ROAD BARRIERS MANAGEMENT SYSTEM: A TOOL TO OPTIMIZE THE ALLOCATION OF RESOURCES

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ABSTRACT

The Province of Pisa has organized since 2007 a database of road accidents where comprehensive data collected by all police departments of the whole provincial territory is assembled. The aims are both managing and archiving of all data and using them to define a policy to optimize the allocation of resources to have less road accidents and less negative consequences.

The road barriers, as passive protection safety tools, constitutes one of the most important elements in road management, specially in cases of hazardous road anomalies common in older road systems.

Government spurs local road administrations to check the condition and functionality of its own road barrier assets and plan the best intervention (conservation, replacement, rehabilitation).

The Province of Pisa defined three classes of hazard (high, medium and low) as regard to the possible consequences to vehicle occupants in cases of skidding. For every road section the hazard is valued for the presence of obstacles or high slopes and the condition of road barrier assets. The accumulation of all these data resulted in the determination that available funds were not sufficient to execute a ideal solution. So the strong need to choose where to install first makes it necessary for the Province to establish a policy of how best to allocate existing funds.

Risk levels for every road section were defined and a ranking of priority were organized.

1. INTRODUCTION

The presence of adequate traffic barriers along the sides of roads is indispensable to ensure a high standard of road safety. Guardrail is a safety barrier installed on highways to reduce the combined effect of severity and frequency of “runoff the road” type crashes. This is accomplished by redirecting a vehicle away from embankment slopes or fixed objects and dissipating the energy of the errant vehicle [8]. CEDR underlined in a recent research on best practices for cost-effective road safety infrastructure investments that warranted guardrail installation has an important benefit to cost ratio (respect to other types of investments: speed limit/reduction of operating speed, junctions layout, traffic control at junctions, traffic calming) [1]. All types of safety barriers are very cost-effective, especially when they are implemented along embankments on rural roads. The first step in achieving the correct application and use of these security devices is to check their condition. Such detailed knowledge allows both to be able to define the critical points that exist along the entire road network and to be able to estimate (on the basis of established criteria) the resources needed to remove the anomalies present.

In Italy, the legal framework of reference for the subject is made up of various Decrees issued by the Ministry of Infrastructure and Transport in a period between 1992 and 2008. These various Ministerial Decrees were accompanied by interpretive circulars and guidelines which, although don't have any legal value, allow both the correct interpretation of the Decree (according to the intentions of the Legislator) and its subsequent application. The main legislative reference is made up of the Ministerial Decree 2367 of 26/06/2004 which, at paragraph 1 article 2 specifies that *"it is the duty of the Ministry of Infrastructure and Transport to carry out studies, research and monitoring of road safety barriers, if needed, with the support of external advisors with experience in the sector".* Inherent in this, as specified by the Directive of the Ministry of Infrastructure and Transport of 25/08/2004 (which refers to paragraphs 1 a) and b) article 14 of the Italian Highway Code), the road administrations that own and manage existing roads must ensure *"the maintenance, management and cleaning of the roads and their margins as well as the equipment, facilities and services and technical inspection of the efficiency of roads".*

Furthermore, in the same Directive *"…road administrations are invited to address a check of the efficiency and maintenance of road safety barriers along the road network under their jurisdiction, with particular reference to installation, providing (where these conditions are not deemed sufficient) to plan to adjust the barriers".*

Recently the European Community enacted "Directive 2008/96/EC of the European Parliament and of the Council of 19 November 2008 on road infrastructure safety management". A stronger action to improve quality of infrastructures as regard road safety is recommended [3]. AIPCR encourages road administration to identify all potential infrastructural lacks connected with the occurrence of crashes [9].

In light of the above and accepting the invitation offered by the Ministry of Infrastructure and Transport, technical staff from the Provincia di Pisa launched a survey of road safety barriers currently in use, aimed at understanding the current condition of the installed barriers and the identification of the stretches of road where it would be necessary to install new barriers. As well as processing the survey, the road network in question was divided into homogeneous sections according to their functional characteristics.

For the definition of how hazardous a stretch of road is in comparison to the passive safety offered by road safety barriers, reference has been made mainly to the possible consequences that may occur to the occupants of a car which impacts the barrier following a road accident. For every surveyed situation, the condition of the barriers, the presence of poor installation and the presence of obstacles and/or high slopes and escarpments in respect to ground level are evaluated. Each type of situation is then assigned a particular level of hazard, based on experience, what is stated in the most recent technical literature, legislative indications, analysis of samples of road accidents and technical and managerial assessments. Risk assessment and management must be an integral part of the decisionalmaking process [4].

The work method used can also be summarised in the flow chart in fig.1. A matrix of the responsibility has also been drawn up which identifies the subjects and the roles that they play in relation to the organisational chart of the managing body.

In the circular of 21st July 2010, entitled *"Uniform application of the rules relating to design, approval and use of road safety barriers in road construction*", the Ministry of Infrastructure and Transportation provided some guidance on this matter. The definition of the field of application of the legislation is of particular importance. The area of applicability must

include definitive projects relative to roads and streets which have a design speed greater than or equal to 70 km/h. In this regard, the circular *"points out that the design speed of a road section must be determined in relation to its functional purpose, with reference to article 2, paragraph 2 of Highway Code and to its planimetric features (radius of curvature), regardless of a possible imposition of a speed limit on the same section. In the case of work to be done on existing roads, the design speed must be calculated by assimilation, according to the Ministerial Decree of 05/11/2001 "Functional and geometric regulations for the construction of roads" for the same functional class and planimetric range of the section."*

As mentioned, every road is assigned a speed range, which must contain the design speeds of the various elements of the stretch of road. The upper limit is related to the maximum speed travelled safely on stretches of road which are straight and flat; this limit must be changed if visibility is lowered by bends or undulations.

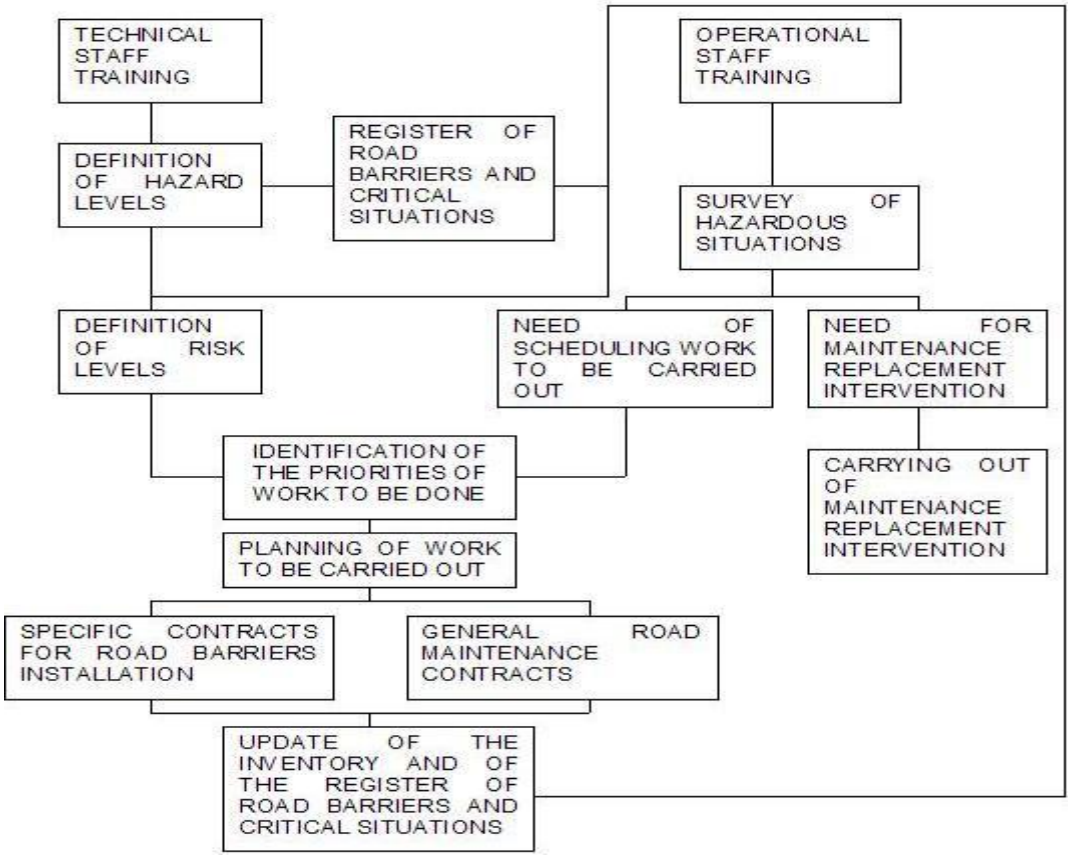

Figure 1 – Road barriers management system

Regarding existing roads, the road network under management is composed of several road sections with a cross section that doesn't conform to its planned function or to any of the typical sections present in the technical regulations. In these cases where a design speed range can't be identified because it is not possible to proceed with a clear and unambiguous classification, the parameter assumed to describe the speed at which a car can travel safely is the threshold speed at (or below) which most vehicles were observed to travel, defined as the 85th percentile V_{85} (only 15% of users exceed the measured speed) of the distribution of speed measured on an identical stretch of road, in conditions of free flow and in good weather and pavement. This parameter can be derived either through specific surveys (observed speed) with respect to a particular stretch or by using estimate models deduced by similar situations in terms of geometry, surroundings and function performed.

2. ANALYSIS AND DEFINITION OF THE LEVELS OF HAZARD

The hazard of a road section, with reference to the skidding and leaving of the carriageway, is mainly related to the possible consequences that might occur to the occupants of a vehicle which impacts the obstacle or barrier. Some recent publications define an hazard rating in relation to lateral obstacles [2] or severity guidelines [4] with a graduation from 1 to 10 in relation to the presence of water hazards consisting of more than two feet of depth, slope ratio much greater than 2:1, fixed objects, exc.

Particularly, the hazard of road sections in relation to passive safety guaranteed by traffic barriers can be divided into three distinct levels: High, Medium and Low.

On the basis of expertise and technical and managerial assessments, it is possible to define the following configurations or situations:

1. absence of necessary road safety barriers;
2. presence of road safety barriers that do not conform to the current regulations (that do not correspond to any of the barriers approved by the Ministry of Infrastructure);
3. presence of adequate road safety barriers (among the barriers approved by the Ministry of Infrastructure) but are characterized by defects in conservation;
4. presence of discontinuities or single obstacles;
5. presence of road barriers (approved or not) installed in a way that doesn't allow them to work properly because necessary deformation isn't possible.

Following this, the various cases are examined individually and a corresponding hazard level is assigned to each one. With the results of the survey, it has also been possible to correlate the situation of every road section (which corresponds to a particular provision of barriers) to its hazard in terms of passive safety.

2.1 Absence of necessary road safety barriers

This situation, in reference to current Italian regulations, could happen in the following cases:

- there are permanent side obstacles present;
- the difference between the height of the embankment and of the ground level is more than 1m;
- the relative gradient of the slope is more than 2/3;
- in the cutting, the water collection device is made up of a concrete trapezoidal ditch.

Figure 2 - Extensive subsiding of the outer edge on a bend with escarpment (high hazard level)

It is possible to associate a specific level of hazard to the following configurations:

- presence of critical situations – for example trees and, more generally, fixed obstacles (e.g. non-compliant signs, buildings, etc.) on the outer edge or in such a position as to make the probability of impact significant in the case of a skidding vehicle out of the road, flows of water adjacent to the slopes in question or, more generally, where the embankment is more than 2m higher than the ground level. In such conditions, the level of hazard is HIGH;
- absence of critical situations: the embankment is less than 2m high or presence of a trapezoidal ditch in the cutting. In these conditions, the level of hazard is MEDIUM.

2.2. Presence of road safety barriers which do not meet current standards

The cases that fall into this category are:

- barriers in good condition with presence of critical situations: MEDIUM hazard level;
- barriers in good condition with absence of critical situations: LOW hazard level;
- barriers in poor localised or widespread condition. The term ‘poor condition’ means that there are critical localised areas (bars deformed by accidents or instability of marginal parts, fixtures that have buckled etc.) or critical areas that extend for a significant length (e.g. barriers with reduced height due to repeated road resurfacing). In the case of poor localised condition and the presence of critical situations, we must distinguish whether the damage is to structural parts (posts, spacers, beams etc.) or to accessorial parts (rails, low rails etc.):
    - structural parts in poor condition with presence of critical situations: HIGH hazard level;
    - localised poor condition of accessorial parts with presence of critical situations: MEDIUM hazard level;
    - structural parts in poor condition with absence of critical situations: MEDIUM hazard level.

2.3 Presence of road safety barriers which comply with the current regulations but are characterised by defects in conservation

Cases that fall into this category may include barriers in poor localised condition (HIGH hazard level in presence of critical situations and LOW in their absence) or extensive (HIGH hazard level in the presence of critical situations and MEDIUM is its absence).

Figure 3 - Detached guardrails and deformed spacers (medium hazard level)

Figure 4 - Detachment from the posts, localised deformation, presence of the railway

2.4 Presence of discontinuities or single obstacles

This category includes the following five cases:

- sections where the barrier is installed for a length which isn't sufficient to fully protect from the hazard of leaving the road in case of skidding (e.g. barriers installed only by the length of bridge or culvert, etc.) HIGH or MEDIUM hazard level in the presence or absence of critical situations;

"Figure 5 - Unprotected tree, inadequate protection of the ditch (high hazard level)"!

- adequate connections between different types of road barriers placed in succession are not guaranteed, this applies to both the case of two different types of metal barriers and to the case of the transition from metal road barriers to other stone or concrete devices (HIGH or MEDIUM in presence or absence of critical situations);

Figure 6 - Inadequate guardrail terminal end (high hazard level)

- presence of inadequate road barriers: e.g. parapets made of stone walls or metal railings or wire rope barriers. This case may arise in situations where maintenance is poor or not. When the parapet is not long enough to significantly limit the probability of impact with the obstacle present: HIGH hazard level. When the length is sufficient but the barrier is in poor condition because it is too low or there are detachments or corroded tubular elements: MEDIUM hazard level (LOW in good condition);
- barriers or road safety devices with serious localised or extensive damage: HIGH hazard level;
- inadequate guardrail terminal ends: HIGH hazard level.

2.5 Presence of road safety barriers (approved or not) installed in a way which doesn't allow them to work properly because necessary deformation is prevented.

These are situations where a lateral road safety device has been installed but it hasn't been possible to remove the cause or one of the causes which called for its installation; in which case, the barrier cannot deform and guarantee the proper absorption of the kinetic energy of the vehicles that leave the road because of skidding. The action to be taken, if possible, would be primarily to remove the obstacle placed too close to the road. LOW hazard level.

Summary of cases identified

Cat.	Description	Hazard level	Code
1	Absence of necessary barriers	HIGH – presence of critical situations	1a
		LOW – absence of critical situations	1b
2	Presence of barriers which do not conform to current regulations	HIGH – poor condition – localised or extensive – of structural parts where there are critical situations	2b2.1; 2b1.1
		MEDIUM – poor localised condition of accessorial parts in presence of critical situations or extensive poor condition in the absence of critical situations	2b1.2; 2b1.3
		LOW – good condition and no critical situation	2a2
3	Presence of approved barriers but characterised by maintenance defects	HIGH – extensive bad condition with presence of critical situations	3b2.1
		MEDIUM – localised bad condition with presence of critical situations; extensive poor condition with absence of critical situations	3b1.1; 3b2.2
		LOW – localised poor condition with absence of critical situations	3b1.2
		NOT PRESENT – barriers in good condition	3a
4	Presence of discontinuities	HIGH – barriers of insufficient length to protect from the hazard, no connection between different barriers, presence of critical situations, parapets of insufficient length, barriers with localised or extensive damage, inadequate terminal-ends.	4a1; 4b1.1; 4b2.1; 4c1; 4d; 4e
		MEDIUM – singular discontinuities, no connection between different barriers, absence of critical situations, parapets of sufficient length in poor condition	4a2; 4b1.2; 4b2.2; 4c2
		LOW – parapets of sufficient length in good condition	4c3
5	Barriers with partially impeded opportunity to deform	LOW – the barrier conforms to the regulations but it is impossible for it to deform correctly or completely because of the presence of irremovable obstacles behind it	5

To summarise, the various sections of road were categorised in relation to their level of hazard as follows:

a) road sections where the road safety devices are not able to guarantee any kind of restraint for a skidding vehicle out of the road due to a reduced or compromised efficiency (e.g. damaged barriers), where there is a serious hazard of elements which might enter the passenger compartment of the vehicle that impacts the barrier, fall into the high hazard level. Also in this classification are road sections which do not have barriers in the presence of critical situations (guardrails would be warranted [4], [5], [6], [7] e [8]):

b) road sections where barriers are partially able to guarantee full restraint for skidding light and heavy vehicles, in presence of serious hazard, but are in good working order (e.g. barriers which are not adequate for the right category of traffic using the road) belong to the medium hazard level. Also part of this level are the stretches of road without barriers and absence of critical situations;

c) Finally, barriers which can't guarantee restraint only for a heavy skidding vehicle, with absence of critical situations and which are in good working order fall into the low hazard level.

The survey carried out by the technicians of the Provincia di Pisa identified that around 35% of roads out of a total of approx. 1,100km require new installations or essential modifications of installed barriers system. Fig.7 shows, in percentages, the length of road sections which correspond to the three levels of hazard identified.

The graph shows that it is necessary to do work on approximately 770 km of road (out of a total of 2,200km, considering both sides of each road) – of which, approx. 33km are classified as low hazard, approx. 263km as medium hazard and approx. 474km are classified as high hazard. It is clear, therefore, that identifying the priorities for action on the sole basis of intrinsic hazard of the section in relation to the road safety devices is not a valid reference for choosing which sections to work on, given the lack of available resources.

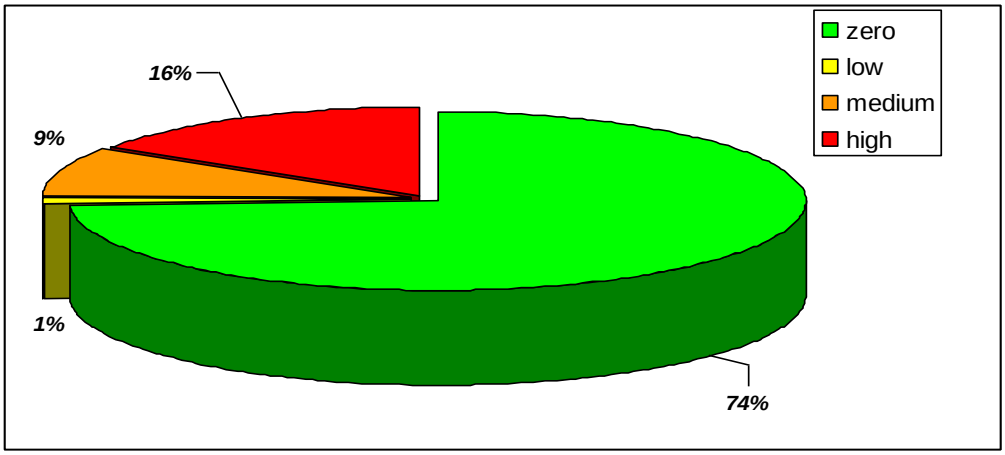

Figure 7 – Levels of hazard on the road network managed by the Provincia di Pisa

3. DEFINITION OF RISK LEVELS

The allocation of a level of hazard to a particular road section is not, therefore, sufficient to define the priority of work to be carried out on a section of road to make it conform to current regulations.

Therefore, it is necessary to establish benchmarks, which are useful in determining the order of the priority of action. Such necessity also comes from the fact that by looking at the assignment of hazard levels to single stretches of road surveyed, the resources required to bring all sections of road with anomalies to the regulations prescribed by law, is considerably higher than the availability of the administration. In addition, there are circumstances where stretches of road that have been assigned a low or medium hazard level, experience very high levels of traffic. In other circumstances stretches of road assigned with a high hazard level experience hardly any traffic: these situations show the difficulty in choosing the priority of action to be taken.

The risk is, in fact, determined by the product of the probability of an accident occurring and its seriousness (risk = probability x seriousness or hazard). In this specific case of barriers, it is useful to also keep in mind another factor which could give information regarding the magnitude of the hazard. The travelling speed of the road can be very significant in predicting and evaluating the extent of damage that could potentially be caused to the vehicle and its occupants following impact with an obstacle or leaving the carriageway. It is known that an increase in speed increases the damage of impact more than proportionately. Moreover, the travelling speed also provides indications regarding the likelihood that limited balanced conditions are triggered and therefore vehicles leave the road and skid or there are conditions where vehicles hit other vehicles.

In general, we can assume that the factors which can be taken into consideration to decide the probability of an accident happening and its potential severity is the observed

frequency of accidents and the design or the observed speed of that road section.
The number of accidents per kilometre, for example, could highlight the sections where there is a higher probability that the barriers could be an efficient solution to reduce the damage of an accident. It would be better to have disaggregated and filtered data which would allow us to take into consideration only the accidents involving vehicles leaving the road or skidding, but it is also true that a certain proportion of accidents, though dependent on other causes (e.g. head or side-on collision) mean that the vehicle leaves the road. So, using only the number of total accidents as reference at this stage in planning work to be done in the entire road network is perhaps the most reasonable thing to do.

Two observations should be made in regard to design speed. The first is that it is linked to the obligation to respect the specific national legislation regarding barriers, at least in terms of installation requirements. The second is that in every case, the travelling speed is an indication of both the likelihood of skidding and the severity of impact with the external environment in the case of losing control of the vehicle. It is therefore evident that by increasing the design speed (and most likely the travelling or operational speed) an increased risk must be expected.

In the cases where data relative to accidents isn't available, it seems reasonable to compensate in part with traffic flow data, making these not the only, but certainly a predominant factor in determining the number of accidents for a road section.

As we are talking about existing roads, reference should be made not only to the design speed, but to the speed gathered from the speed diagram and/or to the observed speed.
In particular, four groups of road sections can be identified in relation to design or travelling speed S_d:

a) sections with a S_d of ≥ 90km/h
b) sections with a 70 km/h ≤ S_d > 90 km/h
c) sections with 50 Km/h < S_d > 70 km/h
d) sections with a S_d ≤ 50 km/h

It is important to underline the fact that although the Italian regulatory system clearly indicates the priority sections as those with a S_d > 70km/h (for which the application of regulations, in terms of directing a specific design and the reference to codified procedures, is obligatory) part of the road under management (however very common throughout the country), although characterised by a lower design speed, presents critical situations which, in any case, necessitates the installation of traffic barriers in order to make roads safe.

Cross-referencing the hazard with the design speed, it is possible to determine the 'potential magnitude' of the damage that a vehicle could incur in case of skidding out of the carriageway. In figure 8, five levels of potential are defined, expressed increasingly from 1 to 5. Obviously, at a higher speed, the highest potential is applicable.

DESIGN SPEED	POTENTIAL MAGNITUDE		
S_d ≥ 90km/h	5	5	5
70 km/h ≤ S_d > 90 km/h	4	5	5
50 Km/h < S_d > 70 km/h	2	3	4
S_d ≤ 50 km/h	1	2	3
	LOW HAZARD LEVEL	MEDIUM HAZARD LEVEL	HIGH HAZARD LEVEL

Figure 8 – Potential magnitude of damage which a vehicle could suffer in case of skidding out of the carriageway"

As for the frequency of accidents, every road administration that owns and/or manages a road network can choose the most appropriate levels for their objective, resource and managing policies.

There is no doubt that the main objective of each road administration is to reduce the amount of damage to users. Therefore there is a tendency to try and decrease the number of accidents where death and/or injuries occur. The accident rate, on the other hand, compares the number of accidents with death and/or injuries to traffic flows. In this case, it is more useful to identify not so much the most hazardous stretches of road as much as those with the most accidents. Therefore, the number of accidents per kilometre per year is more useful than the accident rate.

In our case, we chose to refer to the number of accidents with deaths and/or injuries per km per year, specifying three conditions: high, medium or low occurrence. By medium occurrence, we mean a number of accidents equal to the average rate over the entire network with a tolerance of 30%. Road sections with a number of accidents over 30% more than the network average are considered to have a high occurrence of accidents. Equally, road sections with a number of accidents over 30% less than the network average are considered to have a low occurrence of accidents.

Therefore the intention to take action primarily where accidents are more frequent is reiterated.

OCCURRENCE OF ACCIDENTS	LEVEL OF RISK				
High	Notable	Significant	Elevated	Elevated	Alarming
Medium	Modest	Notable	Significant	Elevated	Elevated
Low	Modest	Modest	Notable	Significant	Elevated
POTENTIAL	1	2	3	4	5

Figure 9 – Definition of level of risk

The combination of the probability and the potential according to the methodology adopted provides 15 possible combinations (as indicated in figure 9), with an increasing degree of associated risk. Therefore five risk levels have been defined: modest, notable, significant, elevated and alarming. In this way, each homogenous section of road, in relation to whether it is equipped with traffic barriers or not, has been assigned a level of risk which obviously corresponds to the priority of action to be taken. It is obvious, therefore, that the allocation of resources will see to take action in relation to level of risk, carrying out work firstly on sections with an alarming level of risk, then elevated and so on and so forth.
Figure 10 is an excerpt of a database created by the technical staff of the Provincia di Pisa to show both the relevant criticality associated to road safety barriers and the classification of each one of the sections of road in relation to the risk level determined by the procedure explained.

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Figure 10 – Excerpt of the database relative to traffic barriers in the Provincia di Pisa

Figure 11 summarises the value of the results achieved by applying the procedure to the roads under the jurisdiction of the Provincia di Pisa: the chart shows, in percentage terms, the distribution of the length of road sections according to the different levels of risk identified.

Therefore, of the 770 km of road that needs work, about 38.5 km have an alarming risk level and about 23 km an elevated risk level. Overall, 485 km have a modest or notable risk level, while the remaining sections have a significant risk level.

4. EVALUATION AND INTERPRETATION OF RESULTS

Once the subdivision of the road sections according to the corresponding risk level has been completed, it is then necessary to proceed with further refinement of the ranking of the work to be carried out: in this sense, it could be useful to introduce additional evaluation factors.

These factors mainly have reference to the abnormalities in the plano-altrimetric layout (sections where there are variations in speed greater than 20km/h between successive elements of layout, or with loss of visibility due to the presence of other obstacles), the complexity of the work to be done (defined as the average cost to carry out the work to the highest standard) and the average daily traffic of the stretch of road.

Once the speed diagram of the section of road in question is established, the eventual anomalies in the safe speed of different sections can be identified. If speed variations between successive elements of layout are found to be greater than 20km/h, it is possible that in that section, there are episodes of vehicles leaving the road or skidding in spite of the administrative constraints of the speed limit. It is therefore necessary, down to the design of the work to be carried out, to address this condition and to give priority to the sections where these anomalies occur over others (with an equal risk level).

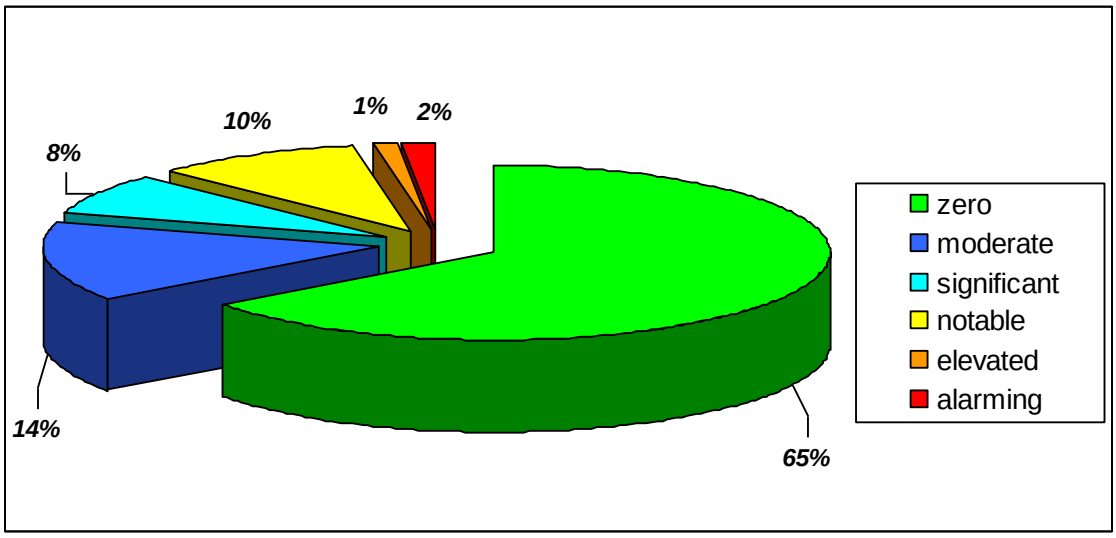

Figure 11 – Percentage distribution of sections of road of the network of the Provincia di Pisa in relation to risk levels

Another element which certainly cannot be neglected in the evaluation of planning work to be done is the schedule of the work to be carried out, because work that requires short response times and low cost (e.g. replacement of guardrails or posts of a damaged barrier) must be preferred to replacing a whole section in good condition but without a certificate of approval. In part, this evaluation has already been incorporated into the definition of hazard associated with the critical issues identified.

As previously described, A.D.T. (Average Daily Traffic) can still be an element of screening to give priority to sections of road with high usage (with equal risk level).

This additional screening is also needed to understand whether the work of installing or improving traffic barriers is the most effective solution for the safety of the section of road.

5. CONCLUSIONS

This document describes a procedure established by the Provincia di Pisa which can be used to define the order of priority for action regarding road safety barriers. The necessity to define an indicative parameter of the priority for action stems both from the need to reduce the possible damage caused to users in accidents involving skidding and from a lack of adequate resources to quickly guarantee the safety of the entire road network under its jurisdiction.

The proposed procedure is inspired by the theory of risk, according to which, the risk ran by the general public in suffering damage caused by an accident taking place on a section of road is the product of the probability that the event happens with that magnitude.

Therefore, the various critical issues which may affect the traffic barriers were divided into three levels of hazard: low, medium and high. By combining this parameter with the travelling speed at which the accident could happen, the potential magnitude of the produced damage is known. The combination, therefore, of potential with the probability of its occurrence, measured in terms of number of accidents on the section in question, allows us to define the risk level associated to every section of road according to five categories; modest, notable, significant, elevated and alarming.

For a given risk level, a further screening can be carried out, keeping in consideration other possible indicators such as the presence of anomalies in the section, the complexity of the work to be done and the average daily traffic.

The application of the procedure to the road network managed by the Provincia di Pisa has enabled a ranking of priorities for work to be carried out based on the risk level.

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