Road safety strategies:
An analysis with system dynamics

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Abstract

This paper constructs a system dynamics model in order to analyze the evolution over time of the number of traffic accidents in a generic region in which different scenarios are considered. Mainly, a set of three instruments is used to fight against them: information campaigns, traffic legislation and a monitoring system. The structure of the model is assembled by considering two aspects. First, the influence of the instruments on the causes of the traffic accidents and then, the structure takes into account how authorities adapt the intensity of the instruments in according to certain target. The simulation model integrates several non-linear relationships and delayed links in addition to two random elements. A Monte-Carlo simulation is employed to obtain significant paths of traffic accidents under different scenarios and public strategies. The simulation results exhibit how the instruments work in every scenario and its global efficiency. The best solution is not always the same. Sometimes, the lower number of traffic accidents requires that the instruments are used continuously, but on occasions, it is obtained when the instruments are used intensively. Then, under a tight budget, the implementation of a public road safety strategy requires a special analysis of costs and efficiency.

Keywords: Traffic Accidents, Road Safety, Public Policies, Dynamic and Stochastic Simulation

INTRODUCTION

As vehicular traffic started to grow, governments were forced to enact rules in order to regulate traffic. Nowadays, the problem is not regulation, but safety because of the high number of fatalities that have made vehicle collision one of the leading public health problems worldwide. The aim of the modern traffic laws is to affect those drivers' behaviors that the evidence points out as hazardous. In this regard, many countries regulate and enforce specific actions such as driving without exceeding a certain level of alcohol in blood, without exceeding a limit of speed or the use of the helmets, seat-belts and child restraint systems.

There is a certain consensus, not exempt from controversy, about how to reduce the prevalence of accidents when the infrastructures are maintained in excellent conditions. This solution entails an efficient combination of three elements over time: legislative changes, road safety information campaigns and the use of a traffic surveillance system. According to Global Status Report on Road Safety (2009, pp. 47), these instruments are a successful combination in many countries to fight against the traffic accidents. That report contains individual profiles for 178 countries including the evolution of deaths per 100.000 inhabitants from 1986 to 2007. These profiles show a perceptible reduction of fatalities when countries have a national road safety strategy with measurable targets and certain degree of enforcement. However, other countries without a specific road safety strategy or with a low level of enforcement obtain worst outcomes. Obviously, certain exceptions can be found. For example, the Russian Federation has proper strategies and poor results whereas Qatar would be an example of the opposite situation: no national safety road strategy and excellent results.

The fight against the accidents requires that these three instruments are combined in an efficient way over time. The combination is essential for taking advantage of a mutual support. The instruments have certain limitations when are considered one by one. The legislative changes aimed to update the traffic laws, have a weak effect on drivers by themselves, for obvious reasons. The surveillance system aspiring to road users obey the law, requires a legislative support if it wants to be a deterrent tool. The public information campaigns are usually costly regardless of its purpose. Moreover, they must be used in a proper proportion: too explicit or too long about a specific issue could generate contrary effects than expected. Therefore, if the success of these set of instruments depends on their efficient combination, how should they be scheduled over time? An option would be to use the combination framed in a reactive strategy and another one, would be to consider a proactive scheme. Whereas the former does not use the instruments unless specific situations arise, the last one employs them continuously.

This paper examines the influence of three public road safety policies on the number of traffic accidents. One of the policies is a proactive strategy and the others ones are reactive strategies. Whereas the slogan of one of the reactive strategies is to operate strong and quick, the performance of the other one requires the moderation. The study is tackled with a system dynamics approach since a causal structure can explain the influence of the instruments on the causes of accidents. Additionally, different feedback loops can be established by linking the causes of the accidents to the traffic authorities' strategies, which determine the intensity of use of each instrument.

System dynamics methodology has been employed in many occasions to analyze the transport field. An example is the special issue that System Dynamic Review dedicated to transportation in 2010. However, to our knowledge, the literature has not studied the aspects tied to road safety strategies in a specific way. Nevertheless, there are some relevant studies related to the topic in the last years. Sterman (2000, pp. 178) constructs a model that explain why road-building programs do not alleviate traffic congestion. Minami et al. (2009) develop a system dynamic model for evaluating the lessons learnt from accidents that would lead to a reduction in U.S. Army combat vehicle accidents; Mehmood (2010) constructs a system dynamics model to simulate the driver's behavior in relation to law enforcement, traffic monitoring, and education in the Emirate of Abhu Davi. Finally, it is important to emphasize the paper of Friedman in 2006 that uses a model to evaluate the effect of road conditions on accident development.

The rest of the paper is structured as follows. First, it examines the main elements taking part in the basic causal structure. Then, it is formulated a simulation model being analyzed its validation and results under different options. The last section contains some final conclusions and remarks.

STRUCTURE OF THE MODEL

Nested feedback loops of negative polarity make up the basic structure of the model as Figure 1 shows. The causal structure accepts that road crashes are the result of any of the many varieties of failure affecting the informational and mechanical interactions that link driver, the vehicle and the environment. Nevertheless, the diagram assumes that the traffic accidents are caused by two exclusive facts: traffic violations and the traffic incidents. A traffic accident is caused by a traffic violation when at least a traffic law has been infringed in any aspect. On the other hand, no law has been broken when in a traffic accident is involved a traffic incident. In any case, both types of accidents have the same hazard of causing serious human and material damages. Some examples about the first determinant would be: dangerous driving such as driving too close, excessive speed on rural and urban zones , excess load, driving in the opposite lane, etc. Examples for traffic incidents could be: the driver suffers a sudden illness, driving under an unexpectedly inclement weather, driving in unexpected conditions due to a natural disaster, and so on.

Due to the fact that the causes of accidents selected affects mainly drivers, the road safety measures to affect them are specialized on that type of road user: public campaigns of information and awareness, systems of control and monitoring and updating traffic laws. Additionally, the different character of the two causes determining the traffic accidents decides that the number of these instruments affecting them is also different.

The traffic incidents are only influenced by recommendations that are spread by the information campaigns. However, traffic violations are affected by the three road safety instruments. This assumption is based on both empirical and theoretical studies. For instance, the Dirección General de Tráfico (DGT, 2010), which is the Spanish traffic national authority, points out that road users obey traffic rules depending on two elements: the risk perception of the driver and the expected consequences of breaking the traffic rules. The first element takes into account three aspects: the personal characteristics of a driver, their attitudes with regard to the risks as well as their knowledge about the risks associated to the different behaviors. This factor would explain why the youngest drivers are more prone to commit traffic violations (Renner et al. (2000)) or why females are involved in less traffic accidents. The DGT recommends carrying out information campaigns to affect positively this element. That recommendation is also given by Chen (2009) who, in addition, specifies that road safety interventions, driver education and training programs are influential elements on drivers. The second element that influences on the driver behavior is related to the perception that they have about the consequences of disobeying the traffic rules. If a driver notices that their conduct is controlled and, consequently, could be severely penalized, in general, drivers prefer to comply with the traffic rules. Though, of course, there are people that obey rules regardless of control and also, there are people very unruly. Therefore, this second element depends on both the monitoring capacity and the traffic legislation, which determines the economic, administrative and penal consequences of the traffic violations.

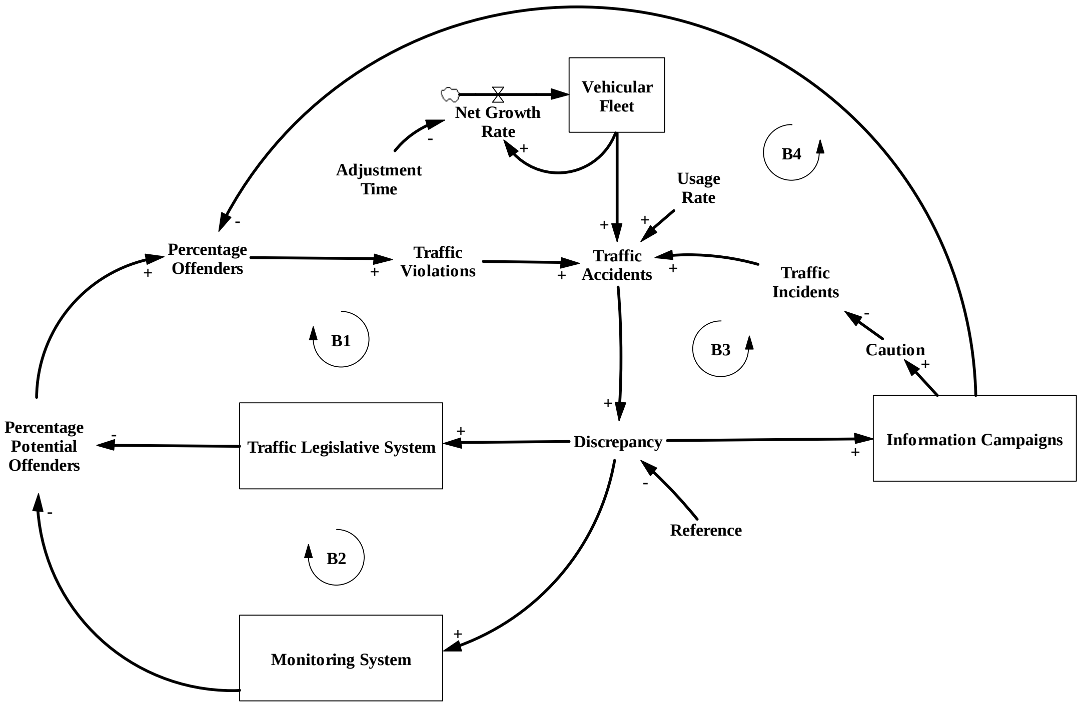

Figure 1: Nested feedback loops

The influence of the instruments on the different causes of accidents is reflected in the causal diagram. This distinguishes a loop connecting the information campaigns with the drivers' caution, which impacts positively on the occurrences without violations. The connections of all instruments with traffic violations are modeled in two steps. First, the drivers´ response to the legislative system and the monitoring systems is considered. Then, the reaction of those potential offenders to the information campaigns is harmonized. The outcome is a drivers' percentage that feel inclined to disobey the law, which is a necessary condition to have an accident in this line, though it might not be sufficient.

The diagram also relates the traffic accidents to the public road safety strategies, which determine the intensity of use of the instruments. This process is articulated by assuming that the traffic authority sets a target of traffic accidents exogenously. Then, the intensity of the instruments is adjusted to the current traffic accidents-target ratio. In general, the intensity increases as the ratio rises. However, the intensity also depends on the public strategy implemented and a same value of the ratio could produce different responses of the instruments.

These relations close the nested loops though the causal structure also includes the vehicular fleet and its usage rate which both influences positively on the traffic accidents.

SIMULATION MODEL

The model select as time unit the week and then, it sets parameters, initial conditions of the levels and formulates variables. The simulation horizon is a year, which is a period long enough to check the capacity of the public strategies against the traffic accidents.
The *vehicular fleet* is assumed constant during the simulation. The *usage rate* is also considered constant except during Christmas holidays, summer months and Easter where its value increases[1]. Traffic accidents are determined by using the index of use on the vehicular fleet and then, the percentages of incidents and violations.

The percentage of traffic violations is higher than the percentage associated to the other causes. This fact is evidenced by different studies. Ayuso et al. (2010) find that 89.9 per cent of traffic accidents in Spain involve at least a traffic violation. A directive of the EU (SEC (2008) 350) confirms that 75 per cent of all road deaths in the EU are caused by at least one between four offences: speeding, drink-driving, non-use of seat belts and falling to stop at a red traffic light. This pattern is similar in all over the world. For example in the US (2008) according to the National Highway Traffic Safety Administration (NHTSA), there were three distinguished causes: distractions, alcohol and speed. The distractions are many times related to use of mobile phones; 32 per cent of total traffic fatalities involved a driver with a blood alcohol concentration equal or higher to that allowed and speeding is a contributing factor in 31 per cent of all fatal crashes.

The percentage of potential offenders is defined by using an inverted S-shape. That kind of graph was used by De Waard et al., in the seminal paper of 1994, to specify the variation of speed in relation to the surveillance intensity. The S-shape is adapted to this model to describe the percentage of potential offenders as a function of the surveillance intensity, given a constant legislative level. If the legislative level varies, the model continues adopting the inverted S-shape though the graph is pushed up or down. The underlying assumption is to consider that as the legislative level increases, the same increases of surveillance will produce better results.

In the model, the percentage of offenders is the percentage of potential offenders but corrected slightly. The correction indicates the information absorbed by the drivers and supplied by the information campaigns. On the other hand, this model considers two random numbers to introduce certain degree of uncertainty affecting the two causes of the accidents. These numbers try to represent the luck in a dangerous situation, which undoubtedly is present in the circumstances around any traffic accident.

[1]Though the traffic density can vary depending on the season of year, the day of the week, the hour of the day and so on, the results of this model do not alter significantly when more variation for these variables are considered.

Modelling the instruments

The legal system is modelled by using a third order material delay. That selection assumes that the legislative process is as slow as it occurs in the real world. The three levels connected by the material delay indicate the drafts that are transformed in laws in process that, in turn, some of them are transformed in laws in force. This last level is also affected by a flux that eliminates the out-of-date laws. The dynamic of the legislative process is propelled when the traffic accidents exceeds a threshold in accordance with the current strategy implemented. On the other hand, this subsystem connects with the general structure since the level of laws in force takes part in the definition of the potential offenders directly.

The dynamic of both the information campaigns and the surveillance system, is governed by a negative loop around a discrepancy. That variable is defined by a difference between a desired value, which is specified by the public strategy implemented, and the current value attained by the instrument. In this way, each instrument is adjusted gradually until the discrepancy tends to zero. In addition to that process, the impact of the information campaigns on the drivers also considers a learning process. The reason is to account that this instrument impacts on drivers in two different ways. First, there is an immediate effect that is usually forgotten in a short period of time. The learning process starts and drivers will retain their information for more time, if the information campaigns continue over time about the same issue. The information learnt is the link that connects this instrument with the causes of the traffic accidents.

Road safety strategies

The model implements three strategies for fighting against the traffic accidents. One of them is a proactive strategy. The instruments in this strategy are always working even if the number of accidents is null. The intensity of the instruments increases as the number of traffic accidents rises. The others two strategies are reactive. They might not work during certain intervals of time. Unless the number of accidents-target ratio attains a certain threshold, the instruments are not activated. There are two important differences between the two reactive strategies. In addition to different thresholds to initiate, the instruments are used with different intensity levels. A strategy is called strong reactive strategy as it reacts quicker and stronger than the other one, which is called weak reactive strategy.

Validation

The simulation model was undergone to different possibilities for values of parameters and initial conditions of levels what provided a deep knowledge of its responses and sensitivities. Several validations were carried out: the structure assessment test, the dimensional consistency test, the extreme conditions and sensitivity (see Barlas (1996), Sterman). In particular, the analysis of extreme situations was thorough. Situations such as a null level of laws in force, a null level of learning and very high or very low references were observed. In all cases, the model continues responding properly and, as a result, it was considered appropriated to implement the policies to study.

A Monte-Carlo procedure

The simulation model contains two random numbers that were considered in order to quantify the percentages associated to the causes of accidents. Then, each selection of these numbers could influence on the simulation results that they will not be generalist but particular. A Monte-Carlo simulation was carried out to overcome the problem. The aim is to obtain more accurate paths of traffic accidents. Fifty iterations for each variable, in the different scenarios, found paths of traffic accidents to 5 percent of significance level.

Scenarios

For each one of the public policies (proactive and reactive) two different targets about the number of accidents are selected: low and medium. Moreover, for each one of the targets, three different scenarios are considered. Every scenario combines three possible characteristics of the region where the strategies are implemented. The combinations are about the initial value of legislative system (low, medium and high), the traffic density (high and medium) and the quality of infrastructures (excellent and medium).

Results

Observing the paths of the number of traffic accidents some conclusion are easy to draw. For instance, when the paths of traffic accidents for two scenarios with the same characteristics apart from the targets are compared, the path with lower target provides lower number of accidents. In contrast, that accomplishment requires an intensive use of the instruments over time. Likewise, the observation of the paths determine that if the traffic density increase, the number of traffic accidents also increases regardless of the public strategy implemented.

If the target of accidents is to attain a medium value, regardless of the scenario, the paths show a clear singularity: the preventive strategy always produces the weekly lower number of accidents and the weak reactive strategy determines the weekly higher number. The number of accidents of these strategies exhibits a clear gap during the whole simulation. Without modifying the target, the number of accidents of the strong reactive strategy depends on the traffic density. If the density is medium, the weekly number of accidents of the strong reactive strategy is close to the preventive one. During certain periods of time even both strategies overlapped. Though, when the traffic density is high, then the strong reactive strategy is close to the weak reactive one. However, only during short periods of time, both strategies might overlap. Figure 2 and Figure 3 show these peculiarities for two specific scenarios.

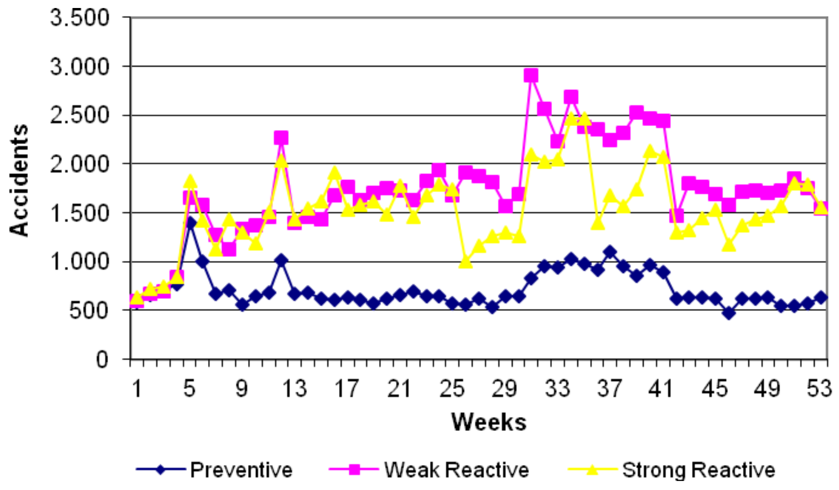

Figure 2: Medium target, high density, excellent infrastructures and high legislative level

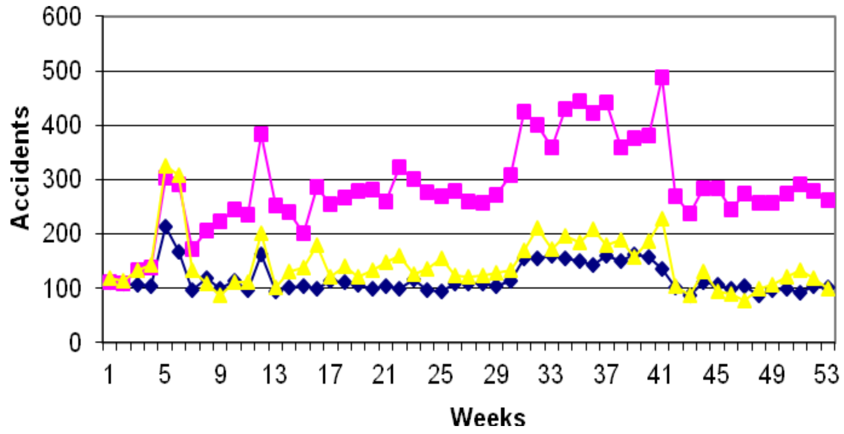

Figure 3: Medium target, medium density, excellent infrastructures and high legislative level

If the target of accidents set by the public strategy is low, the three paths show a number of accidents closer to each other regardless of the scenario analysed. Nevertheless, in all the scenarios, the strong reactive strategy produces lower number of accidents at least during certain periods of time. Now, the proactive strategy produces worst results than the weak reactive strategy. Figure 4 and Figure 5 show the weekly number of accidents under the new target and the same characteristics as Figure 2 and Figure 3, respectively.

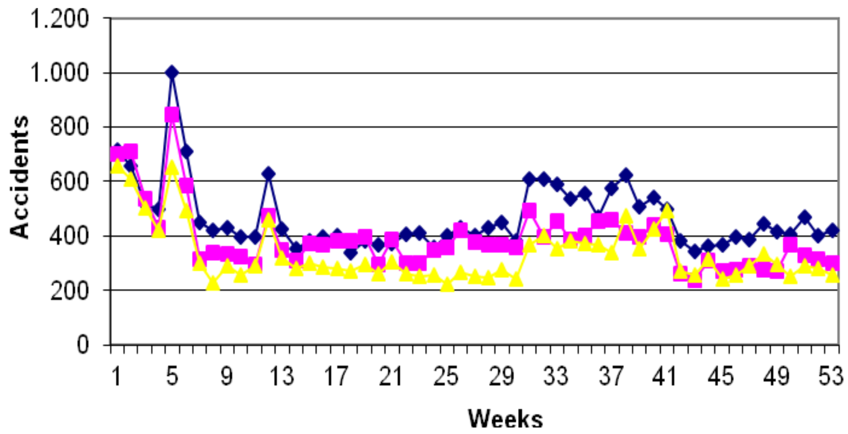

Figure 4: Low target, high density, excellent infrastructures and high legislative level

The cost of the strategies

Governments agree that the fight against the traffic accidents is essential to avoid both severe injuries and fatalities. It is undoubtedly that the cost associated to the traffic accidents is high not only from a human view but also from a material view. However, the strategies to fight against them are not cheap and, in many occasions, they have to be adapted to the traffic budget, which might be very tight. Consequently, it seems important to determine the public strategy to be implemented in each situation by taking into account the target to be achieved as well as the available budget. Table 1 collects four parameters associated to the scenarios considered above. The parameters are obtained by the simulations. Observe that knowing the cost of the instruments, the parameters associated to the instruments, which are included in Table, could determine the cost of each strategy.

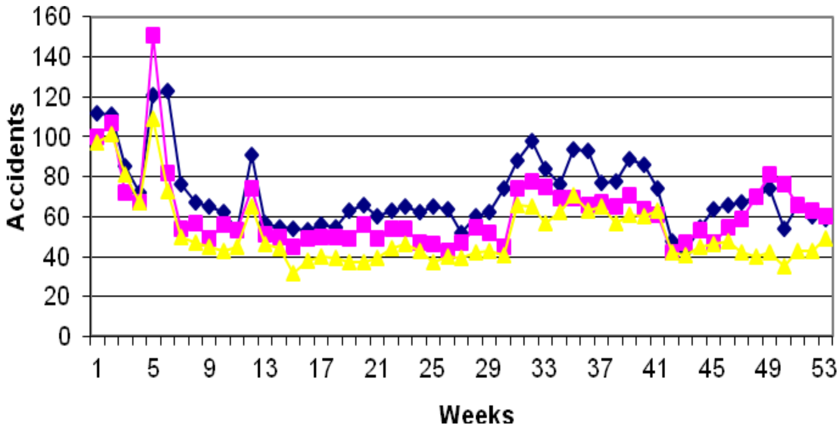

Figure 5: Low target, medium density, excellent infrastructures and high legislative level

Table 1 confirms the conclusions already established above. However, it is not easy to draw more general implications from it. The diversity of the results makes difficult the comparisons between the intensities used by the strategies for each one of the instruments. Nevertheless, it is possible observe that for each strategy, the lower number of accidents requires that the instruments are used highly intensity being the exception the laws in effect for the weak reactive strategy.

Table 1: Results of the scenarios

Strategies	**Preventive**	**Weak Reactive**	**Strong Reactive**
Instruments	Medium target ↑ Low target ↑ ***Scenarios***: (Figure 2 / Figure 4) → High density (Figure 3 / Figure 5) → Medium density		
Weekly Average Information Campaigns[2]	(2 / 4.23) (2 / 4.23)	(0.04 / 5.47) (0.04 / 5.62)	(2.19 / 5.92) (2.02 / 5.92)
Weekly Average Monitoring[3]	(1.08 / 2.79) (1.08 / 2.83)	(0.14 / 1.32) (0.14 / 1.66)	(1.09 / 8.71) (1.11 / 9.59)
Weekly Average Laws in Effect[4]	(0.77 / 0.77) (0.77 / 0.78)	(0.77 / 0.76) (0.77 / 0.76)	(0.77 / 0.85) (0.77 / 0.86)
Weekly Average Accidents	(727.25/439.13) (123.92 / 74.89)	(1703.94/382.02) (282.79 / 61.83)	(1529.3/ 328.66) (143.79 / 51.62)

[2] The index varies from 0 to 6.
[3] The index varies from 0 to 10
[4] The index varies from 1 to 0.

CONCLUSIONS

It is clear that traffic accidents are a serious problem nowadays. Governments usually put into practice road safety measures to fight against them. However, the outcomes of the implantation of these public policies are uncertain and, additionally, they are usually costly. This paper tackles this matter by constructing a model in which is possible to test different road safety strategies. In particular, the paper tests three strategies combining three instruments, which are considered essential by different researches. Each strategy is characterized by a different intensity of use of the instruments. The results of the simulation show that the strategy that produces lower number of accidents is not always the same. Sometimes it is better use a reactive strategy, but on occasions, it is better to use a preventive one.

On the other hand, the adoption of the strategies, either reactive or preventive, has a different cost because the use of the resources and their availability is different. Therefore, when the implantation of road safety measures is restricted to a budget, it seems important to determine the cost associated to each strategy. Once again, the diversity appears as an essential element in the results of simulation. The comparisons between strategies are not simple. In all cases, there is not proportionality between the use of the instruments and the results.

These findings assure that the implementation of public road safety strategies require a particular study. A same strategy seems that is not a universal solution not only from a budgetary view but also from a road safety view.

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