Low-cost engineering measures for casualty reduction. Application on the national road network.

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1. Introduction

Accident occurrence is the result of the contribution of several factors associated with the traffic system, namely: road user, road environment and vehicles. English and American studies revealed that about 93% of all accidents involve human factors and nearly 33% are associated with road environment [1, 2]. Finnish studies also revealed that the road environment may lead to wrong driver behaviour, especially where road design discontinuities prevent the driver from being able to predict the environment and situations ahead [3, 4].

Road administrations have the responsibility to provide a road environment with the best equilibrium between road infrastructure demand and drivers capabilities throughout all the road life cycle [5].

A study on standardization and rationalization of low cost engineering measures (LCEM) application, aimed at road infrastructure correction and road safety improvement, was developed by the National Laboratory of Civil Engineering (LNEC) for the Portugal Roads Institute (IEP) – Road Administration. Some selected results of this study are presented in this paper [6], also including the results of some safety analysis of low cost engineering measures application on Portuguese roads.

2. Infrastructure intervention for road safety improvement

According to the Organization for Economic Co-operation and Development (OECD), integrated programs on road safety aiming to reduce accident severity should focus on several traffic system elements, namely by adaptation of road environment characteristics to the intended road uses [7].

The application of road safety measures is based on general knowledge on road safety phenomenon, sometimes complemented by the results of the analysis of accident data in the area being corrected. The periodic revision of highway design rules and road safety impact studies are examples of *a priori* type of interventions [8]. In *a posteriori* type of corrective actions, general knowledge on road safety is complemented by insight on specific problems of the area being treated, obtained with the analysis of the accidents that occurred in the area. This type of intervention may further be divided in four types of actions: black spot treatment, route action (itinerary treatment), area wide treatment (especially suitable for urban areas) and the mass action with the application of a specific treatment to part of the network [9].

Better safety results are achieved with road correction if the procedures for its implementation include the following steps:

- Safety area diagnosis to identify the places with greater road influence on accident occurrence or the primer factors associated with the road.
- Safety analysis on each selected place for intervention.
- Selection of appropriate safety measures and safety monitoring of the corrected sites.
- Evaluation of results.

Within the decision process for selecting the correction measures, it is necessary to take into account the available budget for the program, the results of the diagnosis and the foreseen benefits. Safety developments monitoring and results evaluation are very important for the system efficiency improvement, since it allows a prevision of benefits improvement, and consequently, better future investment decisions.

From a safety point of view, road environment correction is especially important because it has frequently allowed casualty reductions of about 30% on interventioned places, starting since the first year.

Table 1 presents the efficiency evaluation results of several types of road correction in some counties of the United Kingdom [10]. In this correction program, 1832 places were interventioned, between 1993 and 1999 by local administrations. The investment first year rate of return rates were all above 100%, and only in one case, under to 200%.

Table 1 – Road intervention efficiency on the road network of some U.K. counties (1993-1999).

Interventions		Change in the average annual number of personal injury accidents		Average investment	
Type	Number	(%)	Number	(Euro)	1st year return rate (%)
Cycle track	12	-65	3.79	95535	444
In an area	10	-47	2.58	128088	225
In an itinerary	69	-46	1.68	36206	520
Traffic calming outside intersections	63	-49	1.48	63973	260
Intersections with signals	159	-37	1.35	56857	266
In curves	265	-54	1.12	17366	722
In roundabouts	164	-35	1.03	65410	176
Pedestrian crossings	250	-32	0.97	44083	246
Outside intersections (general)	398	-29	1.05	44142	266
Intersections without signals	468	-37	0.90	19267	523
Average	1832	-38	1.13	37805	372

[1] For 1999 prices.

According to international experience, LCEM can offer very good benefit/cost relations, as long as their selection takes into account, not only the main type of accidents, whose frequency or severity are intended to decrease, but also the guaranty that the application of measures will not have undesirable effects either on the efficiency of traffic operation or on environmental issues.

One of the main characteristics of LCEM relies on the fact that they can always be applied within the road limits. This fact combined with the low cost and fast effect attainment, justifies the favourable cost/benefit relation, even for those roads where major interventions are expected in a short term (3 to 5 years).

3. Low cost engineering measures

3.1 Rumble strips

Rumble strips are safety devices to alert drivers for the possibility of having to make a change on the driving operation.

They consist of a repeated pattern, raised or lowered in relation to pavement surface, with a different texture, that creates noise and vibration on vehicles when tires role over them.

Although rumble strips don’t convey information on the appropriate driving behaviour, the correct driving action is easily identified by the visual information collected by the driver, on the road environment and signs.

Rumble strips may be applied on the road surface to alert the drivers to changes on road design that may be dangerous. In this case they are usually applied near intersections, tolls booths, horizontal curves, lane reductions, work zones, etc.

Rumble strips may also be applied on the edge of the carriageway, to alert drivers to the fact that they have left the road. In some countries, shoulder rumble strips are also used to diminish shoulder use by slow vehicles.

Rumble strips application must take into account important negative side effects, normally associated with noise generation, improper use of opposite lane and maintenance issues.

According to some studies, the application of rumble strips on rural areas has been associated with 20 to 60% of accident reductions [11, 12].

3.2 Traffic signs

Information needed for orientation, operation and vehicle control is mostly visual. This is why the driver must properly and timely receive relevant visual information, in order to allow him to control the vehicle as well as ensure pedestrian safety.

Vertical signs are devices placed laterally to lanes or above them, with the proper support in each case. They are aimed at warning, informing and orienting drivers in conditions that may lead to dangerous situations.

Regulatory signs inform drivers about local impositions, and how they should act; danger signs alert drivers for potential risky situations and information signs inform the drivers on their itinerary, destiny and service locations.

Road markings are delineation systems installed on road pavement for:

- Vehicle position and movement control through visual information that identifies the legal and safety limits of roadway.
- Driving direction regulation, changing lane and overtaking.
- Zone or lane identification, where manoeuvres are allowed, forbidden or mandatory.
- Lane discipline increment, particularly during night periods and adverse weather conditions.
- Dangerous zones identification aid, like obstacles or pedestrian crossings.

Longitudinal road lines define the road and lane limits. They can be continuous or discontinuous, white (slightly silvered if they are reflector) or yellow in case of work zone application.

Edge lines are used to mark the carriageway limits. They are quite effective in guiding under bad atmospheric conditions, or when shoulders are small or nonexistent. They are particularly effective when applied simultaneously with the axial line, since they can increase lateral restriction sensation and also contribute for lower speeds.

Road markings may be complemented by road studs application to the pavement surface. Their colour should be the same as the one of the road line that they are replacing or complementing. In order to be seen, they can be internally-illuminated or retroreflective. In any case, they must simulate the effect of traditional road marking. By its application average accident reductions of 10 to 40% may be achieved [11, 12].

Marker posts may be used to improve road delineation, especially under low visibility conditions. This measure is particularly effective in roads without any marked limits, and is able to improve from 30 to 40% in accident reductions [11].

Lane reduction arrows are obliquely placed on the lane that is about to end and warn the drivers for the need to change lane. For a smooth transition, lane reduction arrows should be placed before the transition zone and be repeated until the end of the lane.

Chevron markings are inverted “V” shaped yellow markings placed with regular spacing in the middle of traffic lanes. These markings are designed to improve road safety through the encouragement of an inter-vehicular minimum distance practice.

3.3 Roadside improvement

Roadside plays a primordial role in what concerns to occupants of uncontrolled vehicles, since if adequately designed, it may prevent a run-off-road manoeuvre from ending up as a serious accident. Roadside areas provide space for parking broken vehicles, as well; besides that, they can complement road functions, namely by integrating the road infrastructure in the environment, creating a positive psychological feeling in vehicle occupants.

At the design level, obstacle free areas should be considered. In those areas, which include shoulder and medians, it should not be allowed to place any kind of obstacles that may put into danger the occupants of uncontrolled vehicles [13].

Side slope is one of the factors that may affect the possibility for an uncontrolled vehicle to overturn and for the driver to be unable to safely recover vehicle control. Whether the side area is an embankment or an excavation, it is important to have a low slope and the rounding of breaking points that may contribute to the loss of vehicle control, since these are the sites where the vehicle tends to loose ground contact.

Medians separate traffic flows with opposite directions. They are also considered recovery areas for uncontrolled vehicles and for emergency stops. Being so, they should be clear and have a minimum with of 20 m.

However, since this is not always an economic solution, smaller medians may be adopted, if they are properly equipped with drainage organs and safety barriers, depending on traffic volume. Sometimes medians are also equipped with antiglare screens to mitigate dashing risk caused by vehicle head lights running on opposite direction. Occasionally, these screens are obtained with vegetation.

The shoulder may be used for emergency manoeuvres of uncontrolled vehicles area and for emergency stopping, immobilized vehicle parking and for pedestrian and cyclist use. The shoulder structure also provides lateral support to the road and pavement.

Shoulder area should be clearly separated from the carriageway by means of edge lines. Shoulder width should not be too high to deter drivers from circulate in it; it should not be very narrow either, because this would reduce its effectiveness.

In what concerns roadside fixed objects that might be a danger for some drivers of uncontrolled vehicles, the first possible solution should be the removal of the obstacle. However, if that isn’t possible, there are other solutions, such as the removal to a more distant location or the use of break-away posts. Only if none of these options is possible, the application of safety barriers should be considered.

According to before-after studies, a 40% accident reduction may be achieved with the reduction of side slope [11]. The results of a meta-analysis made by Elvik and Vaa on three American studies revealed a 22% average reduction on personal injury accidents obtained by a slope reduction of 1:3 to 1:4 and a 42% average reduction on personal injury accidents obtained by a slope reduction from 1:4 to 1:6 [12]. A 25% to 30 % accident reduction is associated with the application of safety barriers on rural road medians [11, 12]. A 20% to 60% accident reduction may be achieved with the construction of paved shoulders [11].

3.4 Anti-skidding pavement surface layer application

The application of a new layer can only be considered a low cost engineering measure if it is applied in restricted areas. Its consideration on sharp curves, near pedestrian crossings, intersections or roundabouts with a high number of run-off-road accidents, can be very advantageous.

A 30 to 40% of accident reduction was reported with the application of an anti-skidding layer on the approach to intersection on high speed road [11].

3.5 Improvement of sight conditions

Stopping sight distance is the minimum distance needed for a vehicle, running at a specific speed, to stop, after its driver perceived an obstacle on the roadway. This distance is very important for road safety, since it has to increase for higher speeds. To maintain an appropriate road safety level, suitable speed limits must be set, to assure that there is no visual obstruction by the vegetation and that access to the road doesn’t occur at inappropriate places.

Drivers of vehicles that change direction on intersections may have to take quick decisions on when to move forward, as a function of road design and conflict identification. These decisions are made in a matter of seconds, and any misinterpretation can be a factor for accident causation. As so, visibility triangles and intersection design are important road safety issues.

Several studies reached the same conclusion: accident rates grow proportionally to small decreases in visibility distance. A 10 to 60% accident number reduction was obtained by the improvement of visibility conditions, with relation to head-on collisions and lateral collisions on turning movements [11].

3.6 Traffic channelization

Traffic channelization aims at reducing conflicts between vehicles and vehicles and pedestrians. It facilitates correct trajectory selection, capacity increase and traffic control and maximizes driver/road communication. It also reduces the number of decisions that a driver must deal with at a certain place, giving him time to think on the next decision and then act accordingly.

In single carriageway two way-two lane roads, there are two traffic channelization solutions: the first is to introduce turning lanes (left or right) which are secure places for vehicles that are going to turn, thus reducing risk of accident and encouraging drivers to wait for the right time to turn; the second solution is to use shoulders as an additional lane for overtaking vehicles that are waiting to turn left. This solution is not very expensive, since, if shoulders are already paved, it's only necessary to paint the corresponding markings. Note that, although the Portuguese Highway Code doesn't allow driving along thee shoulders, in some busy intersections it happens anyway, being very effective at traffic jam reduction.

Traffic canalization measures may contribute to reductions (15% to 57 %) in the number of personal injury accidents [10, 12].

3.7 Traffic control devices

Signals are used for traffic regulation, namely to give way, inform about regulations, warn drivers of dangerous situations and produce a traffic orientation through appropriate signs. They are usually used in intersections where conflicts are higher enough to justify the need for single movement's management.

The application, for instance, of traffic control signals at four leg junctions may lead to a 30% reduction in personal injury accidents, and 35% on property damage only [12]. A 45% reduction on accident number may be achieved with the installation of general traffic control devices [11].

3.8 Road lights

Road lights are intended to provide enough lighting for drivers to travel with comfort and safety during night periods or under low visibility conditions.

This solution is commonly applied where there is the possibility of conflicts between vehicles and pedestrians or cyclists. Portuguese design standards have a recommendation for the installation of road light at intersections. In rural roads, the implementation of lighting on unlit roads may lead to a 64% reduction in fatal accidents [12] (20 to 50% of total accident reduction [11]).

4. Coordinated interventions in special cases

For specific situations, as horizontal curves, intersections and roads through small towns, a group of engineering measures can be applied in a coordinated way, for the achievement of better results.

Horizontal curves are normally considered zones with high driving difficulties, and therefore, they should be treated with a special delineation system that provides enough guidance for drivers, particularly for those that are not familiar with the road. This can be achieved through retroreflective delineation devices, placed with a regular spacing, being especially important when road markings are no longer visible by drivers, as for example, during rain periods [14]. Chevrons, road studs and marker posts are some of the retroreflective delineation devices that can be used to inform drivers on the danger that is about to come. A curve signalization system was recently adopted in Portuguese rural roads, based on their classification according to the danger they represent. This danger is a function of accident risk increment and of the amount of speed reduction.

Uniform vertical signs and horizontal markings application (with retroreflective materials) may allow for 50% in the reduction of accident numbers [15].

From the safety point of view, intersections are critical zones of the road network. Any intersection should allow road users to go forward or change direction with the maximum safety. Intersection design should be obvious, have a good visibility on traffic control devices and also on other users.

Intersection operation can be improved through several types of measures, namely: a stopping sight distance increase (by vegetation pruning or recolocation of obstructions like walls, fences or signs); a lower speed limit to decrease stopping sight distance requirements; measures to the diver behaviour conditioning, such as higher sign posts (with a slip-base) in order to be seen by drivers during night periods; parking restrictions before intersections; application of stopping line marking closer to the intersection, so that drivers can get a better view of conflicting traffic; and signal application, when justified.

As benefits of this kind of intervention, a 48% accident reduction can be mentioned, which was obtained by the signals application at intersections [11].

Rural roads crossing minor urban areas should be specially designed, so that local safety is not disturbed by long distance traffic. Village gateways should be specially focused, since they designate the start of potentially dangerous zones. They can be made in several ways, but the most commonly used elements are entry signs and coloured pavement surfaces combined with speed limits, signs or narrowings. These solutions can be associated with physical elements such as fences, wall, vegetation, medians, kerb-stones, countdown signs, humps application, raised intersections, etc.

Notice that safety conditions treatment can be too severe for village's traffic mobility, so, in that case, it's recommendable to evaluate the need for a bypass.

A 75% of accident reduction was achieved with gateway treatments in large villages on trunk roads of the United Kingdom [16].

5. Examples of the application of low cost engineering measures in Portugal

5.1 EN6

Specific studies were carried out in Portugal to evaluate the efficiency of engineering safety measures, since the practice in other countries may not fit to the Portuguese traffic system.

One of these studies has included an analysis on the efficiency of several measures undertaken on a Portuguese road (EN 6): the application of a narrow median, a new pavement layer, changes on speed limits and new speed-actuated traffic signals (Fig. 1) [6].

Figure 1 – Speed control with traffic signs (EN 6).

This analysis took into consideration traffic volumes, accidents and space mean-speeds, for both periods (before and after the intervention).

For control zone purposes, part of another road, the EN125 (Faro), was chosen, since it presents similar characteristics to EN6, before the intervention. The consideration of this control site allowed for the historic quantification of accidents development (EN 6 and EN 125).

In what concerns traffic volumes, reference must be made to the fact that both roads were affected by the construction in their vicinities of new roads with a higher hierarchy, inducing traffic redistribution. In the case of EN 6, high speed drivers were diverted to a new motorway, both in interventioned and non-interventioned stretches.

In the statistical study of accident data, some steps were taken, in order to avoid bias, namely:

- Regression to mean was resolved through the use of Abbess estimator for accidents expected number, which mitigates the bias effect [17]:

$$\hat{m} = \frac{\bar{x}^2}{s^2} + \left(\frac{s^2 - \bar{x}}{s^2}\right)x$$

$\bar{x}$ - average value of observed accident frequencies on similar entities to the one in study
s^2 - respective variance.

- Migratory effects associated with accident occurrence were not considered, since the road used for comparison is not linked with the road where the engineering measures were applied.
- Time trends associated with accident occurrence were considered in control zone choice, in order to achieve the correct resemblance between roads.
- The traffic volume changes included in the statistical study were taken into account for accident prediction. Previous studies showed that accident frequencies do not change linearly with average daily traffic changes: they are related to a power of 1.102 (Accidents α $ADT^{1.102}$).

Driver’s behaviour analysis was made by comparison of selected speed distribution parameters, namely the average and the standard deviation comparisons. A 19 km/h average speed reduction was observed for the corrected section and a 5.6 km/h average speed reduction for the non interventioned section.

The results of this study in terms of percentage of accident reduction are presented in Table 2.

Table 2 – Accident reduction on EN6 and on EN125.

	Injury accidents	Serious or fatal accidents	Head-on collisions
EN6			
km 3,2 to 6,9 (intervention zone)	-62%	-82%	-94%
km 6,9 to 18,5	-56%	-57%	-51%
EN125 – Control group			
km 97,0 to 103,4 and 107,4 to 113,9	-7%	-21%	-9%

The results were positive, especially for head on collisions, since a 94% accident reduction (Before:18, After:1) was achieved, against a 51% accident reduction (Before:25, After:15) on the central road section.

5.2 IP5

With the same objective as the previously mentioned study, LNEC developed a study regarding LCEM application in another road (IP5), a single carriageway trunk road, with two lanes, that links the Portuguese costal zone with Spain [18]. This application was subsequently complemented with severe law enforcement actions aiming at driver behaviour improvements.

The selection of engineering measures was based on the predominant accident types (head-on collisions and run-of-the road) and their probable causes (speeding and inadequate overtaking). The following engineering measures were applied: improvement of surface water drainage through the enlargement of water passages and the increase of their number; visibility improvement by vegetation cut; speed limit change from 100km/h to 90 km/h; edge rumble strips construction; suppression of overtaking zones in the most dangerous sites; re-positioning of reflecting road studs at the road axis and at the new no-passing zones; curves signalization through a specific criteria, similar to the one proposed in the SAFESTAR Project (WP6) [19]; application of a slurry-seal wearing course at all curves with a radius equal or less than 300m; installation of signs for mandatory use of daylight running lights; application of delineators at the centre line, spaced according to the curve radius; reinforcement of deceleration lane markings with adequate broken line bifurcation arrows; installation of sign panels in descending lanes of zones with an additional climbing lane, with “no-passing zone for trucks only” imposing a 50 m minimum distance between heavy trucks.

Figure 2 - Application of delineators at the centre line (IP 5).

These measures resulted in lower speeds under night conditions, on difficult road curves, but had no such effect at daylight hours. Reductions in average speeds associated with LCEM application ranged between -11 km/h and -5km/h. Higher speed reductions were achieved with the enforcement campaign, namely an average speed reduction of 17km/h (from 107 km/h), and 20km/h speed reduction in terms of percentile 85 (from 130 km/h). General driver behaviour became more homogeneous; the average distance to the right edge line was reduced on curves and on acceleration and deceleration lanes; specific measures related with truck had no quantifiable effect.

In what concerns to accident analysis, the results revealed a risk reduction of 18%, for a before-after period of one year. The number of fatalities reduced was 46%. This accident number analysis is still not yet completed due to unexpected difficulties in gathering traffic data on other IP roads, used as a comparison group.

6. Conclusion

Systematic application, with technical justification, of LCEM allows a fast and significant casualty improvement. Several LCEM mentioned in this paper are currently being applied in Portugal, although not always exclusively for safety reasons and not on a regular basis.

In this context, the practice of systematic application of uniform LCEM is particularly important for Portugal, especially in what concerns to the promotion of the systematic evaluation of the application results. A positive contribution for this goal has been achieved through some of the mentioned studies.

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