * P_{pl} + I_{dl} * P_{dl} + I_{sc} * P_{sc}$$

The condition of suitability of a road section is therefore connected to various indexes and can be considered as the result of the various relative suitability indexes (Fig.7):

$$I_{suitability} = I_G + I_F + I_V + I_C + I_r + I_A$$

The value to be given to the weights in the various suitability indexes is also conditioned by all those conditions preceding the passage on that section. For example if we get $R<R_{min}$, after the check, this is a warning sign which indicates to investigate and control.

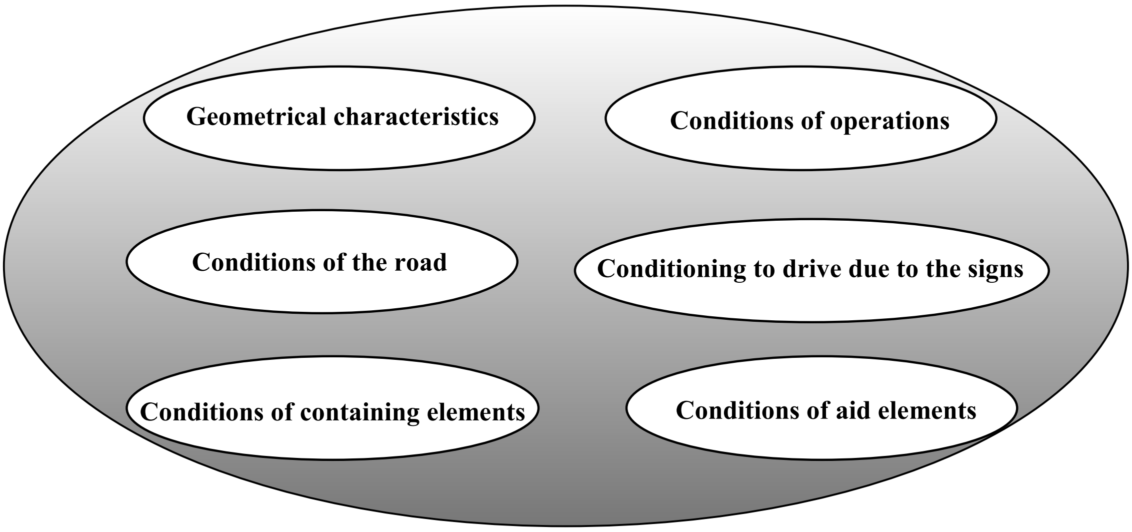


Fig. 7 - Elements characterizing the suitability of a road section

Driver has a knowing and mnemonic behavior, this condition after a straight length has a determined pondering value (the section is potentially dangerous), but it is different after a series of curves, maybe all ones in the same conditions.
It is evident that a suitability index with low value is sufficient to strongly degrade the global suitability.

7. DEFINITION OF FORECAST INDEX

We may introduce the forecast index "I_{PRE}" to differentiate those road sections which, even if they have the same suitability index, are characterized by a certain expectation of the user, so to be more dangerous with regard to the other sections.
The procedure to define forecast index needs the use of the following indexes:

- *IT = Traffic Index aimed to quantify traffic variations in each section, it may be expresse as:*

$$IT_i = \frac{TO_{MAX}}{TO_{MED}}$$

where:

- TO_{MAX} = maximum hourly traffic flow in a road section (during a determined period of time)

- TO_{MED} = medium hourly traffic flow along the whole section (relevant to the same period of time).

It is evident that when the value of TO_{MAX} in a section is major of the corresponding TO_{MED} road conditions are very bad, the contrary happens when $TO_{MAX} < TO_{MED}$.

- *I_A = Altimetric index, allows to assign different values on the basis of longitudinal grade (positive or negative) and considering if the characteristics of the section are similar or different;*

- *I_{PL} = Planimetric Index, by means of which are assigned different values on the basis of different planimetric characteristics (curve, clothoid, straight lenght) and considering if the characteristics of the section are similar or different.*

The driver must use a certain care to adapt his driving to face different planimetric or altimetric elements.

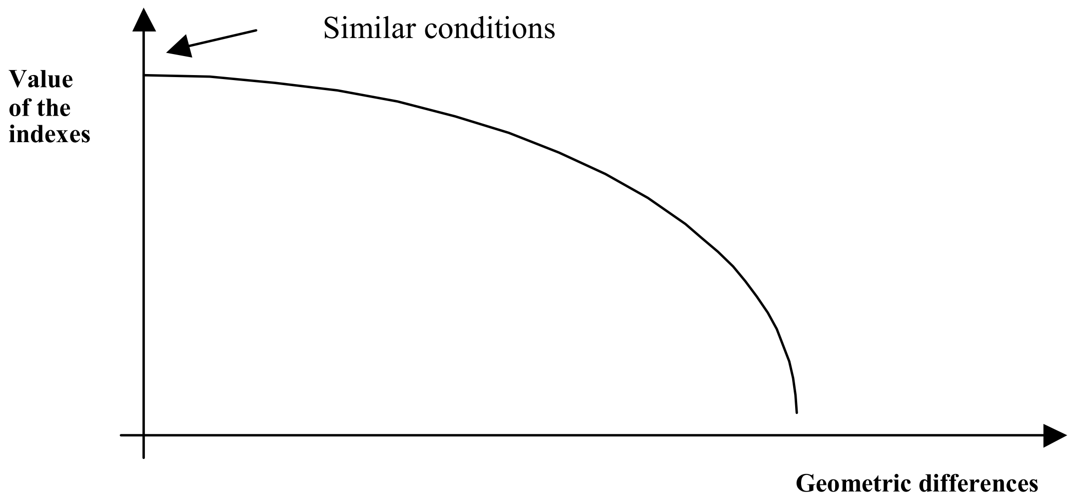


Fig. 8 - Variations of plane-altimetric indexes

Planimetric and altimetric indexes have value 1 if the section under analysis has the same characteristics of the previous one, on the contrary case they will have a value inferior to 1, which importance has to be pondered in function of the different geometrical characteristics of the succeeding sections.

- I_C = *Surrounding Index, which allows to assign different value on the basis of the variations of the conditions of the environment surrounding road lanes.*

  When the user has to drive on a road with many sudden changes of the conditions as for example: at grade section-tunnel, high lighted area-dark area, he needs a certain time to adapt him-self. We may establish a scale of values on the basis of the time needed for the adjustment. We give value 1 when the succeeding sections have similar characteristics, then if the time needed for adjustment increases, of course the value 1 decreases.

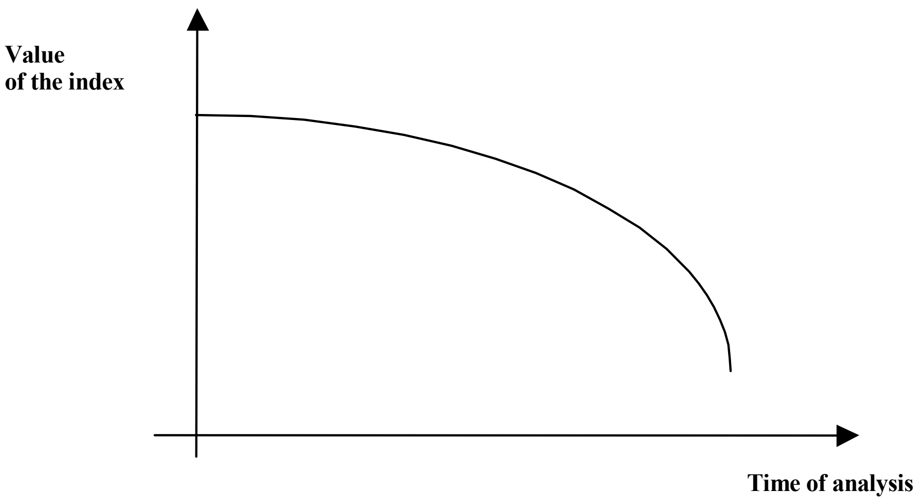


Fig. 9 - Variations of the surrounding environment index

- I_L = *Length Index, it is used to ponderate numerically the influence of the longitudinal development of the single road sections; we may express it as follows:*

  $$IL = \frac{SL_i}{SL_{min}}$$

  where:

  ♦ SL_i represents the length of the section under analysis;

  ♦ SL_{min} represets the smallest defined section.

By means of the estimation of the indexes I_T, I_{PL}, I_A, I_C, I_L, we may determine the forecast index (I_{PRE}) with the following relations:

$$I_{PRE} = I_T * I_A * I_{PL} * I_C * I_L$$

With the introduction of the suitability index we have realized an instrument to individuate the adequacy of the sections in order to accomplish their task, while the I_{PRE} (forecast index) allows to individuate the influences that plane-altimetric and traffic characteristics and the surrounding environment of the elementary section under examination have on road conditions in relation to what the user may expect.

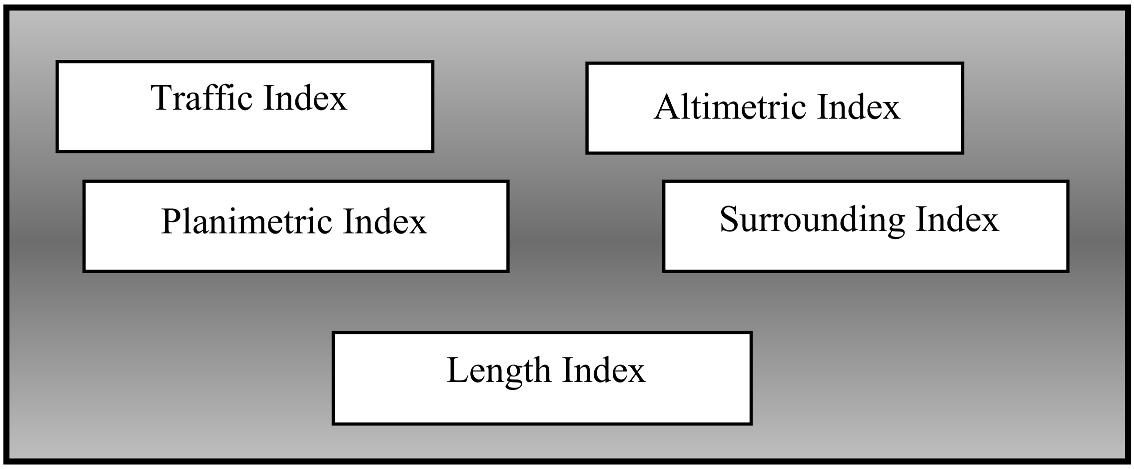


Fig. 10 - Terms for the definition of forecast index

As the primary purpose of the definition of the various indexes is to establish a hierarchy of operations of the various road sections, it is essential an univocal index able to define the capacity of the section to accomplish, with the highest safety, the task it was designed for. Therefore the operation index (I_F), defined by the inter-action between suitability index (that keeps into account the physical characteristics of road section) and forecast index (that keeps into account user's expectations) is:

$$I_F = I_{suitability} * I_{PRE}$$

Operation index of road section, as per its definition, represents the parameter of correlation with the probability that, in that determined section, a road accident may occur.

8. EVALUATION OF PERFORMANCE INDEX

Driving is a dangerous activity, and therefore it is impossible to eliminate accidents. The task of road engineers is to reduce at the minimum injuries and damages caused by road accidents in terms of human beings and material damages.

We may define for each elementary section a risk matrix (Fig. 11), the first line indicates all the events which may cause damages or injuries and the first column shows the quantification of damages and injuries.

The terms of the first line come from the application of the event tree, it is possible to report all the events which may be cause of accidents.

To completely define the first column of the matrix it is necessary instead to evaluate the probable importance of the accidental events.

The study of the different accidental events demonstrated that the seriousness of the accidental events depends by the physical characteristics of the section.

EVENT / DAMAGE	**SPEED**	**TRAFFIC**	**FOG**	**RAIN**	
1					
2					
3					
4					
n					

$\sum D_i \cdot P_i$

Fig. 11 - Matrix of the risk relevant to a generic section

The final result of the matrix, which is the total of all the events which may produce injuries and damages, multiplied per the probable injury or damage, gives the total risk peculiar to the elementary section.
Physiological accidentality cannot be completely eliminated being connected to the adopted design regulations, to the running vehicular park and to the human behaviour, so it is essential to study its distribution along the infrastructure.
Several studies showed that physiological accidentality depends on traffic flow, on road category, and on accident typology so that we may elaborate a diagram for each type of road and type of accident which may occur.

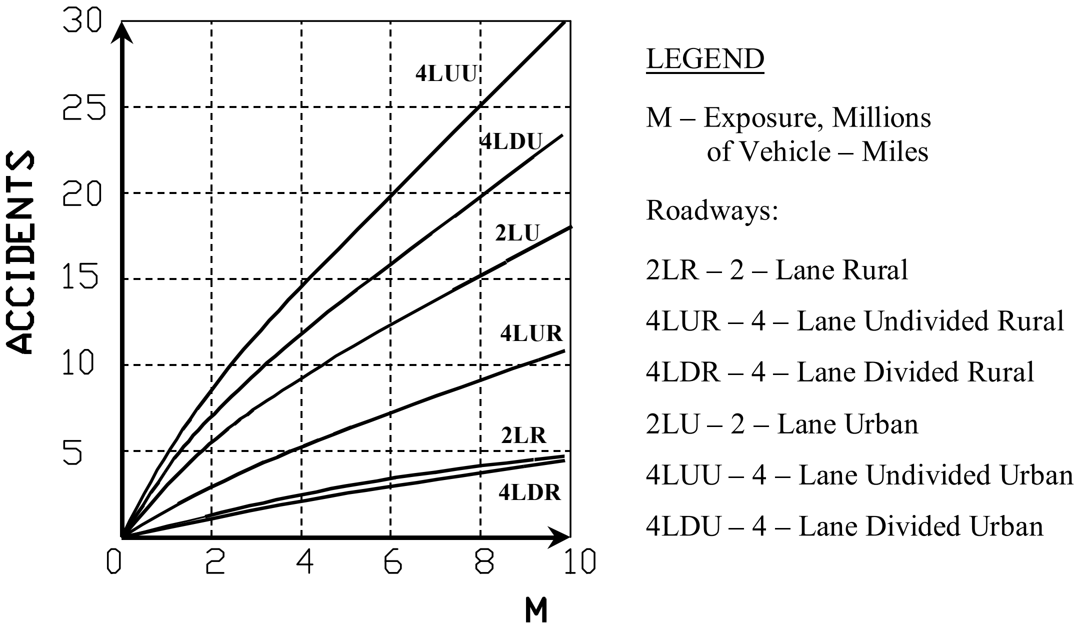


Fig. 12 - Values of physiological accidentality, on American roads, type of accident: vehicle back-crashing.

It is evident that, characterizing road sections through the operation index, the roads with a lower I_F value have an higher probability to be place of accidents; furthermore, if they are characterized by high wideness and by geometric characteristics, then, the accidental risk is very strong for these road sections.
We may introduce a new global parameter to classify elementary road sections; it is the performance index. Such index is directly connected to the risk value by means of logical process, so when higher is the risk level, less performing is the road section (Fig. 13).

LEVEL OF RISK	INDEX OF PERFORMANCE
Normal (only damages)	*HIGH*
Conditionning (very important damages)	*MEDIUM*
Ecceptional (damages and injured persons)	*LOW*
Extreme (damages and loss of human beings)	*VERY LOW*

Fig. 13 - Scale of Performance values of a road infrastructure section

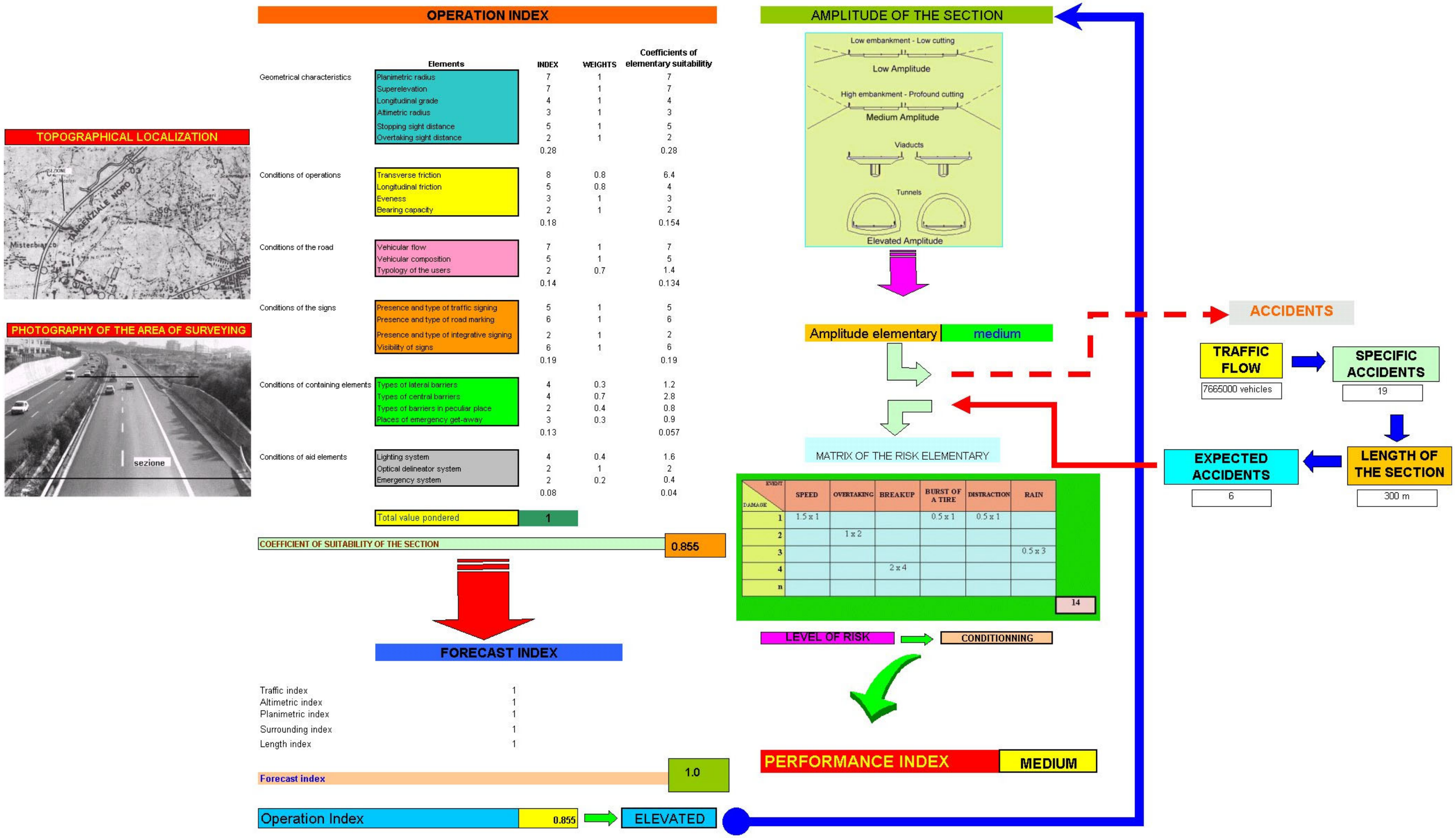
With the use of the performance index we may individuate those sections which have the inclination to be place of accidents with high consequences in terms of human beings and damages.

9. CONCLUSIONS

Road infrastructures are characterized by a certain level of risk. Often vehicles running over the road may cause accidents, which represents the bad connection road-vehicle. Unfortunately road conditions, also the most efficient and best developed conditions, are always characterized by a certain risk of non-operation, so that many researchers agree on the definition of "physiological" accidentality of road infrastructures.

The definition of a suitability index of road sections is the first fundamental step to be done in order to study road risks. Besides, being driving a mnemonic activity it is essential to use an index which keeps into account the expectations of the user when driving on the various road sections, this index was defined "forecast index". Taking into account the expectations of the user of road infrastructure, the fundamental element is to individuate the performance indexes of the road net and, in order to obtain an implementation of road safety, specially in the actual reality, when the enormous technological progress of the vehicles allows high running speeds which do not consent to the driver any hesitation about the manoeuvres to be done.

KEY-WORDS: ACCIDENT, DANGER, DATA ACQUISITION, DESIGN, ROAD USER, SAFETY.


TOPOGRAPHICAL LOCALIZATION
PHOTOGRAPHY OF THE AREA OF SURVEYING
sezione
OPERATION INDEX
Elements
INDEX
WEIGHTS
Coefficients of elementary suitability
Geometrical characteristics
Planimetric radius 7 1 7
Superelevation 7 1 7
Longitudinal grade 4 1 4
Altimetric radius 3 1 3
Stopping sight distance 5 1 5
Overtaking sight distance 2 1 2
0.28 0.28
Conditions of operations
Transverse friction 8 0.8 6.4
Longitudinal friction 5 0.8 4
Eveness 3 1 3
Bearing capacity 2 1 2
0.18 0.154
Conditions of the road
Vehicular flow 7 1 7
Vehicular composition 5 1 5
Typology of the users 2 0.7 1.4
0.14 0.134
Conditions of the signs
Presence and type of traffic signing 5 1 5
Presence and type of road marking 6 1 6
Presence and type of integrative signing 2 1 2
Visibility of signs 6 1 6
0.19 0.19
Conditions of containing elements
Types of lateral barriers 4 0.3 1.2
Types of central barriers 4 0.7 2.8
Types of barriers in peculiar place 2 0.4 0.8
Places of emergency get-away 3 0.3 0.9
0.13 0.057
Conditions of aid elements
Lighting system 4 0.4 1.6
Optical delineator system 2 1 2
Emergency system 2 0.2 0.4
0.08 0.04
Total value pondered 1
COEFFICIENT OF SUITABILITY OF THE SECTION 0.855
FORECAST INDEX
Traffic index 1
Altimetric index 1
Planimetric index 1
Surrounding index 1
Length index 1
Forecast index 1.0
Operation Index 0.855 ELEVATED
AMPLITUDE OF THE SECTION
Low embankment - Low cutting
Low Amplitude
High embankment - Profound cutting
Medium Amplitude
Viaducts
Tunnels
Elevated Amplitude
Amplitude elementary medium
MATRIX OF THE RISK ELEMENTARY
EVENT
DAMAGE
SPEED
OVERTAKING
BREAKUP
BURST OF A TIRE
DISTRACTION
RAIN
1 1.5 x 1 0.5 x 1 0.5 x 1
2 1 x 2
3 0.5 x 3
4 2 x 4
n
14
LEVEL OF RISK
CONDITIONNING
PERFORMANCE INDEX MEDIUM
ACCIDENTS
TRAFFIC FLOW
7665000 vehicles
SPECIFIC ACCIDENTS
19
LENGTH OF THE SECTION
300 m
EXPECTED ACCIDENTS
6

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