

STUDY ON THE IMPACT OF HEAVY TRANSPORT VEHICLES' BRAKING SYSTEM ON ROAD SAFETY IN COSTA RICA



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Summary

Accidents that involve heavy vehicles might show a high mortality rate, this is why it is important to study ways of reducing them.

An analysis was carried out in this research as of the regulations concerning the braking systems of heavy vehicles in Costa Rica, so as to identify opportunities of improvement in relation to road safety. The analysis showed several regulatory weaknesses, among which we find: lack of regulatory controls of vehicles importation, the friction coefficient associated to maximum braking distance is not specified, the use technologies that guarantee a stable braking is not compulsory, the measuring procedure of braking efficacy in vehicle inspection shows some deficiencies and no controls have been established on maintenance practices of vehicles fleets.

Keywords: Heavy transport vehicles, Braking System, Regulations, Mortality Rate.

1. INTRODUCTION

Accidents that involve heavy vehicles may show high mortality rates. As a matter of fact, in some cantons in Costa Rica, mortality rate associated to three axle semitrailers was of 0.08 to 0.16, sometimes surpassing the mortality rate of passenger vehicles. An action that might help reduce the mortality rate of accidents involving heavy vehicles is improving the regulations associated to the braking systems, so as to ensure the suitable working of braking systems and the application of adequate maintenance practices. This is so, considering that heavy vehicles braking maneuver show some special features such as: braking distance of heavy vehicles can be longer than light vehicles, articulated vehicles might present stability problems such as skidding and jack-knifing and their braking systems may require dissipating higher amounts of energy, among others.

This study was therefore carried out to assess the braking requirements of heavy vehicles in Costa Rica. The specific goals are: determining what type of braking systems are commonly used in heavy vehicles of some fleets in the country, analyzing the braking requirements of heavy vehicles according to Costa Rican regulations, comparing the braking requirements for heavy vehicles in other jurisdictions and estimating the fatality rate associated to the different types of heavy vehicles in national road of the high risk cantons: Osa, Pérez Zeledón, Puntarenas, and San Carlos.

2. BRAKING ASPECTS OF HEAVY VEHICLES

The behavior of heavy vehicles during braking can be very different to that of light vehicles, considering that the former can have longer braking distances, the braking distance might be significantly affected by weight variations and articulated vehicles might present stability problems such as skidding and jack-knifing.

The braking distance largely depends on the type of technology used for braking systems. The braking systems of heavy vehicles can be hydraulic, pneumatic or a combination of both. Hydraulic brakes can be found in heavy vehicles of light and medium duty, while medium and heavy duty vehicles usually use air brakes. Conventional air braking systems are characterized by the fact that their reaction time may increase the braking distance, considering that during the braking process the air chambers must achieve a certain pressure value so that brakes are effective and allow the activation of the mechanism that carries out the braking action, this reaction time, according to international rules, is of around 0.45 s and 0.6 s depending on the vehicle weight and its configuration. Besides, according to Fitch (1994) in the air brake systems the effective pressure is not reached simultaneously in all axles: the farthest the axle from the air storage tank, the longer it will take to fill the chamber with air, which leads to an unsynchronized activation of brakes, thus affecting the compatibility among the braking systems of the components of an articulated vehicle; this is why for several international laws the permitted pressure threshold is located between 1 psi and 2 psi or 0.5% depending on the configuration of the vehicle.

The freight status of vehicles affects the braking distance and paradoxically, when heavy vehicles are not loaded they might show longer braking distances. This is so because their braking systems are selected for full load, therefore, the retardant force (R) applied to brakes can be higher than the necessary to stop the vehicle (Fancher and Mathew 1987). From another point of view, as shown in equation 1, the use of friction (μ) in each axle depends on the weight it supports, therefore, the less the weight (W) the higher the use of friction. To avoid wheels' lock up, the use of friction must be less than the friction available between the pavement and the tire rubber (Sayers,1999), thus, by applying an excessive braking force, wheel lock up might occur and the consequent sliding of tires (p. 39) which is undesirable considering that it might cause loss of stability and an increase of braking distances. In fact, Hady and Cebon (1995) showed that the braking distance of heavy vehicles with ABS brakes may result longer when vehicles are unloaded considering that more opening and closing cycles of the brake shoe occur to avoid the lock up (p.3)

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Controlling the braking stability is important because it allows stopping vehicles in a controlled manner. When braking is carried out unstably, there is a risk that the braking distance might increase, or that the vehicle might overturn and/or leave the road among other inconveniences. As for articulated vehicles, this can show a higher risk considering that semitrailer's skidding and jackknifing may occur. These phenomena may occur due to an unbalancing of the braking system torque, the lock up of some wheels, the trajectory (curve or straight) of the vehicle at braking time or the load condition among other factors.

To avoid unbalancing problems of the air braking systems and to avoid excessive braking distances, it is important to use suitable maintenance techniques. When brakes are unbalanced, the braking efforts lie on the braking system on one side of the vehicle, this increasing the warming and wear and may cause skidding and jackknifing. Some maintenance deficiencies, such as leaks in the air lines could increase the response time of brakes, increasing the braking distance.

There are some technologies that help improve the braking stability, reduce braking distances and avoid problems associated to maintenance. Among these technologies, we highlight the electronic systems of stability (ESC), the automatic slack adjusters, double wedge brakes, the air disc brakes, load sense valves (LSV), anti-lock brakes (ABS) and electronic brakes (EBS).

It has been demonstrated that some of these technologies of the braking systems have had a positive impact on road safety of some countries. First of all, Garrot and Dunn (2007) determine that certain combinations of technologies might reduce up to 30%

¹ In this context the components of an articulated vehicle are the different vehicles that make it up. For example: a truck with a semitrailer T3S2, the truck (T3) is a component, and the semitrailer (S2) is the other component.

the braking distance of some heavy vehicles, so according to Bendix (2011) in the USA the FMVSS 121 was modified so as to make the reduction of braking distance of some semitrailers an obligation. Secondly, Allen (2010) determine that in seven US states ABS brakes contributed to reducing 6% of the total accidents involving heavy vehicles. Thirdly, according to Billing (2002), some years after the automatic slack adjusters were made compulsory in Canada, during road inspections, the amount of vehicles that were held out of circulation was reduced to 50%. Fourthly, DOT (2012) indicated that the ESC can help reduce between 28% and 36% of overturns and 14% of accidents associated to loss of vehicle control.

3. REGULATIONS ON BRAKING SYSTEMS OF HEAVY VEHICLES IN COSTA RICA AND OTHER JURISDICTIONS

3.1 Regulations in the US, Canada, Europe and Australia

Regulations concerning braking systems in heavy vehicles may vary throughout the world. It is important to know which are the variations and relate them with the maximum weight allowed in each jurisdiction to avoid performance problems in the braking systems and compatibility problems between the braking systems of vehicles combinations. Anyhow, Table 1 shows a summary of the aspects considered in the regulations of the different jurisdictions.

Table 1. Aspects Considered in the Regulations of the Braking Systems of Heavy Vehicles in Different Jurisdictions

Technology	USA*	Canada [‡]	Europe [°]	Australia [¢]
ABS	Yes	Yes	Yes	Yes
LSV	No	No	No	No
ESC	No	No	Yes	No
EBS	No	No	No but ...	No
Air disc brakes	No but...	No	No	No
Automatic slack adjusters	Yes	Yes	Yes	Yes

*Information obtained from the FMVSS 105 (2011) and FMVSS 121 (2011). [‡]Information obtained from de CMVSS 105 (2005) and the CMVSS 121 (2010). [°]Information obtained from the UNECE Vehicle Regulation N° 13 (2008). [¢]Information obtained from the ADR 35/03 (2009) and the ADR 38/03 (2007).

It is important to highlight that none of the jurisdictions obliges the use of LSV considering that it is unnecessary due to the use of the ABS brakes. Besides, none of the demands the use of EBS; nevertheless, European regulations are designed to make it easy to comply with them if heavy vehicles have EBS brakes. Similarly, it is not compulsory in any of the jurisdictions the use of air disc brakes, but American regulations are designed to make them easy to comply with when vehicle equipped with air brakes use air disc brakes.

Another important aspect is that some jurisdictions do not demand homogeneous braking distances. This is the case for the US, considering that the FMVSS 121 the braking distance demanded may vary according to the vehicle's configuration and the maximum authorized weight; as for example, starting at 80 km/h and with a surface of 0.9 friction coefficient, the braking distance demanded for 3 axles trucks is of 54 m o 66 m depending on the maxium authorized weight.

Other controls used in some of these jurisdictions and that contribute to improving road safety are road inspections and vehicle inspection, as they have the possibility of banning vehicles with dangerous defects to circulate and promote suitable maintenance techniques.

3.2 Positive aspects of regulations in Costa Rica

In Costa Rica there are five regulations associated to the braking systems of heavy vehicles. They are: Law N° 9078 or Public roads transit and road safety Law, Decree N° 31363-MOPT or the regulation for circulation on roads based on the weight and dimension of heavy vehicles, the technical regulation for carrying out conversion studies and/or modifications of heavy vehicles, Decree N° 17266-MOPT or the regulation of safety devices in vehicles and manual procedures for technical revision of vehicles in Vehicle Inspection stations. The combination of all these regulations shows some positive aspects for road safety, as indicated below:

- 1- For vehicles to obtain the circulation permit (marchamo), they must comply with some minimum maintenance standards which are determined under the scrutiny of periodic vehicles inspection. Besides, heavy vehicles must own permits of weight and dimension for circulation.
- 2- Heavy vehicles must have a braking system that is able to stop the vehicle safely, rapidly and effectively. Besides, service brakes must act upon all the wheels and its action must be symmetric in relation to the longitudinal axle and it requires that all trailers and semitrailers with a maximum weight of 750 kg or more must have their own braking system.

4. METHODOLOGY

The study of the car accidents involving heavy vehicles was based on for risk cantons: Osa, San Carlos, Pérez Zeledón and Puntarenas. The data base of car accidents allowed the identification of the geographical location, the types of accidents, their harshness and the vehicles involved in the accidents. Nevertheless, this did not allow neither the identification of the role of vehicles (if it hit or was hit) nor the mechanical characteristics that influenced on the accident. Besides, the data base did not provide information about the configuration of heavy vehicles involved in the accident.

To complete the information about the configurations, the license plates registered in official reports were used as well as the data base of the Weight and Dimension Department of the National Council of Transportation which gave us the possibility of knowing the 77% of the types of heavy vehicles involved in car accidents, without being aware of the amount and type of trailers and semitrailers of articulated vehicles.

The TPD estimates carried out by the Department of Sectorial Planning of the Ministry of Public Works and Transport were used to determine the exposition of vehicles in relation to national roads in the risk cantons and afterwards field visits took place to classify the vehicles in each area.

As a result, the mortality rate (T) for diverse types of vehicles was estimated, using the equation, where VKT are millions of kilometers traveled by vehicles and f the frequency of lethal accidents.

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$$(2)^2$$

5. RESULTS

Heavy vehicles had a low implication in car accidents with casualties² (8%-11%), while the percentages of fatalities (number of people deceased) was approximately double (16%-24%) as shown in figure 1.

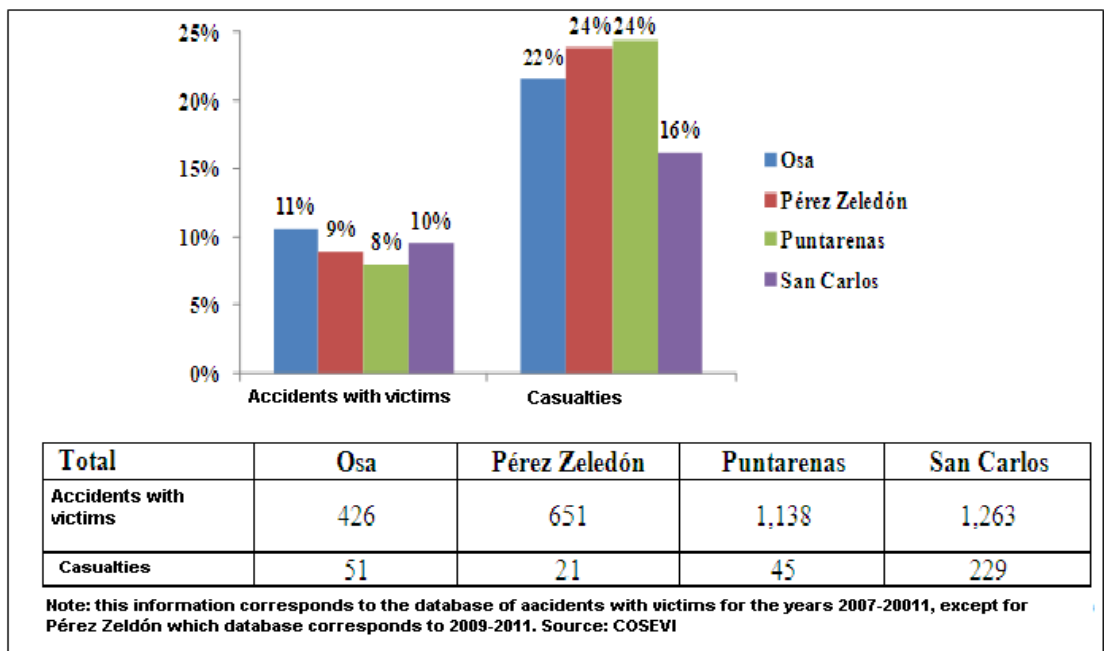


Figura 1. Participation of heavy vehicles in car accidents and percentage of casualties.

The percentage of heavy vehicles traveling around the cantons in consideration is lower in relation to other vehicles. (Figure 2). Nevertheless, in most of the cases, the

² Accidents with casualties: accidents where at least one person was either injured or killed.

mortality rates resulted higher than in passenger vehicles which circulate the most in those areas as it is shown in Table 2 where mortality rates of heavy vehicles were underestimated considering that only 77% of those vehicles were categorized.

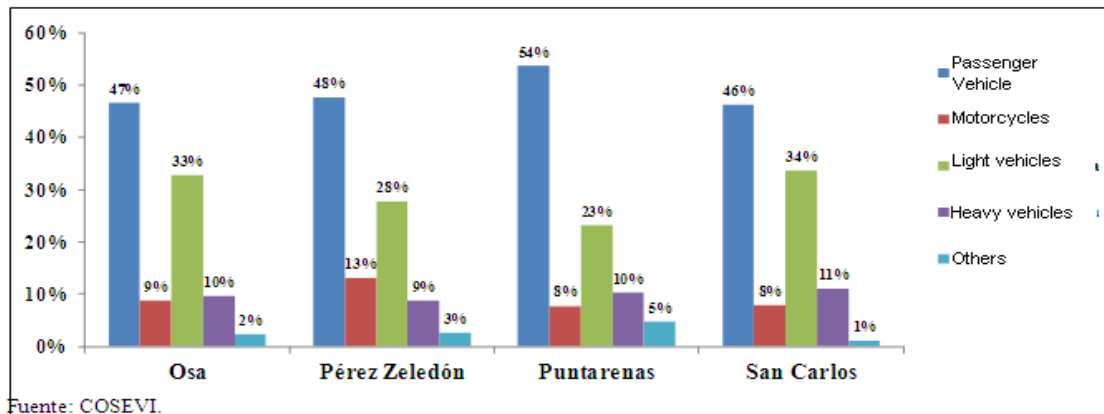


Figure 2. Vehicles that travel through these cantons' roads.

Table 2. Mortality rate for each type of vehicle.

Canton	Passenger Vehicle	Truck C2	Truck C3	Semitrailers T3
Osa	0.05	0	0	0.16
Pérez Zeledón	-	0	0	0.11
Puntarenas	0.03	0.04	0.06	0.08
San Carlos	0.13	0.12	0.06	0.03

Besides, six companies completed the survey carried out to study the heavy vehicles' market in Costa Rica, which showed that the predominant technologies are vehicles with S cam drum brakes (such is the case for air brakes' vehicles), retardants and automatic slack adjusters. What is more, the majority of companies indicated that they might import vehicles with ABS brakes or load-sensing valves. On the contrary, the possibility of importing technologies such as EBS brakes, ESC systems, improved S cam drum brakes and air disc brakes is scarce.

Ten companies were part of the survey focused on the companies that own heavy vehicle fleets. The survey showed that the majority uses S cam drum brakes and retardants, half of them own vehicles equipped with load-sensing valves, less than half uses vehicles with ABS brakes and automatic slack adjuster and very few use EBS brakes and ESC systems.

Moreover, the survey revealed that only two of the people in charge of maintenance had been properly trained in the maintenance of heavy vehicles. Lastly, two companies were determined to carry out a wrong procedure to manually correct the balancing of air brakes, considering that they use a technique that consists of tightening to its maximum the adjustment bolts of air brakes and then loosen them $\frac{1}{4}$ of turn in all wheels.

6. ANALYSIS OF RESULTS AND CONCLUSIONS

Results show that, even though the percentage of participation of heavy vehicles in car accidents with victims is low (8%-11%), they can show high mortality rates. There are many factors that can cause car accidents: then, regulations should be designed aiming at reducing the consequences of car accidents. Nonetheless, Costa Rican regulations have several defects that do not help prevent heavy vehicles to present certain braking problems. Among the deficiencies and opportunities of improvement we find the following:

1. In Costa Rica there are no regulations as for the homologation of imported vehicles, they just have to pass the Vehicles' Inspection. However, the Vehicles' Inspection manual does not indicate if the efficacy of the braking should be measured with loaded or unloaded vehicles. This is important considering that the braking distances stipulated in the technical regulations for carrying out conversion and/or modifications to heavy vehicles were based on the braking distances set by the US before the FMVSS 121 of 2011, and because maximum authorized loads for heavy vehicles in Costa Rica are sometimes higher than maximum weights of exporting countries, as the US and European Union. This means that the braking performance of imported vehicles can be different to what is established by Costa Rican regulations, and this is not reflected in the tests carried out for Vehicles' Inspections.
2. Lack of regulations for trailers and semitrailers. The circulation permit is compulsory only for automotive vehicles, consequently the owners of trailers and semitrailers are not obliged to bring them to the Vehicles' Inspection, consequently only 6% of the registered semitrailers undergo the Vehicles' Inspection and this could mean many semitrailers with defective braking system in circulation. This could bring as a result many accidents due to problems of stability during braking such as skidding and jack-knifing or it could result in an increase in braking distances.
3. Jointly with the previous problem, there is poor control over the circulation of defective vehicles considering that in Costa Rica there are no mechanical inspections in roads that help enforce the Vehicles' Inspection controls.
4. In the technical regulations on the carrying out of conversion and/or modification studies of heavy vehicles, the friction coefficient according to which the vehicles must comply with the braking distances required is not stipulated, this can lead to ambiguities in the selection of the braking systems.
5. In the braking requirements heavy vehicles are not obliged to have systems that can prevent wheels' lock up, such as the ABS brakes and the load sensing valves,

which is important to prevent wheels' lock up in any load condition. There is no obligation for vehicles with S cam drum air brakes to have automatic slack adjusters which help prevent braking problems associated to brakes wear.

On the other hand, sometimes, modifications in the regulatory aspects respond to the possibility of incorporating certain types of technologies. Studies of the features of vehicles sold and of those which make up fleets of some companies show that the use of ABS brakes and automatic slack adjusters can be made compulsory. This could be carried out in two manners: by demanding the incorporation of such technologies only in new imported vehicles or by demanding it in used imported vehicles and in vehicles already circulating in the national territory. The first method is simpler but probably its impact on road safety might not be as significant considering that the percentage of used heavy vehicles is of 45% due to the fact that the amount of used imported vehicles is high and because the national fleet does not renew so often. On the contrary, the second method would produce a bigger impact on road safety taking into account that there would be a higher amount of vehicles with such technologies, but the government should carry out studies to determine if it is possible to properly install ABS brakes and automatic slack adjusters in used vehicles, create installation technique guides and certify authorized garage to install them. It is worth mentioning that the demand for ABS brakes would not have such a huge impact on the Vehicles Inspection unless a failure warning signal is required in such systems so as to make it easier for inspections to be carried out and some defects are incorporated to the vehicles' inspection manual.

Another important aspect is that in the future, there could be stricter braking requirements for three axle trucks, bearing in mind that in most of the cases such vehicles showed the highest rate of mortality (see Table 2), but currently, the technologies allowing this are not available in the country. Besides, so as to reduce the braking distances allowed, some studies on performance and compatibility of braking technologies for maximum load have to be carried out, as maximum authorized weights in Costa Rica are higher than in other jurisdictions such as the US and Europe.

Lastly, it was determined that it can be convenient that the government establishes a training program on maintenance of fleets of heavy vehicles. This is so, due to the fact that some maintenance managers have not been properly trained. What is more, one of the main causes of rejection of vehicles during the Vehicles Inspection is the instability of braking; nevertheless, some companies apply an inadequate technique that consists of tightening to its maximum the adjustment bolts of air brakes and then loosen them $\frac{1}{4}$ of turn. This technique does not either always allow correcting the unbalance, or identifying the brakes that are unbalanced to look for the problem later.