Study on the Impact of Heavy Transport Vehicles Braking System Requirements on Road Safety in Costa Rica

Carlos Güémez Shedden

Research and Statistics Area, COSEVI (Consejo de Seguridad Vial), San Jose 745-1150, Costa Rica

Abstract: Accidents involving heavy vehicles might show high mortality rates, so it is important to study ways of reducing them. In this research, it was carried out an analysis of the regulations concerning heavy vehicle braking systems in Costa Rica. And some opportunities of improving road safety regarding heavy vehicle braking systems were identified. The analysis showed several regulatory weaknesses, among which were found: lack of regulatory controls of vehicles importation, the friction coefficient associated to maximum braking distance is not specified, the use of technologies that guarantee a stable braking is not compulsory, the measuring procedure of braking efficacy in vehicle inspection shows some deficiencies, and little controls have been established on maintenance practices of heavy vehicle fleets.

Key words: 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 counties in Costa Rica, mortality rate associated with three axle semitrailers was of 0.08~0.16, sometimes surpassing the mortality rate of passenger vehicles. An action that might help to 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 paper considers that heavy vehicles braking maneuver shows 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;
- estimating the fatality rate associated to the different types of heavy vehicles in national road of the high risk counties: 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

Corresponding author: Carlos Roberto Güémez Shedden, M.E., research fields: road safety and vehicle safety.

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 vehicles weight and its configuration. Besides, according to Fitch [1], 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 components¹ 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 [2]. From another point of view, 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, as shown in Eq. (1):

$$\mu = R/W \quad (1)$$

To avoid wheels' lock up, the use of friction must be less than the friction available between the pavement

and the tire rubber [3]. Thus, by applying an excessive braking force, wheel lock up might occur and the consequent sliding of tires, which is undesirable considering that it might cause loss of stability and an increase of braking distances. In fact, Hady and Cebon [4] showed that the braking distance of heavy vehicles with ABS (anti-lock brake systems) 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.

Controlling the braking stability is important because it allows stopping vehicles in a controlled manner. When braking is carried out unstably, there is some risk that the braking distance might increase, or that the vehicle might overturn and/or leave the road, among other problems. As for articulated vehicles, this can show a higher risk considering that semitrailer's skidding and jack knifing 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 forces are mainly produced by the brakes of one side of the vehicle, thus 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 to improve the braking stability, reduce braking distances and avoid problems associated to maintenance. Among these technologies, we highlight the ESC (electronic stability systems), the automatic slack adjusters, double wedge brakes, the air disc brakes, LSV (load sense valves), ABS (anti-lock brake systems) and EBS (electronic brakes).

It has been demonstrated that some of these technologies of the braking systems have had a positive

¹In 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.

impact on road safety of some countries. First of all, Garrot and Dunn [5] determined that certain combinations of technologies might reduce up to 30% of the braking distance of some heavy vehicles. So according to Bendix [6], in the USA, the FMVSS 121 [7] was modified to reduce the required stopping distance of some semitrailers.

Secondly, Allen [8] determined that, in seven US states, ABS brakes contributed to reducing 6% of the total accidents involving heavy vehicles.

Thirdly, according to Billing [9], 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 (Department of Transportation) [10] indicated that the ESC can help to 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.

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 these 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, using air disc brakes is not compulsory in any of those jurisdictions, but North 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 in 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 three-axle trucks varies from 54 m to 66 m depending on the maximum authorized weight.

Other controls used in some of these jurisdictions that contribute to improve road safety are the roadside inspections done by traffic officers and periodic technical inspections of vehicles. As they have the possibility of banning vehicles with dangerous defects to circulate and promote suitable maintenance techniques.

Table 1 Aspects considered in the regulations of the braking systems of heavy vehicles in different jurisdictions.

Technology	USA ^a	Canada ^b	Europe ^c	Australia ^d
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

Source: ^ainformation obtained from FMVSS (Federal Motor Vehicle Safety Standard) 105 [11] and FMVSS 121 [7]; ^binformation obtained from CMVSS (Canadian Motor Vehicle Safety Standard) 105 [12] and CMVSS 121 [13]; ^cinformation obtained from the UNECE (United Nations Economic Commission for Europe) Vehicle Regulation No.13 [14]; ^dinformation obtained from ADR (Australian Design Rules) 35/03 [15] and ADR 38/03 [16].

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 No. 9078 about public roads transit and road safety [17]; the Decree No. 31363-MOPT about the regulation for circulation on roads based on the weight and dimension of heavy vehicles [18]; the technical regulation for carrying out conversion studies and/or modifications of commercial vehicles [19]; the Decree No. 17266-MOPT about the regulation on safety devices for motor vehicles [20]; and the *Manual of the Procedures for Technical Revision of Vehicles in vehicle Inspection Stations* [21]. The combination of all these regulations shows some positive aspects for road safety, as indicated below:

(1) For vehicles to obtain the circulation permit, 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 four risk counties: Osa, San Carlos, Pérez Zeledón and Puntarenas. The data base of road 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 in 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 (CONAVI by its name in Spanish), which gave us the possibility of knowing 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 AADT (annual average daily traffic) estimates carried out by the Department of Sectorial Planning of the Ministry of Public Works and Transport (MOPT by its name in Spanish) were used to determine the exposition of vehicles in relation to national roads in the risk counties, 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 Eq. (2):

$$T = \frac{f}{VKT} \quad (2)$$

where, VKT (vehicle kilometers of Travel) was millions of kilometers traveled by vehicles and f was the frequency of lethal accidents.

Lastly, some surveys were carried out to study if certain braking technologies were available in the Costa Rican market, the possibility of introducing some technologies in the national market, and to determine the possibility of introducing some technologies in the national market, to study the types of braking systems technologies used by some companies with heavy vehicle fleets, and to evaluate some of their maintenance practices.

5. Results

Heavy vehicles had a low implication in car accidents with casualties² (8%~11%), while the percentages of fatalities (number of people deceased)

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

Study on the Impact of Heavy Transport Vehicles Braking System Requirements on Road Safety in Costa Rica

was approximately double (16%~24%) as shown in Fig. 1.

The percentage of heavy vehicles traveling around the counties in consideration is low in relation to other vehicles (Fig. 2). Nevertheless, in most of the cases, the

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.

Country	Osa	Pérez Zeledón	Puntarenas	San Carlos
Accidents with victims	426	651	1,138	1,263
Casualties	51	21	45	229

Fig. 1 Participation of heavy vehicles in road accidents and percentage of casualties.

Note: This information corresponds to the database of accidents with victims for the years 2007~2011, except for Pérez Zeledón County which database corresponds to 2009~2011.

Source: COSEVI (*Consejo de Seguridad Vial*).

Fig. 2 Classification of vehicles travelling through the highways of these high road accident risk counties.

Source: COSEVI.

Table 2 Mortality rates for different types of vehicles.

County	Passenger vehicles (%)	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

Note: The information on the types of vehicles involved in road accidents in the Pérez Zeledón County was not available, except for those cases where heavy vehicle did participate.

Source: COSEVI.

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 having heavy vehicle fleets were surveyed. The survey showed that the majority of those companies use S cam drum brakes and retardants. Half of them own vehicles equipped with load-sensing valves, less than half use 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 adjustment bolts of air brakes and loosening them 1/4 of turn in all wheels.

6. 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, so regulations should be designed aiming at reducing the consequences of car accidents. Nonetheless, Costa Rican regulations have several defects that do not help preventing heavy vehicles from presenting certain braking problems. Among the deficiencies and opportunities of road safety improvement, it was found the following:

In Costa Rica, there are no regulations as for the homologation of imported vehicles. They are just

required to comply with 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 commercial 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 in the vehicles' technical inspections.

Due to 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 required to take them to the vehicles' technical inspection. Consequently, only 6% of the registered semitrailers undergo the vehicles' inspection. So there could be many semitrailers with defective braking system in circulation. As a result, this might produce 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.

Jointly with the previous problem, there is poor control over the circulation of defective vehicles, considering that in Costa Rica there are no roadside inspections that help to enforce the vehicles' inspection controls.

In the technical regulation regarding the realization of studies of conversion and/or modification of commercial vehicles, it has not been stipulated the friction coefficient that should be used for calculating braking power, and then, selecting the braking systems that would allow heavy vehicles to be able to comply with the maximum permitted braking distances. This is a problem because it can produce ambiguities in the selection of the braking systems.

In the braking systems' requirements, heavy vehicles are not obliged to have systems that can prevent wheels' lock up, such as the ABS and load sensing valves, which is important to prevent wheels' lock up in any load condition. Besides, there is no obligation for vehicles with S cam drum air brakes to have automatic slack adjusters which help to prevent braking problems associated to brakes wear.

On the other hand, sometimes, modifications in regulatory aspects respond to the possibility of incorporating certain types of technologies. The analysis of the features of vehicles sold and of those which make up fleets of some companies showed that the use of ABS and automatic slack adjusters could 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 45%, due to the fact that the amount of used imported vehicles is high and because it could take a long time to renew the national vehicle fleet.

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 and automatic slack adjusters in used vehicles, create installation technique guidelines and certify authorized automotive workshops to install them.

It is worth mentioning that the making mandatory ABS 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*. For instance, the inspection manual could incorporate defects associated to: cutting ABS wires (because it is

known that some commercial vehicle owners cut the wires when the ABS malfunctioning signal activates) and wheel speed sensors gotten out of adjustment. Besides, according to Hart [22], inadequate braking balance is a problem that could appear when mixing technologies like ABS and loading sensing brakes in articulated vehicles. Therefore, braking unbalance due to incompatibility of braking technologies could be another aspect to be incorporated in the vehicles technical inspection if such combinations of technologies are done.

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 (Table 2). But currently, the technologies allowing this are not available in the country yet. 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, for the 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 heavy vehicle fleets. This is so due to the fact that some maintenance managers have not been properly trained. Moreover, one of the main causes of rejection of vehicles during the vehicles' inspection is braking instability. Nevertheless, some companies apply an inadequate technique that consists of tightening to its maximum adjustment bolts of air brakes and loosening them 1/4 of turn. This technique does not either always allows correcting unbalance, or identifying the brakes that are unbalanced to look for the cause of the problem.

References

- [1] Fitch, J. W. 1994. *Motor Truck Engineering Handbook*. Warrendale: Society of Automotive Engineers.
- [2] Fancher, P., and Mathew, A. 1987. *A Vehicle Dynamics Handbook for Single-Unit and Articulated Heavy Vehicles*. Michigan: University of Michigan Transportation

Research Institute.

- [3] Sayers, M. 1999. *Vehicle Dynamics Programs for Roadway and Roadsides Studies*. Michigan: University of Michigan Transportation Research Institute and the Federal Highway Administration.
- [4] Hady, M., and Cebon, D. 1995. "An Investigation of Anti-Lock Braking Systems for Heavy Good Vehicles." *Journal of Automobile Engineering* 209 (4): 263-71.
- [5] Garrot, W. R., and Dunn, A. L. 2007. "NHTSA Research Efforts to Significantly Improve Braking Performance of Medium and Heavy Trucks." In *Proceedings of 20th Technical Conference on the Enhanced Safety of Vehicles*, Lyon, France.
- [6] Bendix. 2011. *The Compelling Case for Air Disc Brakes in Heavy Truck Braking: A White Paper*. Ohio: Bendix.
- [7] National Highway Safety Administration. 2011. FMVSS (Federal Motor Vehicle Safety Standard) 121. Air Brake Systems.
- [8] Allen, K. 2010. *The Effectiveness of ABS in Heavy Truck Tractors and Trailers*. Washington, D.C.: NHTSA (National Highway Traffic Safety Administration).
- [9] Billing, J. 2002. *Assessment of the Effect of Automatic Slack Adjusters on Brake Adjustment*. Ottawa: National Research Council of Canada.
- [10] DOT (Department of Transportation). 2012. *Federal Motor Vehicle Safety Standard: Stability Control System for Heavy Vehicles, Proposed Rule*. Washington, D.C.: DOT.
- [11] National Highway Safety Administration. 2011. FMVSS (Federal Motor Vehicle Safety Standard) 105. Hydraulic and Electric Brake Systems.
- [12] Transport Canada. 2005. CMVSS (Canadian Motor Vehicle Safety Standard) 105. Hydraulic and Electric Brake Systems.
- [13] Transport Canada. 2010. CMVSS (Canadian Motor Vehicle Safety Standard) 121. Air Brake Systems.
- [14] UNECE (United Nations Economic Commission for Europe). 2011. UNECE Vehicle Regulation No. 13: Uniform Provisions Concerning the Approval of Vehicles of Categories M, N and O with Regard to Braking.
- [15] Department of Infrastructure and Regional Development. 2009. ADR (Australian Design Rules) 35/03—Commercial Vehicle Brake Systems.
- [16] Department of Infrastructure and Regional Development. 2007. ADR (Australian Design Rules) 38/03—Trailer Brake Systems.
- [17] Hady, M., and Cebon, D. 1995. "An Investigation of Anti-Lock Braking Systems for Heavy Good Vehicles." *Journal of Automobile Engineering* 209 (4): 263-71.
- [18] MOPT (Ministerio de Obras Públicas y Transportes). 2003. Decreto No. 31363-MOPT: Reglamento de Circulación en carretera con Base en el Peso y las Dimensiones de los Vehículos de Carga (Decree No. 31363-MOPT: Regulation for Circulation on Roads Based on the Weight and Dimension of Heavy Vehicles. (in Spanish)
- [19] CFIA (Colegio Federado de Ingenieros y Arquitectos). 2011. Reglamento Técnico para la Realización de Estudios de Conversión y/o Modificación de los Vehículos de Carga (Technical Regulation for Carrying out Conversion Studies and/or Modifications of Commercial Vehicles. (in Spanish)
- [20] MOPT (Ministerio de Obras Públicas y Transportes). 1986. Decreto No. 17266-MOPT: Reglamento de Dispositivos de Seguridad en Vehículos Automotores (Decree No. 17266-MOPT: Regulation on Safety Devices for Motor Vehicles). (in Spanish)
- [21] COSEVI (Consejo de Seguridad Vial). n.d. *Manual de Procedimientos para la Revisión Técnica para Vehículos Automotores en las Estaciones de RTV (Manual of the Procedures for Technical Revision of Vehicles in Vehicle Inspection Stations)*. San Jose: COSEVI. (in Spanish)
- [22] Hart, P. 2010. "Development of the Australian Brake Balance Code of Practice." Presented at the 11th HVTT (Heavy Vehicle Transport Technology Conference), Melbourne, Australia.