'4TH INTERNATIONAL SYMPOSIUM ON HIGHWAY GEOMETRIC DESIGN'
(Topic Area: Basis for design policy/criteria)

EFFECTIVENESS AND COST-BENEFIT ANALYSIS OF THE SAFETY COUNTERMEASURES APPLIED ON HIGH ACCIDENT RATE ROADS SECTIONS IN THE SPANISH REGIONAL ROAD NETWORK OF CASTILLA Y LEÓN

Author Contact Information:
Aquilino Molinero
Department of Accident Analysis and Human Factor (Fundacion CIDAUT)
Affiliation: Research Engineer
Address: Parque Tecnológico de Boecillo, Parcela 209. 47151 (Boecillo) Spain
Phone: +34 983 54 80 35
Fax: +34 983 54 80 62
Email: aqumol@cidaut.es

Co-authors Contact Information:
Oscar Martín Pérez
Department of Accident Analysis and Human Factor (Fundacion CIDAUT)
Affiliation: Research Statistician
Address: Parque Tecnológico de Boecillo, Parcela 209. 47151 (Boecillo) Spain
Phone: +34 983 54 80 35
Fax: +34 983 54 80 62
Email: oscmar@cidaut.es

José Miguel Perandones
Department of Accident Analysis and Human Factor (Fundacion CIDAUT)
Affiliation: Research Engineer
Address: Parque Tecnológico de Boecillo, Parcela 209. 47151 (Boecillo) Spain
Phone: +34 983 54 80 35
Fax: +34 983 54 80 62
Email: jospei@cidaut.es

Carlos Martín Martínez
Department of Road Maintenance of Junta de Castilla y León
Affiliation: Head of Road Safety Section
Address: Rigoberto Cortejoso, 14. 47014 (Valladolid) Spain
Phone: +34 983 41 90 00
Fax: +34 983 41 99 99
Email: marmarcr@jcyl.es

David Pedrero
Department of Accident Analysis and Human Factor (Fundacion CIDAUT)
Affiliation: Head of Department
Address: Parque Tecnológico de Boecillo, Parcela 209. 47151 (Boecillo) Spain
Phone: +34 983 54 80 35
Fax: +34 983 54 80 62
Email: davped@cidaut.es

[4 Tables and 4 Figures: 1,500 words]
[English abstract length: 250 words]

Total word count: 6,739 words

ABSTRACT

The "*High Accident Rate Roads Sections* (HARRS)" are defined as dangerous sites where accident counts are substantially high. Nowadays, the respective administrations in charge of these networks invest efforts on enhancing safety in these HARRS, mainly through the implementation of different road infrastructure safety countermeasures.

This paper presents a study aimed at analyzing the "effectiveness" and "cost-benefit" ratio of several countermeasures applied (modification of the layout, pavement surface upgrade, improvement of signals and road marking,…) during the last decade by the Spanish regional road network administration of Castilla y León (CyL) over 29 HARRS located on this network.

The "Empirical Bayes" (EB) methodology has been applied over these sections to calculate the "Effectiveness" and "Cost – Benefit" ratios for each countermeasure implemented in these sections.

The research has been structured as follows:

1. Characterization of the road infrastructure of each one of the 29 HARRS.
2. Selection of road sections similar to each one of the 29 HARRS studied where no countermeasures were applied in the period of study in order to be used as comparison groups.
3. Estimation of number of accidents that would have happened in each HARRS if no countermeasure would have been implemented.
4. Calculation of "effectiveness" and "cost–benefit" ratios associated to these countermeasures.

The results obtained will be very important and useful for the Local, Regional or National administrations, specially when selecting and prioritizing a list of safety countermeasures to be applied over their road networks, taking into account the budgetary restrictions for all administrations.

INTRODUCTION

Traffic accidents are considered as one of the main epidemiologic problems nowadays. Although the number of accidents and fatalities has decreased during the last decade in areas as North America and Europe (Reference 1), it still remains as a relevant figure. In the region of 'Castilla y León' (CyL), Spain (see Figure 1), the trend is also downward, in such a way that in this regional road network (composed of 11,287 kilometres) the number of injury accidents has decreased by 44% (Reference 2) from 2004 to 2008, as well as the number of fatalities (from 2007 to 2008, the total number of fatalities has decreased by 30%).

It can be agreed that all the strategies applied for road safety improvement could be classified, in general, into three groups: vehicle – human - infrastructure. From the last point of view – infrastructure – local, regional or national administrations are continuously devoting resources for upgrading its road network, specially in those road sections denominated HARRS '*High Accident Rate Roads Sections*'.

This paper shows how different road countermeasures applied over some HARRS located in the Spanish regional road network of 'Castilla y León' (CyL) have help (or not) to improve road safety. The structure of this paper allows the reader to understand the method used to determine the safety improvement of a specific infrastructure countermeasure.

This study has been carried out by the 'Foundation CIDAUT' for the 'Regional Administration of 'Castilla y León - Department of Road Maintenance'.

Objective of the study

The main objective of this study has been to analyse the 'Effectiveness' ('E') of 36 infrastructure countermeasures (junction layout upgrade, pavement surface upgrade, roadside treatment, improvement of the signals and road marking,…) applied during the last decade by the Spanish regional road network administration of 'Castilla y León' over 29 HARRS located in this network. The interpretation of the concept ('E') means to know 'the decrease (or increase) of road accidents percentage during a period of time after the implementation of the respective road countermeasure'.

On the other hand, another goal of this study has been to estimate the 'Cost-Benefit' ratio ('CB') associated to each one of these countermeasures, which means to understand the relation between the economic cost of each countermeasure and the economic benefit obtained through the avoidance of traffic accidents after its implementation.

The reason of having selected these specific countermeasures is they are the most important ones (from an economic and frequency point of view) carried out over this network, therefore, this study can be considered as a very useful and verifiable tool since the results obtained will offer how effective and beneficial all the countermeasures are. All these 36 countermeasures applied and analysed during this study can be classified into the following groups:

- Improvement of the pavement surface: 8 countermeasures.
- General safety upgrade of a road section (improvement of the pavement surface, carriageway widening, improvement of the signals and road marking,…) – non urban area: 11 countermeasures.
- General safety upgrade of the intersections (improvement of the pavement surface, carriageway widening, improvement of the signals and road marking,…) – non urban area: 6 countermeasures.
- Modification of the road layout – non urban area: 4 countermeasures.
- Modification of the junction layout: from a 'cut roundabout' to a 'roundabout' – non urban area: 3 countermeasures.
- Modification of the junction layout: from a '+ intersection' to a 'cut roundabout' – non urban area: 2 countermeasures.
- Modification of the junction layout: from a 'T intersection' to a 'roundabout'– non urban area: 1 countermeasure.
- Modification of the junction layout: from 'an intersection with a lane to turn left' to a 'roundabout' – urban area: 1 countermeasure.

Through the results obtained from this study, road technicians and experts from the different administrations, specially from 'CyL', will have more information about which kind of road countermeasures mean higher 'effectiveness' and 'cost-benefit' ratio.

Magnitude of the problem

The concept of HARRS can be defined as (Reference 3) '*that road section in which, from a statistic point of view, the number of accidents is significantly higher than the average happened in similar sections*'. Therefore, they are identified considering traffic volume, as well as the number of accidents, period of time and length of road (at least 1 kilometre).

The analysis of the information concerning accidents in the regional road network of 'Castilla y León'(Reference 3) shows that during the last year concerning available information (2007), the number of HARRS located on this network was '20'. In the same way, around 7% of the total number of injury accidents in this road network happened in these locations. These HARRS covered 22.8 km, which means 0.2% of the total length of this regional road network.

On the other hand, the evolution of HARRS shows that the number of these locations has decreased by 60% in the last years. This fact, together with the downward trend of the accidentality in this regional road network mentioned previously, proves the positive contribution of the strategies carried out under the different 'Road Safety Programmes' in the Regional Road Network of 'CyL'.

METHODOLOGY

The methodology used in this study concerns to the statistical method so-called '*Observational Before-After studies in Road Safety'* (Reference 4). The way of calculating the effectiveness ('E') and the cost-benefit ('CB') effect of each one of the 36 countermeasures applied over the 29 HARRS selected in this study is mainly based on comparing the 'number of accidents happened

in the HARRS before and after the application of the respective countermeasure', and the 'number of accidents which would have happened if no countermeasure would have been applied'.

Step 1: Compilation of information and definition of the variables to be used for the analysis of the 'Effectiveness'

Previous to further analyses, it is necessary to identify the relevant information needed for the determination of the effectiveness of each road countermeasure. This information has been given by the own 'Department of Road Maintenance' of the regional administration of 'CyL'. As follows, the information analysed is:

- List and allocation of the 29 HARRS to be analysed (2001-2006). All the HARRS belonged to this regional network and which different countermeasures have been applied over during this period of time, have been analysed in this study.
- Description of the 36 road countermeasures applied over these HARRS, including economic costs.
- 'Road infrastructure inventory software' concerning the 29 HARRS.
- Possible new codification of the regional road network of CyL, taking into account HARRS allocation.
- List of the accidents happened in the 29 HARRS 'before' and 'after' the implementation of the countermeasures. The only important criterion to be mentioned is the fact that the period of analysis must consider at least one year after the implementation of the countermeasures. The period of analysis 'before' or 'after' the implementation has been included in an interval from '1' to '6' years, depending on the availability of information (specially for the period 'after the implementation' in which this availability is reduced to 1 year in several occasions).
- 'AADT' (Annual Average Daily Traffic) trends in the 29 HARRS. The different values considered in this study belong to the interval from 700 to 7,500 vehicles/day.

A general characterization of each one of the 29 HARRS, as well as the 36 countermeasures, is shown in Table 1 and Table 2, whereas Figure 2 is an illustrative example of the kind of information which is characterizing a HARRS.

Step 2: Selection of the 'Control' road sections for the 'Effectiveness' analyses

The statistical method - Empirical Bayes - (Reference 4) selected for the calculation of the 'E' and 'CB' effect for each one of the 36 countermeasures needs to analyse specific information ('number of accidents before and after the implementation of the countermeasure') from the so-called 'cases' (the own 29 HARRS) – information already obtained in the previous 'Step 1' - and from the so-called 'controls' (road sections similar to the respective 'cases' but with no countermeasure applied over them during the period of time considered).

This similarity between 'cases' and 'controls' is based not only on road geometric aspects, but also on variables such as 'AADT', type of area (urban or not), presence of close intersections,… The identification of these 'controls' has been possible through the deep analysis

of the 'Road infrastructure inventory software' belonging to the own regional administration of 'Castilla y León' – see Figure 3.

For each one of the 'cases', the number of 'control' sections has been very different. This number has varied from '2' controls (in the situation in which the case had very special characteristics) to '33' controls (for situations concerning more common 'cases'). On other hand, it is important to mention that the period of time in which in these controls there must not have been any countermeasure applied includes 'number of years in which the countermeasure was being applied over the respective case' and a 'suitable number of years after and before the application of the countermeasure over the respective case' (suitable number based on the availability of information concerning number of accidents, geometric characteristics,..)

The main goal of this step 2 is *'to estimate the number of accidents that could happen in the 'cases' (HARRS) if the respective countermeasures would not have been carried out in that HARRS'*. Later, this estimation will be used in the calculation of the effectiveness.

$$Effectiveness = 1 - \frac{(Number\ of\ 'real\ or\ observed'\ accidents\ in\ the\ HARRS\ after\ the\ countermeasre)}{\dfrac{(Estimation\ of\ the\ number\ of\ 'expected'\ accidents\ in\ the\ HARSS\ if\ the\ countermeasure\ would\ not\ have\ applied)}{1 + \dfrac{Variance\ of\ the\ estimation\ of\ 'expected'\ accidents}{(Estimation\ of\ 'expected'\ accidents)^2}}}$$

Equation 1.- Calculation of the 'Effectiveness' based on Bayes empirical method.

where:

- 'Number of 'real or observed' accidents in HARRS after the countermeasure' is information available from 'Step1'.
- 'Estimation of the number of 'expected' accidents in HARRS if the countermeasure would not have been applied' as well as 'Variance of this estimation' are available after 'Step2'.

Step 3: Analysis of the information concerning the accidents happened in the 'controls'

Once the most suitable 'controls' have been selected for each 'case' (HARRS), the information concerning the accidents happened in the 'controls' have been analysed. Figure 4 shows how this information has been used, seeing now that the accidents happened during the period of time when the countermeasure was being implemented are considered for this step 3. The reason of considering accidents happened in the 'control' locations 'before, during and after' the period of time of the countermeasure is the necessity of estimating the number of accidents that could have happened in the HARRS if the countermeasure would not have been applied.

Step 3.1: Estimation of the number of accidents that could have happened in the HARRS if the countermeasure would not have been applied

This is one of the most important steps in the study together with the correct selection of the 'controls' (Step 2). Through 'non linear regressions', a specific value is obtained which means 'the estimation of the accidents that could have happened in the HARRS if the countermeasure would not have been applied'. To adjust the parameters of the model (non linear regression model), the information concerning accidents happened in the 'controls' has been used. Although a very detailed model could have been considered using parameters as AADT, geometry, infrastructure characteristics, environment,… most of these aspects have been already taken into account in the selection of the 'controls' ('controls' have been chosen as similar as possible to the 'cases' relative to these characteristics). This is the reason the regression model has only considered the parameter 'AADT' for estimating the accidents that would have happened in the 'case'. In this way, the non linear model to be adjusted was: '$Y = \alpha * F_1^{\beta}$', where:

- 'Y' would be the estimation of the number of 'expected' accidents in the HARSS if the countermeasure would not have applied.
- 'F_1'would be AADT in that road section.
- 'α' and 'β' would be constant parameters once the model is adjusted.

As synthesis, the results obtained up to this step are the following ones:

- Estimation of the number of 'expected' accidents in each HARSS if the countermeasure would not have applied (result from the Step 3.1). Associated to these estimated values, there are also the respective 'variances' due to being working with estimations.
- Number of 'real or observed' accidents in each HARRS before the countermeasure (result from the Step 1).
- Number of 'real or observed' accidents in each HARRS after the countermeasure (result from the Step 1).
- Estimation of the number of 'avoided' accidents in each HARSS as the subtraction of the 'real or observed accidents in each HARRS' from 'the estimation of the 'expected' accidents' after the countermeasure (result from the Step 3.1).

Step 4: Calculation of the 'Effectiveness' value

Once the accidents 'that a specific countermeasure could have avoided in a HARRS' have been estimated, it is possible to calculate the 'effectiveness' value for this countermeasure using the previous Equation 1.

The interpretation of this value is as follows (for instance, if a countermeasure has associated an effectiveness value equal to '0.95'):

To have applied this countermeasure has meant, during the years of analysis after the countermeasure, ***a reduction of the 95% of the accidents in this HARRS concerning the accidents which could have happened if there has not been any countermeasure***

This value (95%) means this countermeasure would achieve a reduction equal to 95% of the accidents, if it would be applied over locations with similar characteristics to the specific HARRS analysed (characteristics as AADT, environment or geometry).

Lastly, from a correct statistical point of view, a 'Confidence Interval' (CI) must be associated to each 'Effectiveness' value because it has been calculated with estimators of unknown parameters. The 'E' value will have statistical significance if this 'CI' does not contain the value '0' at the associated level of confidence. In those situations in which the respective 'CI' has contained it, more number of accidents and years under analysis would have helped to obtain a better CI.

Step 5: Calculation of the 'Cost-Benefit' ratio

Once the 'Effectiveness' for each countermeasure has been obtained, the second ratio to be obtained in this study is the 'Cost-Benefit' ratio (CB). The calculation of this ratio demands the following information to be available:

1. Economic cost of the countermeasure under analysis:
   On one hand, it has to be considered that a countermeasure has a limit number of useful years. On the other hand, it is obvious that the number of years under analysis (after the countermeasure application) is lower than the total number of useful years. These reasons must be considered in the calculation of 'CB' ratio, therefore a suitable prorate was taken into account in the calculation of the term 'Economic cost of the countermeasure under analysis'.
2. Economic cost of the avoided accidents through this countermeasure:
   Actually, this cost could be considered as a 'benefit' due to this concept refers to the accidents avoided through the implementation of this countermeasure. In the same way as the previous concept ('Economic cost of the countermeasure under analysis'), the calculation of this benefit should only consider the number of years under analysis after the implementation.

$$Cost\text{ - }Benefit_{\substack{During\ the\ 'x'\ years \\ after\ the\ countermeasureg}} = \frac{Benefit\ of\ having\ avoided\ the\ accidents\ during\ the\ 'x'\ years\ under\ analysis}{Annual\ cost\ of\ the\ countermeasure\ during\ 'x'\ years\ of\ analysis\ after\ the\ countermeasure}$$

Equation 2.- Calculation of the 'Cost-Benefit' rate for a countermeasure.

Step 5.1: Economic cost of the countermeasure under analysis

The value of the 'economic cost' to be introduced in the Equation 2 must only consider the economic cost of the countermeasure proportionately calculated for the years analysed in the study concerning the period after the application of this countermeasure. The literature gives the following method for calculating the annual (instead of total) economic cost of a countermeasure:

$$g = K_0 \cdot \frac{i \cdot (1+i)^n}{(1+i)^n - 1}$$

Equation 3.- Calculation of the annual cost of a countermeasure.

where:

g: Annual cost of the countermeasure.
Ko: Total cost of the countermeasure.
i: Type of monetary loan (an average value has been used: 4% → i=0.04).
n: Number of useful years of the countermeasure.

Step 5.2: Benefit of the avoided accidents through the implementation of the countermeasure

In general terms, the calculation of the benefit associated to the avoided accidents after the implementation of the countermeasure can be divided as follows:

Benefit of having avoided a number of accidents after having applied a countermeasure = (Number of fatal accidents avoided x years after the countermeasure Unit cost of a fatal accident) + (Number of non fatal accidents avoided x years after the countermeasure * Unit cost of a non fatal accident)*

Equation 4.- Calculation of the benefit obtained from avoiding a number of accidents.

Each concept of this equation can be calculated:

- *Number of fatal accidents avoided during the x years after the countermeasure:*
  This value has been obtained after multiplying *'Number of accidents avoided x years after the countermeasure'* (result from Step 3.1) and *'Percentage of fatal accidents happened in that HARRS'* (result from the analysis of the real accidents happened in the HARRS before the countermeasure and the accidents happened in the 'controls' before, during and after the countermeasure)
- *Number of non fatal accidents avoided during the x years after the countermeasure:*
  This value has been calculated in the same way as the previous one.
- *Unit cost of a fatal and non fatal accident:*
  Literature (Reference 6) shows the different cost associated to an accident, depending on the severity. Of course, these costs have been extrapolated to Spain (see Table 3).

  In the same way the economic cost of a countermeasure has been calculated proportionally for the total number of years considered after its application, the economic cost of an accident will be calculated considering also the number of useful years a person would still have at the moment of the accident. The equation which takes into account this consideration is as follows (to be applied for fatal and non fatal accident cost):

$$g = K_0 \cdot \frac{i \cdot (1+i)^n}{(1+i)^n - 1}$$

Equation 5.- Calculation of the annual cost of a road traffic accident.

where:

g: Annual cost of the road traffic accident (depending on the severity).
K_o: Total cost of the accident (depending on the severity).

i: Type of monetary loan (an average value has been used: 4% → i=0.04).
n: Number of useful years resting for a person who has suffered an accident = 25 years.

In this way, the following results have been obtained:

Annual cost of a fatal accident in Spain = 104,096.95 €/year.
Annual cost of a non fatal accident in Spain = 3,144.58 €/ year.

Therefore, the benefit associated to each countermeasure would be:

*Benefit of having avoided a number of accidents after having applied a countermeasure = (Number of fatal accidents avoided x years after the countermeasure * 104,096.95 €) + (Number of non fatal accidents avoided x years after the countermeasure * 3,144.58 €)*

Finally, the result of the equation 2 (CB calculation), as well as the interpretation, is as follows (in the specific case of, for example, having a countermeasure which has associated a 'effectiveness' rate equal to '0.95' and a 'Cost-Benefit' rate equal to '1.65:1'):

'*For each euro dedicated to this countermeasure **the society has saved 1.65 €** through the avoidance of the 95% of the accidents during the x years after the countermeasure*

'EFECTIVINESS' AND 'COST-BENEFIT' RATIOS FOR 36 INFRAESTRUCTURE COUNTERMEASURES APPLIED OVER THE 29 HARRS

Once the working methodology used in this study has been detailed in the previous chapter, all the results are shown (see Table 4) concerning the 36 countermeasures applied. Although the interpretation of these ratios has been already explained, as follows a more specific justification is given:

- Effectiveness ('E'):
  - 'E>1' → It does not make sense an 'Effectiveness' rate higher than '1' because this should mean that the 'number of avoided accidents through the implementation of the countermeasure' would be higher than the 'real accidents happened in the HARRS'.
  - '0<E<1' → This is the most successful option because it should mean that the 'number of avoided accidents' would be, obviously, lower than the 'real accidents happened in the HARRS' and higher than '0'. This means the countermeasure is 'effective'.
  - 'E<0' → This value would mean that the 'number of avoided accidents' would be lower than '0' (negative value), because the 'estimation of the number of 'expected' accidents in HARRS if the countermeasure would not have been applied' would be lower than the 'real accidents happened'. This means the countermeasure is 'ineffective'. A possible justification could have been the AADT evolution has been growing during the last years therefore the number of accidents has grown; or another justification could have been the fact that the users have perceived this road section as safer after the implementation of a countermeasure (e.g.: improvement of the pavement surface) and drove in a faster and careless way.

- Cost-Benefit ('CB'):
  - 'CB = b:1 with b>1' → It is the most successful option because it would mean the benefit obtained from the avoidance of accidents through the implementation of the countermeasure is higher than the cost of this countermeasure.
  - 'CB = b:1 with '0<b<1' → This is a loss-making situation because it would mean the benefit obtained from the avoidance of accidents through the implementation of the countermeasure is lower than the cost of this countermeasure. This situation can appear if 'E<0'; it can appear if 'E>0' but the percentage of fatal accidents avoided is low (cost associated to fatal accidents is very high, so the highest number of fatal accidents avoided, the highest benefit obtained); or this situation can appear even if the countermeasure cost is so high that it is difficult to obtain a good result concerning benefit from avoided accidents.
  - 'CB = b:1 with b<0' → This is the worst situation because it means the benefit obtained from the avoidance of the respective countermeasure is even lower than the benefit obtained when 'CB = b:1 with '0<b<1'; therefore, if for instance 'CB=-0.33:1' it should be 'for each euro dedicated to the implementation of a countermeasure, the society would have obtained a benefit of -0.33€ , therefore, a real loss-making equal to '1.33€'.

In general aspects, there have been three types of countermeasures concerning 'E' and 'CB' ratios (as it can seen in Table 4):

- 'Effective' and 'Beneficial' countermeasures:
  These countermeasures have associated the following values: '0<E<1' and 'CB = b:1 with b>1'.
  In this category, the countermeasure group *'Modification of the junction layout: from a cut roundabout to a roundabout'* has to be specially mentioned because it is the countermeasure type with best values. As example, the number of accidents in HARSS 22 (through the countermeasure 22b) has decreased from '17' accidents during the last three years before the countermeasure to '0' accidents during the next three years after the countermeasure.
- 'Effective' but 'loss economic making' countermeasures:
  These countermeasures have associated the following values: '0<E<1' and 'CB = b:1 with '0<b<1'. There are not countermeasures with '0<E<1' and 'CB = b:1 with 'b<0'
- 'Ineffective' and 'loss economic making' countermeasures:
  These countermeasures have associated the following values: 'E<0' and 'CB = b:1 with b<0'.
  In this category, the countermeasure group *'Modification of the junction layout: from a '+ intersection' to a 'cut roundabout' – non urban area'* has to be specially mentioned because it is one of the countermeasure types with worst values. As example, the number of accidents in HARSS 11 (through the countermeasure 11b) has increased from '4' accidents during the last three years before the countermeasure to '5' accidents during the next four years after the countermeasure.

SECONDARY EFFECTS FROM THE IMPLEMENTATION OF THE 36 COUNTERMEASURES OVER THE 29 HARRS

In some situations, the application of specific countermeasures can mean some undesirable effects. So, instead of deleting a HARRS from the road network through this countermeasure, it can happen this HARRS still exist or even a new HARRS can appear in the same road or in an adjacent one (this effect is so called 'displacement effect'). In this study, the following effects have happened:

- There has been a possible 'displacement effect' in 5 HARRS, therefore new HARRS –close to the previous ones - have appeared after or during the application of the countermeasure.
- Seven out of the 29 HARRS continued as HARRS after or during the application of the countermeasure. Nevertheless, more information should be analysed related to the type of accidents happened after the implementation of the countermeasure. This may permit to know if the safety problem is different or not compared to the initial situation.
- During the period of application of the countermeasures (road works), an important number of accidents happened in the selected HARRS under analysis.

CONCLUSIONS AND NEXT STEPS

The present paper shows the results obtained after analysing the '*Effectiveness*' and '*Cost-benefit*' rate of 36 road countermeasures applied over 29 HARRS located in the regional road network of the Spanish region of 'Castilla y León' during the period 2001-2006. All these countermeasures (suitable size sample) have been classified into the following 8 groups:

- Improvement of the pavement surface.
- Safety arrangement of the section (non urban area).
- Safety arrangement of the intersection (non urban area).
- Modification of the road layout (non urban area).
- Modification of the junction layout: from a cut roundabout to a roundabout (non urban area)
- Modification of the junction layout: from a '+' intersection to a cut roundabout (non urban area).
- Modification of the junction layout: from a 'T' intersection to a roundabout (non urban area).
- Modification of the junction layout: from an intersection with a lane to turn left to a roundabout (urban area).

Through this paper, the author has provided a demonstration of how to calculate the 'Effectiveness' and 'Cost-Benefit' ratio associated to specific type of infrastructure countermeasures. The statistical methodology ('*Empirical Bayes Method*') used for the determination of these ratios has needed the selection of road sections (so called 'controls') similar to the own HARRS (so called 'cases') analysed during this study. The particularity of these 'controls' is the similarity to the 'cases' (based on geometric, traffic and environmental variables) but without any road countermeasures during the period studied (period including the respective number of years in which the countermeasure was being applied and a specific number of years 'after' and 'before' this previous application period).

The results concerning these two ratios have been very different, finding for instance that there are:

- 'Very effective' and 'very beneficial' countermeasures (for example, '*Countermeasure 22b - Modification of the junction layout: from a cut roundabout to a roundabout'* with 'E=0.95' and 'CB=1.36 : 1', through it, the number of accidents has decreased from '17' accidents during the last three years before the countermeasure to '0' accidents during the next three years after the countermeasure.
- 'Effective' but 'loss economic making' (for example, *'Countermeasure 6 - General safety upgrade of the intersection'* with 'E=0.78' y 'CB=0.52 : 1').
- 'Ineffective' and 'loss economic making' countermeasures (for example, *'Countermeasure 11b - Modification of the junction layout: from a '+ intersection' to a 'cut roundabout' – non urban area'* with 'E=-1.78' y 'CB=-0.86 : 1', through it, the number of accidents has increased from '4' accidents during the last three years before the countermeasure to '5' accidents during the next four years after the countermeasure or for example *'Countermeasure 16b - General safety upgrade of the intersection'* with 'E=-1.78' y 'CB=-0.86 : 1').

The origin of this mentioned casuistic has been diverse. For instance, the 'inefficiency' of a countermeasure can be due to an increase of AADT value in that HARRS, therefore a higher accidentality rate can appear; or this inefficiency can be due to the human behaviour and the way of driving after a specific countermeasure (for instance, after an 'improvement of the pavement surface' and the possible 'exceed speed' associated). Concerning some countermeasures which have meant 'loss economic making', this situation is logic when theses countermeasures have associated a 'Effectiveness' value lower than '0'; although even if 'E' is higher than '0' (this means there has been a reduction of accidents) if the percentage of fatal accidents avoided is low then 'CB' rate will be lower than '1:1' or even than '0:1'.

On the other hand, it must be taken into account that the specific values of these two ratios calculated for the 36 countermeasures are only valid to be extrapolated to locations where there are similar characteristics (geometry, traffic density and environment) to the ones from the HARRS selected. Therefore a next step should be to calculate these two ratios for locations in which countermeasures have been applied and with different characteristics (geometry, AADT and environment) to the already analysed. Through these new analyses, a wider range of countermeasures would be measured.

It is also important to emphasize the fact that there are secondary effects coming from the application of the countermeasures. Therefore, although the first objective of these countermeasures is to delete the own HARRS, there can be situations in which the HARRS does not disappear or even a new HARRS appear close to the previous one due to the so-called 'displacement effect' of the HARRS. An in-depth analysis of the accidents happened in this new HARRS will help to understand this effect.

As colophon, all these results will have an important added and verifiable value for the road technicians and engineers (specially for those belonging to the 'Road maintenance department' of the regional administration of 'Castilla y León') whenever they want to select which road countermeasure could be more effective to be applied over a road section with high accident rate with the aim of avoiding these accidents.

ACKNOWLEDGEMENT

- To the CyL regional administration 'Department of road maintenance' for their support during the acquisition of road accident data.

REFERENCES

Reference 1.- United Nations Economic Commission for Europe. Statistic of Road Traffic Accidents in Europe and North America. New York and Geneva, 2007.
Reference 2.- Consejería de Fomento de la Junta de Castilla y León (2008).
Reference 3.- Estrategia para la Seguridad Vial de Castilla y León '*Estudio de Accidentes 2007*', Junta de Castilla y León, 2008.
Reference 4.- Hauer E. '*Observational Before-After studies in Road Safety'*. Emerald editions. University of Toronto, 2007.
Reference 5.- Baum, H., T. Geisler, J. Scheider, and J.A. Buhne, '*Cost benefit of the ESP'*, Institute for Transport Economics at the University of Cologne, 2007.
Reference 6.- ICF Consulting '*Cost Benefit Analysis of Road Improvements*', London 2003.

LIST OF TABLES AND FIGURES

TABLE 1 General description of the 29 HARRS under analysis in this paper

HARRS code	Description and pictures	HARRS code	Description and pictures
HARRS 1	Straight road section in non urban area with a cut roundabout at the end, with AADT around 2,000 vehicles/day and with several accesses from paved (or not) paths. Width of the carriageway is 4.90 meters (m) and there are not any shoulders. There is not central road mark (dividing the lanes). Maximum legal speed is equal to 90 Km/h. The types of countermeasures applied are: • Improvement of the pavement surface (Countermeasure 1).	**HARRS 16**	Road section in non urban area with several accesses (paved or not) and 'Y' intersection. AADT around 4,500 vehicles/day. Width of the carriageway is 7 m and for shoulders (not paved) is equal to 0.5 m (each side). The accesses are paved only in a short part of them. The 'Y' intersection is characterized because from the main road it is not possible to access in both directions to the secondary road, on the other side it is possible to access from the secondary road to the main road in both directions. Maximum legal speed is equal to 90 Km/h. The types of countermeasures applied are: • General safety upgrade of the section (Countermeasure 16a). • General safety upgrade of the intersection (Countermeasure 16b).
HARRS 2	Urban road section with AADT around 7,000 vehicles/day, with several urban accesses as well as pedestrian crosses. Width of the carriageway is 6.70 m and for shoulders is 0.75 m (each side). There is central road mark (dividing the lanes) and side marks (dividing lanes from shoulders). Maximum legal speed is equal to 50 Km/h. The types of countermeasures applied are: • Improvement of the pavement surface (Countermeasure 2).	**HARRS 17**	Winding road section in non urban area with several accesses (paved or not) and bends. AADT around 4,250 vehicles/day. Width of the carriageway is 7 m and for shoulders (not paved) is equal to 0.5 m (each side). The accesses are paved only in a short part of them. The maximum curvature (Curvature = 10,000 / Radius) is equal to 30. Maximum legal speed is equal to 90 Km/h. The types of countermeasures applied are: • General safety upgrade of the section (Countermeasure 17).
HARRS 3	Winding road section in non urban area with a cut roundabout, with AADT around 2,000 vehicles/day and with several accesses from paved (or not) paths. Width of the carriageway is 7 m and for shoulders is 0.5 m (each side). There is central road mark (dividing the lanes) and side marks. Maximum legal speed is equal to 90 Km/h. The types of countermeasures applied are: • Improvement of the pavement surface (Countermeasure 3).	**HARRS 18**	Winding road section in non urban with several accesses (paved or not) and bends. AADT around 3,500 vehicles/day. Width of the carriageway is 7 m and for shoulders (not paved) is equal to 0.5 m (each side). The accesses are paved only in a short part of them. The maximum curvature is equal to 29 (Curvature = 10,000 / Radius). Maximum legal speed is equal to 90 Km/h. The types of countermeasures applied are: • General safety upgrade of the section (Countermeasure 18).
HARRS 4	Cut roundabout located in non urban area, with AADT around 3,000 vehicles/day. Width of the carriageway is 7 m and for shoulders is 0.5 m (each side). There is central road mark (dividing the lanes) and side marks. Undertaking is forbidden. Slight curved section (with maximum curvature equal to 20). This cut roundabout has large deceleration lanes (both directions) but short acceleration lanes. Maximum legal speed is equal to 70 Km/h. The types of countermeasures applied are: • General safety upgrade of the intersection (Countermeasure 4).	**HARRS 19**	Road section in non urban area with several accesses (paved or not), bends and one 'Y' intersection. AADT around 3,500 vehicles/day. Width of the carriageway is 7 m and for shoulders (not paved) is equal to 0.5 m (each side). There are central and side marks (to delimitate lanes and shoulders). The accesses are paved only in a short part of them. The 'Y' intersection is characterized by a central waiting lane in curved section to access to the secondary road, but from this secondary road it is only possible to access to the main road in the opposite direction. Maximum legal speed is equal to 90 Km/h, although the recommended speed is equal to 60 Km/h. The types of countermeasures applied are: • General safety upgrade of the section (Countermeasure 19).
HARRS 5	Straight road section in non urban area, with a deviation lane to allow turning left and with a cut roundabout at the end of the road section. AADT around 3,500 vehicles/day. Width of the carriageway is 7 m and for shoulders is 0.5 m (each side). There is central road mark (dividing the lanes) and side marks. Undertaking is forbidden in the surrounding of the cut roundabout. Good visibility. The cut roundabout has large deceleration lanes (both directions) but short acceleration lanes. Maximum legal speed is equal to 90 Km/h. The types of countermeasures applied are: • General safety upgrade of the section (Countermeasure 5).	**HARRS 20**	Road section in urban area with several accesses (paved), a roundabout and a cut roundabout. AADT around 2,500 vehicles/day. Width of the carriageway is 7 m and for shoulders (paved) is equal to 1 m (each side). There are central and side marks (to delimitate lanes and shoulders). There are pedestrian crossings. The roundabout has two lanes inside and four accesses. The cut roundabout has a deceleration lane, but not an acceleration one. Maximum legal speed is equal to 50 Km/h. The types of countermeasures applied are: • General safety upgrade of the section (Countermeasure 20).

HARRS 6	Road section in non urban area, with a 'Y' intersection in a curved section and with a deviation lane to allow turning left at the end. AADT around 4,000 vehicles/day. Width of the carriageway is 7 m and for shoulders is 0.5 m (each side). There is central road mark (dividing the lanes) and side marks. Good visibility. The 'Y' intersection has large deceleration lanes (both directions) and acceleration lanes. Maximum legal speed is equal to 90 Km/h. The types of countermeasures applied are: • General safety upgrade of the intersection (Countermeasure 6).	**HARRS 21**	Urban road section with several accesses (paved), intersections and a bridge with only a narrow lane. AADT around 3,000 vehicles/day. Width of the carriageway is 6 m, without shoulders. There is central road mark (axis). There are pedestrian crossings. Maximum legal speed is equal to 50 Km/h. The types of countermeasures applied are: • General safety upgrade of the section (Countermeasure 21).
HARRS 7	Road section in non urban area with two cut roundabouts (different sizes). AADT around 4,000 vehicles/day. Width of the carriageway is 7 m and for shoulders is 1 m (each side). This road section is closed to urban area. The first cut roundabout has short deceleration lanes (both directions) and acceleration lanes with paved islands, but the second roundabout has large deceleration lanes (both directions) and acceleration lanes. Maximum legal speed is equal to 100 Km/h. The types of countermeasures applied are: • General safety upgrade of the intersection (Countermeasure 7a). • Modification of the junction layout: from a cut roundabout to a roundabout (Countermeasure 7b).	**HARRS 22**	Road section in non urban area with two cut roundabouts (different sizes). AADT around 4,500 vehicles/day. Width of the carriageway is 7 m and for shoulders is 1.5 m (each side). This road section is closed to urban area. The first cut roundabout has paved islands, deceleration lanes (both directions) and acceleration lanes, while the previous bend (much closed to this cut roundabout) has a maximum curvature equal to 21. The second cut roundabout has also large deceleration lanes (both directions) and acceleration lanes; while the previous bend (also very closed to this cut roundabout) has a maximum curvature equal to 22. This second cut roundabout has direct access to an urban area. Maximum legal speed is equal to 100 Km/h. The types of countermeasures applied are: • Modification of the junction layout: from a cut roundabout to a roundabout (Countermeasure 22a and 22b).
HARRS 8	Winding road section in non urban area with several accesses from paved (or not) paths. AADT around 4,500 vehicles/day. Width of the carriageway is 7 m and for shoulders is 1 m (each side). There is central road mark (dividing the lanes) and side marks. Maximum legal speed is equal to 100 Km/h, although there is vertical signal showing recommended speed equal to 70. The maximum curvature is equal to 40. The types of countermeasures applied are: • Improvement of the pavement surface (Countermeasure 8).	**HARRS 23**	Winding road section in non urban area, with a 'T' intersection in a curve section and several accesses. AADT around 6,500 vehicles/day. Width of the carriageway is 6 m and without shoulders. The maximum curvature is equal to 72. The 'T' intersection has large deceleration lanes (both directions) and acceleration lanes, in central and side parts. This intersection is very closed to urban area. Maximum legal speed is equal to 90 Km/h, although the recommended speed is 70 Km/h. The types of countermeasures applied are: • Modification of the road layout (Countermeasure 23).
HARRS 9	Urban road section with a bend (whose maximum curvature is equal to 44) before crossing a bridge, several accesses from paved (or not) paths and a cut roundabout at the end of the road section. AADT around 4,500 vehicles/day. Width of the carriageway is 7 m and for shoulders is 1 m (each side). There is central road mark (dividing the lanes) and side marks, as well as pedestrian crossings. Maximum legal speed is equal to 50 Km/h. The types of countermeasures applied are: • Improvement of the pavement surface (Countermeasure 9).	**HARRS 24**	Road section in non urban area with two intersections (type T/Y) very closed each other. The first one (T) is in the left side and in curved section (maximum curvature is equal to 79) and the second one is in the right side. In none of them, there are acceleration lanes neither deceleration lanes. AADT around 8,000 vehicles/day. Width of the carriageway is 7 m and for shoulders is 0.5 m (each side). This road section is closed to an urban area. Maximum legal speed is equal to 90 Km/h. The types of countermeasures applied are: • Modification of the road layout (Countermeasure 24).
HARRS 10	Urban road section characterized by an intersection (a deviation lane to allow turning left). AADT around 7,500 vehicles/day. Width of the carriageway is 7 m and for shoulders is 1.5 m (each side). There is central road mark (dividing the lanes and forbidding to overtake) and side marks. Maximum legal speed is equal to 50 Km/h. The types of countermeasures applied are: • Modification of the junction layout: from an intersection with a carriageway to turn left to a roundabout (Countermeasure 10).	**HARRS 25**	Urban road section with several accesses in both sides. AADT around 1,700 vehicles/day. Width of the carriageway is 6 m and without shoulders. There is central road mark (dividing the lanes) and side marks. There are not pedestrian crossings. Maximum legal speed is equal to 50 Km/h. The types of countermeasures applied are: • Improvement of the pavement surface (Countermeasure 25).
HARRS 11	Road section characterized by two types of road sections. The first one is a winding road section in non urban area with several accesses and one intersection '+'. The second one is a winding urban area with several accesses. AADT around 4,000 vehicles/day. Width of the carriageway is 6 m and there are not any shoulders. There is central road mark (dividing the lanes and forbidding to overtake) and side	**HARRS 26**	Winding road section in non urban area. AADT around 1,700 vehicles/day. Width of the carriageway is 7 m, with paved shoulders of 0.5 m width (each side). There is central road mark (dividing the lanes and forbidding to overtake in most part of the road section) and side marks. There are direction vertical signals. Maximum legal speed is equal to 90 Km/h. The maximum curvature is equal to

	marks. Maximum legal speed is equal to 90 Km/h in the first section, although there is vertical signal showing recommended speed equal to 60. The second section is in an urban area with maximum speed equal to 50. The maximum curvature is equal to 150 in both sections. The types of countermeasures applied are: • Improvement of the pavement surface (Countermeasure 11a). • Modification of the junction layout: from a '+' intersection to a cut roundabout (Countermeasure 11b).		60. There is bad visibility. High slope in this road section. The types of countermeasures applied are: • General safety upgrade of the section (Countermeasure 26).
HARRS 12	Road section in non urban area with an intersection 'T' (without central waiting lane) and a bend with accesses. AADT around 2,000 vehicles/day. Width of the carriageway is 7 m, without shoulders. This road section is closed to urban area. T. There is central road mark (dividing the lanes and forbidding to overtake in the curved section) and side marks. Bad visibility in the bend. Maximum legal speed is equal to 90 Km/h. The types of countermeasures applied are: • General safety upgrade of the section (Countermeasure 12a). • General safety upgrade of the intersection (Countermeasure 12b).	**HARRS 27**	Road section in non urban characterized by the presence of a bend (maximum curvature is equal to 41) and a cut roundabout. AADT around 1,750 vehicles/day. Width of the carriageway is 7 m and 0.5 m for paved shoulders (each side). There are central and side road marks (to divide lanes and shoulders). Maximum legal speed is equal to 90 Km/h. The types of countermeasures applied are: • General safety upgrade of the section (Countermeasure 27).
HARRS 13	Winding road section in non urban area. AADT around 700 vehicles/day. Width of the carriageway is 6 m without shoulders. There is central road mark (dividing the lanes and forbidding to overtake in the curved section) and side marks. Bad visibility. The maximum curvature is equal to 108. Maximum legal speed is equal to 90 Km/h. The types of countermeasures applied are: • Modification of the road layout (Countermeasure 13).	**HARRS 28**	'T' intersection in a non urban road section. There is a central waiting lane in one direction, side deceleration lane in the other direction and acceleration lanes in both directions. Central lanes are delimited by paved islands allowing the presence of vertical signals. AADT around 5,000 vehicles/day. Width of the carriageway is 7 m and shoulders with 1.5 m width in each side. This intersection is very closed to industrial area. Maximum legal speed is equal to 100 Km/h. The types of countermeasures applied are: • Modification of the junction layout: from a 'T' intersection to a roundabout (Countermeasure 28).
HARRS 14	Winding road section in non urban area characterized by having two intersections ('+' and 'T'). AADT around 4,500 vehicles/day. Width of the carriageway is 7 m and for shoulders (not paved) is equal to 0.5 m (each side). There is central road mark (dividing the lanes and forbidding to overtake in the curved section and in the intersections) and side marks. This section is closed to an industrial area. Bad visibility in general. The intersection '+' has acceleration lanes only in one direction. The intersection 'T' has acceleration and deceleration lanes. The maximum curvature is equal to 39. Maximum legal speed is equal to 90 Km/h. The types of countermeasures applied are: • Modification of the junction layout: from a '+' intersection to a cut roundabout (Countermeasure 14a). • General safety upgrade of the section (Countermeasure 14b).	**HARRS 29**	Bend in a non urban area. AADT around 4,500 vehicles/day. Width of the carriageway is 7 m, with paved shoulders of 1.5 m width (each side). There is central road mark and side marks. There are direction vertical signals. Maximum legal speed is equal to 100 Km/h. The maximum curvature is equal to 47. Length of the bend is 100 m. There is bad visibility. It is closed to an urban area. The types of countermeasures applied are: • Modification of the road layout (Countermeasure 29).
HARRS 15	Road section in non urban area with several accesses (paved or not) and bends. AADT around 4,000 vehicles/day. Width of the carriageway is 7 m and for shoulders (not paved) is equal to 0.5 m (each side). The accesses are paved only in a short part of them. This section is closed to an industrial area. The maximum curvature is equal to 39. Maximum legal speed is equal to 90 Km/h. The types of countermeasures applied are: • Improvement of the pavement surface (Countermeasure 15a). • General safety upgrade of the intersection (Countermeasure 15b).		

TABLE 2 Type of countermeasures applied over the 29 HARRS located in the CyL road network during 2001-2006

Countermeasure group	Example	Code of the countermeasure applied over the HARRS and belonging to this group
Improvement of the pavement surface		Countermeasure 1 (over HARRS 1) Countermeasure 2 (over HARRS 2) Countermeasure 3 (over HARRS 3) Countermeasure 8 (over HARRS 8) Countermeasure 9 (over HARRS 9) Countermeasure 11a (over HARRS 11) Countermeasure 15a (over HARRS 15) Countermeasure 25 (over HARRS 25)
General safety upgrade of a road section (non urban area)		Countermeasure 5 (over HARRS 5) Countermeasure 12a (over HARRS 12) Countermeasure 14b (over HARRS 14) Countermeasure 16a (over HARRS 16) Countermeasure 17 (over HARRS 17) Countermeasure 18 (over HARRS 18) Countermeasure 19 (over HARRS 19) Countermeasure 20 (over HARRS 20) Countermeasure 21 (over HARRS 21) Countermeasure 26 (over HARRS 26) Countermeasure 27 (over HARRS 27)
General safety upgrade of the intersection (non urban area)		Countermeasure 4 (over HARRS 4) Countermeasure 6 (over HARRS 6) Countermeasure 7a (over HARRS 7) Countermeasure 12b (over HARRS 12) Countermeasure 15b (over HARRS 15) Countermeasure 16b (over HARRS 16)
Modification of the road layout (non urban area)		Countermeasure 13 (over HARRS 13) Countermeasure 23 (over HARRS 23) Countermeasure 24 (over HARRS 24) Countermeasure 29 (over HARRS 29)
Modification of the junction layout: from a 'cut roundabout' to a 'roundabout' (non urban area)		Countermeasure 7b (over HARRS 7b) Countermeasure 22a (over HARRS 22a) Countermeasure 22b (over HARRS 22b)
Modification of the junction layout: from a '+ intersection' to a 'cut roundabout' (non urban area)		Countermeasure 11b (over HARRS 11) Countermeasure 14a (over HARRS 14)
Modification of the junction layout: from a 'T intersection' to a 'roundabout' (non urban area)		Countermeasure 28 (over HARRS 28)
Modification of the junction layout: from 'an intersection with a lane to turn left' to a 'roundabout' (urban area)		Countermeasure 10 (over HARRS 10)

TABLE 3 Distribution of costs associated to traffic accidents in Spain depending on the severity

Severity	Lost output	Human costs	Medical and ambulance costs	Properly damage	Insurance administrative	Police costs	Delay costs	TOTAL (€)
Fatal	390,266	1,016,917	5,253	7,285	204			
Serious	14,765	116,347	8,852	2,928	108			
Slight	1,697	9,670	723	1,718	65			
Fatal	448,806	1,150,000	6,042	8,379	235	1,499	11,250	1,626,211
Serious or slight	4,974	35,000	2,643	2,593	97	68	3,750	49,125

TABLE 4 Final classification of the 36 countermeasures applied over the 29 HARRS under analysis in this paper (classification based firstly on 'Effectiveness' and secondly on 'Cost-Benefit' rate)

Type of countermeasure	Effectiveness (*: No statistical signifance)	Cost-Benefit
General countermeasure 'MODIFICATION OF THE JUNCTION LAYOUT: FROM A 'CUT ROUNDABOUT' TO A 'ROUNDABOUT' – NON URBAN AREA'	0.98	7.44 : 1
Countermeasure22a: Modification of the junction layout: from a 'cut roundabout' to a 'roundabout' – non urban area.	0.95	1.65 : 1
Countermeasure22b: Modification of the junction layout: from a 'cut roundabout' to a 'roundabout' – non urban area	0.95	1.36 : 1
Countermeasure7b: Modification of the junction layout: from a 'cut roundabout' to a 'roundabout' – non urban area	0.94	7.25 : 1
Countermeasure 'MODIFICATION OF THE ROAD LAYOUT'	0.93	0.84 : 1
Countermeasure10: Modification of the junction layout: from 'an intersection with a lane to turn left' to a 'roundabout' – urban area	0.92	0.99 : 1
Countermeasure3: Improvement of the pavement surface – non urban area	0.91	0.86 : 1
Countermeasure24: Modification of the road layout: from two intersections ('T' and 'Y') to a roundabout	0.85	1.75 : 1
Countermeasure28: Modification of the junction layout: from a 'T intersection' to a 'roundabout'– non urban area	0.82	3.09 : 1
Countermeasure29: Modification of the road layout: make the bends slighter	0.80	1.91 : 1
Countermeasure6: General safety upgrade of a 'Y' intersection and an 'intersection with a lane to turn le	0.78	0.52 : 1
Countermeasure13: Modification of the road layout: deletion of bends or make the bends slighter	0.77	0.57 : 1
Countermeasure4: General safety upgrade of a roundabout (improvement of the pavement surface, carriageway widening, improvement of the signals and road marking,…) – non urban area	0.74	0.93 : 1
Countermeasure23: Modification of the road layout: modification of several road accesses, improvement of surface, and arrangement of intersections	0.73	0.36 : 1
Countermeasure9: Improvement of the pavement surface	0.70	0.55 : 1
Countermeasure25: Improvement of the pavement surface	0.70	0.21 : 1
Countermeasure8: Improvement of the pavement surface – non urban area	0.68	0.61 : 1
Countermeasure15b: General safety upgrade of a '+' intersection – non urban area	0.66	9.80 : 1
Countermeasure1: Improvement of the pavement surface – non urban area	0.65	0.14 : 1
Countermeasure27: General safety upgrade of a road section (improvement of the pavement surface and higher carriageway width)	0.63	1.06 : 1
Countermeasure17: General safety upgrade of a road section (improvement of the pavement surface and higher carriageway width without new road vertical and horizontal signals)	0.62	0.34 : 1
Countermeasure12a: General safety upgrade of a road section (improvement of the pavement surface and signals and road marking as well as installation of road restraint systems)	0.60	0.12 : 1
Countermeasure26: General safety upgrade of a road section (improvement of the pavement surface and higher carriageway width)	0.58* (CI:(-0.14 ÷ 1))	0.05 : 1
Countermeasure 'GENERAL SAFETY UPGRADE OF A ROAD SECTION'	0.57	0.61 : 1
Countermeasure 'IMPROVEMENT OF THE PAVEMENT SURFACE'	0.53	0.49 : 1

Countermeasure14b: General safety upgrade of a road section (improvement of the pavement surface and higher carriageway width)	0.47	1.04 : 1
Countermeasure 'GENERAL SAFETY UPGRADE OF INTERSECTIONS'	0.35* (CI:(-0.07÷0.76))	0.64 : 1
Countermeasure18: General safety upgrade of a road section (improvement of the pavement surface and higher carriageway width)	0.35* (CI:(-0.18÷0.88))	0.54 : 1
Countermeasure15a: Improvement of the pavement surface – non urban area	0.31* (CI:(-0.32÷ 0.93))	0.03 : 1
Countermeasure2: Improvement of the pavement surface	0.30* (CI:(-0.11÷0.69))	0.29 : 1
Countermeasure11a: Improvement of the pavement surface – non urban area	0.28	0.63 : 1
Countermeasure5: General safety upgrade of a road section (improvement of the pavement surface and improvement of the signals and road marking)	0.15* (CI:(-0.34 ÷ 0.63))	0.10 : 1
Countermeasure12b: General safety upgrade of a 'T' intersection– non urban area	0.13* (CI:(-0.32÷ 0.57))	0.017 : 1
Countermeasure7a: General safety upgrade of a roundabout– non urban area	- 0.32* (CI:(-1.61÷0.96))	- 0.56 : 1
Countermeasure20: General safety upgrade of a road section	- 0.33* (CI:(-1.64÷0.92))	- 0.03 : 1
Countermeasure14a: Modification of the junction layout: from a '+ intersection' to a 'cut roundabout' – non urban area	- 0.36* (CI:(-1.24÷0.50))	-0.33 : 1
Countermeasure21: General safety upgrade of a road section (improvement of the pavement surface and improvement of the signals and road marking)	- 0.51* (CI:(-1.49÷0.46))	- 0.05 : 1
Countermeasure 'MODIFICATION OF THE JUNCTION LAYOUT: FROM A '+ INTERSECTION' TO A 'CUT ROUNDABOUT' – NON URBAN AREA'	- 0.94	-0.47 : 1
Countermeasure16a: General safety upgrade of a road section (improvement of the pavement surface and improvement of the signals and road marking) – non urban area	- 1.35* (CI:(-3.9 ÷ 1))	- 0.20 : 1
Countermeasure11b: Modification of the junction layout: from a '+ intersection' to a 'cut roundabout' – non urban area	- 1.42* (CI:(-3.36÷0.52))	-0.13 : 1
Countermeasure16b: General safety upgrade of a 'Y' intersection– non urban area	-1.78* (CI:(-4.28÷0.72))	- 0.86 : 1

FIGURE 1 Region of Castilla y León – Spain

FIGURE 2 Variables to be used in the characterization of a HARRS in which a specific countermeasure has been applied (Example: HARRS 22 / Modification of the junction layout: from a 'cut roundabout' to a 'roundabout')

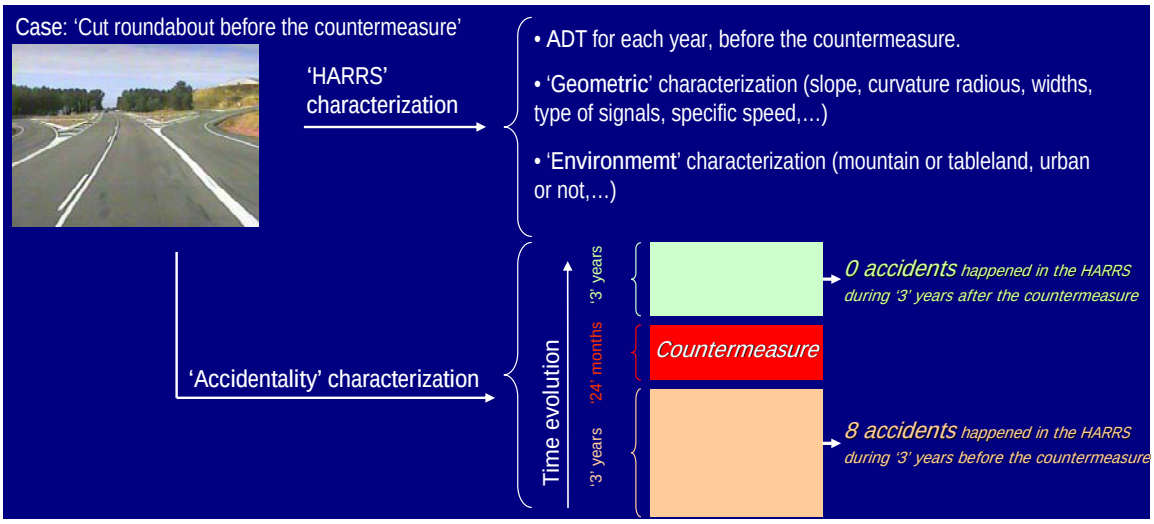

FIGURE 3 Identification of the so-called ‘Controls’ road sections through the ‘Road infrastructure inventory software’ belonging to the regional administration ‘CyL’

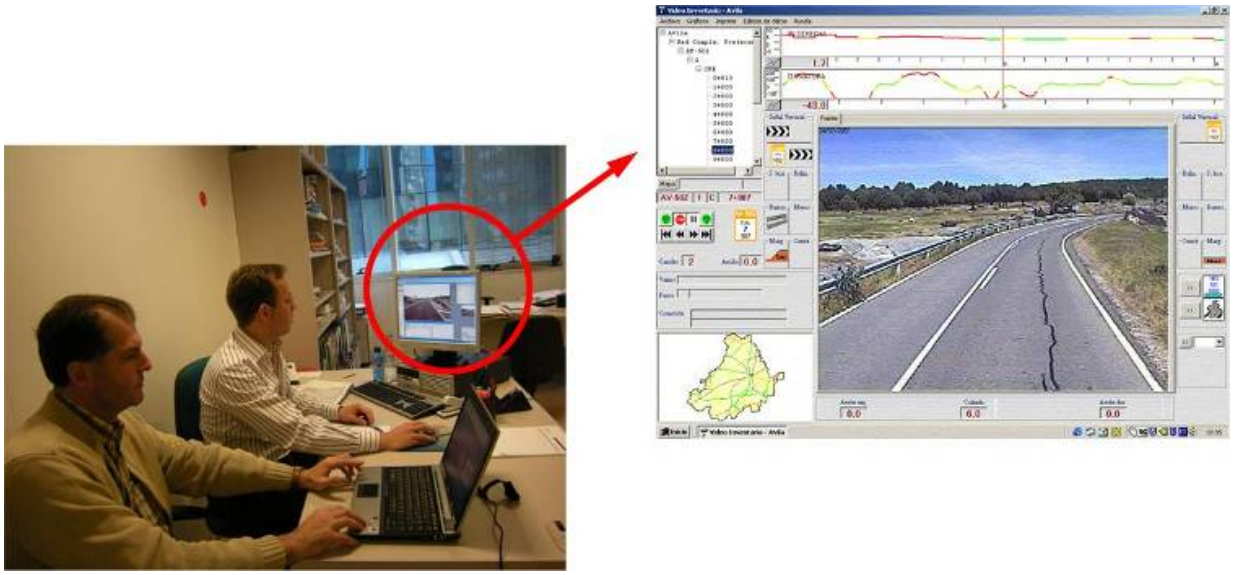

FIGURE 4 Information used from the 'controls' for the estimation of the number of accidents that could have happened in the HARRS if the countermeasure would not have been applied