Heavy Vehicle Age and Road Safety

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ABSTRACT

As a result of the importance of commercial motor vehicle transport internationally, much literature has concentrated on improving our understanding of the factors that influence commercial vehicle accident occurrence and severity. However, vehicle age, an important factor in practice, has been largely overlooked. In the present study the effects of vehicle age on road safety are investigated through accident rates and severity indices for vehicles of different age classes, using detailed reports for more than 13,000 accidents in Greece. Findings suggest that older vehicles have a 4.5 times higher accident involvement probability in comparison with newer vehicles, while accidents involving older vehicles have a four times higher probability of resulting in a fatality. Further analysis suggests that the mean per capita cost to tax payers from commercial vehicle accidents surpasses 100€ per year, more than half of which is attributed to older vehicles. Measures to mitigate the problem are suggested.

KEYWORDS

Roads & Highways, safety & hazards, statistical analysis.

1. INTRODUCTION

Commercial motor vehicles (CMVs) can be defined as ‘any motorized road vehicle which by its type of construction and equipment is designed for, and capable of, transporting, whether for payment or not: (a) more than nine persons, including the driver; or (b) goods’ (EC, 1985). Commercial truck and bus transport is of economic importance in most areas of the developed world. In the USA, for example, the commercial trucking sector has annual revenues of more than U.S.$500 billion and employs nearly 10 million people (Knipling, 2007). North American intercity and charter buses carry an estimated 860 million passengers annually, which is more than those transported by commercial air carriers or rail (Knipling, 2007). Trucks transport over 11 billion tons of goods annually or about 60% of the total domestic tonnage shipped, while there are approximately 711,000 commercial motor carriers registered in the Motor Carrier Management Information System (MCMIS) and about 9 million trucks and buses (Schwartz and Fleming, 2007). Interestingly, alyhiugh large trucks - single-unit or combination vehicles with a gross vehicle weight greater than 4,500 kg - account for 3% of the vehicle fleet and 7% of the total vehicle miles travelled, they are associated with 12% of total roadway fatalities and 23% of passenger vehicle deaths in multiple-vehicle crashes (FHWA, 2006; IIHS, 2005; Lyman and Braver, 2003). In the EU approximately 20,000 (4%) of buses and coaches of more than 5,000 kg are currently involved in accidents involving personal injuries each year (E.C., 2003).

The particular characteristics of trucks and buses strongly influence –in a positive or negative way- the occurrence of CMV accidents. These characteristics relate to:

(*a*) the *vehicle* itself, such as different traction characteristics, increased dimensions and weight, and so on
(*b*) the *driver*, since professional drivers spend more time driving than a typical driver
(*c*) the *commercial use* of CMV vehicles that must meet several efficiency criteria, obey diverse regulations and restrictions and is more sensible to policy-related issues.

Furthermore, unlike motor transportation in general, CMV safety is significantly influenced by the operational requirements of the industry, operational adjustments to meet those requirements, carrier safety management policies and activities, legal and regulatory mandates and restrictions, and multi-faceted enforcement activities (Knipling, 2007).

With respect to road safety, issues related to CMVs have drawn considerable attention from researchers, policy makers, and the general public; however, the relative impact of fleet age on the likelihood of accident involvement or severity has not been quantified. In this paper a large number of accident reports (over 13,000) were used to investigate the influence of CMV age on accident involvement and severity and estimate the cost of CMV accidents to society with respect to vehicle age.

2. BACKGROUND

The social impact of accidents is significant; individuals affected by traffic accidents deal with pain and suffering, medical costs, wage loss, higher insurance premium rates, vehicle repair costs and so on. For society as a whole, road accidents result in enormous costs in terms of lost productivity and property damage and thus efforts to improve understanding of the factors that influence accident occurrence and severity are clearly warranted The increased role of CMVs in accidents and fatal crashes has led to extensive research into the area of large trucks and crash severity factors (Alassar, 1988; Chang and Mannering, 1999; Chirachavala *et al.*, 1984; Khorashadi *et al.*, 2005; Shao, 1987; Tsai and Su, 2004). Nevertheless, bus accidents characteristics remain a relatively under-researched topic with the exception of school bus accidents that have attracted research attention (Hinch *et al.*, 2002; Miller and Spicer, 1998; TRB, 2002; Yang *et al.*, 2009) as they are estimated to account for nearly half of the total bus accidents (Putcha, 2001).

2.1 Vehicle Characteristics

Vehicle characteristics have been a commonly examined risk factor, even though their direct effect on accident occurrence is relatively low in comparison with driver-related factors. Nevertheless, this effect is far from negligible and, if seen in combination with other factors, it appears to be implicated in 30% of the total CMV accidents (Craft, 2005). Truck braking capacity is referred to as an important factor in truck crashes (Clarke *et al.*, 1987). Vehicle maintenance, stability and field of view are also important parameters (Cairney *et al*., 1987) and, although the effects of vehicle inspection frequency on safety have been studied and inspections are found to strongly reduce technical defects in cars (Christensen and Elvik, 2007), no analysis focusing on heavy vehicle inspections has been conducted. Much research has focused on safety issues for different truck configurations (Blower *et al.*, 1993; Braver *et al.*, 1997; Chirachavala and Cleveland, 1985; Forkenbrock and Hanley, 2003; Polus and Mahalel, 1985) without, however, much agreement in their findings.

2.2 Driver Characteristics

Numerous studies have investigated and quantified the influence of truck-driver characteristics on accident frequencies and severity, with three factors appearing as the most important:

2.2.1 Driver fatigue. Fatigue-involved crashes were more likely to result in a fatality and, further, among all fatigue-related accidents, those involving heavy and light trucks were found to be the most common (Baas *et al*., 2000; Williamson and Boufous, 2007). In the USA, about 25% of long-distance truck drivers had fallen asleep at the wheel in the previous year (McCartt *et al.*, 2000).

2.2.2 Training and experience. Although training and experience are among the most decisive factors that determine driver performance (Shao, 1987), it is basically the employer who determines the duration and content of any training or assessment programme (Braver *et al.*, 1997), and driver assessment is exclusively the employer's responsibility (Kuncyté *et al.*, 2003). In general, fatal accident involvement rates for large truck drivers are higher for younger drivers, with younger drivers being over-involved until the age of 27 (Campbell, 1991).

2.2.3 Alcohol consumption and drug use (prescription or illegal). Alcohol consumption and drug use are two known significant contributors to motor vehicle accidents while for truck accidents they significantly affect both frequency and severity (Cairney *et al*., 1987; Craft, 2005; Dunkan et al., 1998; Khorashadi *et al.*, 2005).

2.3 Operating Environment

Operating road environment characteristics have also been found to affect accident rates and severity. For trucks, casualty risk at night is about 1.4 times greater than daytime risk; casualty risk in rural areas is 1.6 times greater than in urban areas. Truck accident rates vary by a factor up to 6.8 depending on road type (Blower *et al.*, 1993; Khorashadi *et al.*, 2005), while severity is affected by high speed differentials and speed limits (Dunkan *et al*., 1998). Despite the fact that fatalities are more frequent on rural European roads, a vast majority of all bus and coach casualties seem to occur on urban roads and in dry weather conditions (Albertsson and Falkmer, 2005; E.C., 2003). The importance of weather conditions as a factor of risk and of truck accident severity is frequently discussed (Shao, 1987), with results from a recent work indicating that weather data can be used as an excellent predictor for overturning-type crashes (Young and Liesman, 2007).

2.4 Road Geometry

The relationship between vehicle accidents and road geometric characteristics has been extensively studied (Firestine *et al.*, 1989; Jorgensen, 1978; Joshua and Garber, 1990; Miaou, 1994; Miaou *et al.*, 1992; Okamoto, 1989; Presby, 1990). Results suggest that, for interstate roads, truck accidents are significantly affected by horizontal curvature and vertical gradient (Mohamedshah *et al.*, 1993); further, as the gradient increases to the point that trucks move at much lower speeds than that of the traffic stream, truck accident rates increase (Jorgensen, 1978). Several major design deficiencies for interchanges that may cause rollovers and jack-knifing have been identified (Firestine *et al.*, 1989); however, we note that a study by Saccomanno and Buyco (1988) finds no significant relationship between geometric variables and truck accident involvement rates.

2.5 Socioeconomic Factors

Although socioeconomic factors and policy measures influence truck accident occurrence, the deregulation of the trucking industry in the US (Motor Carrier Act of 1980) was found not to have a statistically significant effect on truck accidents (Alexander, 1992; Kraas, 1993; Loeb, 1995; Loeb and Clarke, 2007). Similarly, no evidence was found that bus deregulation in Great Britain affected safety performance (Evans, 1994). On the contrary, socio-economic factors such as unemployment rate, population age, and accident price data (medical care and property damage) were found to have a significant effect (Loeb, 1995; Loeb and Clarke, 2007). Compliance with rules on working hours, truck inspection per mile driven (Kraas, 1993) and police enforcement (Alexander, 1992) were shown to be inversely associated with truck-related fatalities and accidents.

2.6 Vehicle Age

Despite its rather obvious potential implications to vehicle technology, stability and overall performance and thus its safety, vehicle age has rarely been addressed as a risk factor for CMV-related accidents, despite the widespread anecdotal evidence of the relationship. A higher likelihood of mechanical failures is often anticipated as average vehicle age increases, potentially leading to an increase in accidents. Furthermore, passive safety (equipment, restraint systems, technology) in newer vehicles has been greatly improved and it may be anticipated that newer vehicles could be involved in less severe accidents.

Improvements in design and technology can influence heavy vehicle safety in two ways; first, the performance of the vehicle itself can be improved, making it better in avoiding or surviving crashes and, second, vehicle-based technologies may be employed to help the driver perform better and be more aware of his or her surroundings, physical and mental state and driving performance. In general, vehicle braking, handling and stability, seeing and being seen, have been largely improved in newer vehicles (Knipling, 2007).

In France in 2005, 4,730 heavy vehicles were involved in accidents, with 37.7% of them having been in circulation for less than 3 years, 49.8% between 3 and 10 years and 12.5% over 10 years (ONISR, 2007). In a US study (Khorashadi *et al.,* 2005) regarding the differences in rural and urban driver injury severities in accidents involving large trucks, vehicle age was considered as a nominal variable with three categories being considered: vehicle model year ‘older than 1981’, ‘1981-1988 (inclusive)’, and ‘after 1988’. In urban areas, pre-1981 model year vehicles were associated with an 84.0% increase in the likelihood of a severe/fatal injury. In a study by Loeb (1995), the effects of policy-related variables on traffic fatalities were investigated covering a 40-year period; although the study included all vehicles, the ratio of 1966 or newer registered vehicles to total registered vehicles was examined as a risk factor. The estimated coefficient for this ratio was found to be statistically significant at the 95% confidence level. In a similar study, Loeb and Clarke (2007) examined the determinants of truck accidents in the USA using a time series data set covering the period 1970-2001 and found that average fleet age – rather than the average age of trucks involved in accidents – was not statistically significant.

3. DATA DESCRIPTION

The data used in this paper cover the period from 1996 to 2004 and contain all recorded accidents (187,899 in total) that occurred on the Greek road network during this period. A total of 8,582 truck accidents that resulted in 1,912 fatalities (accident results are completed on the 30th day after its occurrence), along with 4,773 bus accidents that caused the death of 588 persons were analysed. The basic analysis parameter was vehicle age, whereas secondary variables analysed were area type, road surface condition, and lighting conditions.

The source of accident data used in this study was the national road accidents database held by the National Statistical Service of Greece (NSSG, 2005). This database is built upon a combination of police accident registrations and hospital injury and fatality counts. It contains a broad range of disaggregated variables describing several accident, driver, vehicle, and environment characteristics thus allowing for very detailed analyses to be undertaken. Every crash involving an injury (even the slightest one) is registered in the database; ‘property damage only’ accidents are excluded. The National Technical University of Athens has developed a road accident statistical treatment tool (Santra); Santra is a user-friendly software application based on an MS-Access environment which codes and analyses the NSSG annual accident data. In this paper Santra was used to extract the matrices containing the necessary accident data and analysis parameters.

CMV accident data were combined with the respective traffic data for the extraction of the necessary accident rates. Given the absence of systematic national traffic data, the necessary CMV traffic data (total CMV mileage per weight class and vehicle age) were taken from a recent study conducted by the Greek Association of Motor Vehicles Importers Representatives (Kikidas, 2003), which combined data from CMV repair shops, large carrier databases and a roadside survey. The total annual CMV mileage figures per weight class and vehicle age were calculated by the use of the related official CMV fleet figures provided by both the Hellenic Ministry of Transport (see www.yme.gr) and the Greek Association of Motor Vehicles Importers Representatives (see www.seaa.gr). An assumption was made that for each CMV age group the annual mileage does not change significantly over the study period as indicated by the respective mileage figures for passenger cars (SARTRE, 2004, Yannis *et al.*, 2005a).

4. METHODOLOGICAL APPROACH

The use of absolute numbers and trends of values may lead to conclusions regarding traffic safety that are generally of limited significance due to the lack of exposure information. The use of severity indices overcomes the need for exposure data but corresponding results are obviously limited to the accident severity characteristics examined (Golias and Yannis, 2001). Road accident rates can better describe the road accident phenomenon because they take into consideration the actual traffic patterns and can comprise several accident characteristics; as they are normalised they can serve, under certain conditions, for national or international comparisons.

In the present study, the accident rate method was chosen. The dependent variables estimated were two risk indices per vehicle category: *fatalities* in accidents involving at least one CMV vehicle per 10^8 vehicle-km (veh-km) travelled (by CMV vehicles) and *number of accidents* involving at least one CMV vehicle per 10^8 veh-km travelled. Thus, the following four rates are formed

(*a*) truck risk index for accidents (TRIA) = number of truck accidents per 10^8 veh-km

(*b*) truck risk index for fatalities (TRIF) = number of fatalities in truck accidents per 10^8 veh-km

(*c*) bus risk index for accidents (BRIA) = number of bus accidents per 10^8 veh-km

(*d*) bus risk index for fatalities (BRIF) = number of fatalities in bus accidents per 10^8 veh-km

As already mentioned, the basic analysis parameter considered was vehicle age. This information was indirectly deduced by the year of first registration of the vehicle involved in the accident and the accident date; the following age groups were considered: 0-5 years, 6-10 years, 11-15 years, 16-20 years. The actual age of imported vehicles was not officially registered; a fact that could lead to underestimation of their age class. Nevertheless, the biased estimates were on the conservative side as the error was one of misclassifying older vehicles as newer ones and not vice versa. Vehicles over 20 years of age were not analysed as official vehicle records were not exhaustive before that time and the total fleet could not be estimated. Moreover, these vehicles were basically used for short-distance trips and with very limited accident involvement, thus not influencing the study results.

Mean annual risk rates per vehicle age and type were estimated as the number of accidents (or fatalities) per 10^8 veh-km travelled. In case of accidents involving more than one CMV, each CMV was counted separately, while no consideration for the driver being at-fault was made. For example, a 3 year-old bus and a 10 year-old truck involved in the same accident were counted separately. In this way, the total number considered was higher than the actual number of accidents (separate counting of vehicles in the same accident), providing thus a clearer insight into the correlation between heavy vehicle age and road accidents. Furthermore, the rates estimated were used only for analysis of this type of accident and not for comparison with other vehicle types.

Secondary parameters examined in combination with vehicle age were mainly related to the road environment and are as follows:

(*a*) area type

(i) rural

(ii) urban

(*b*) pavement condition

(i) normal

(ii) wet

(iii) other

(*c*) lighting conditions

(i) daylight

(ii) dusk / dawn

(iii) night.

The levels and values of the secondary parameters were as they appear in the police accident report registrations. It has to be noted that multiple secondary variables could have been examined as well (e.g. operational or driver related). The present study was not an exhaustive analysis and aims at a preliminary investigation of the absolute age effect on safety rather than of its interaction with other variables.

The four dependent variables were estimated for each age class on an annual basis. The mean annual values for the 9 years covering the study period were estimated. Supplementary normalised risk factors were calculated as the proportion of each age class risk relative to the ‘0-5 years’ class index for comparison purposes and for better illustration of the effects of vehicle age. The above-mentioned procedure was then repeated considering secondary parameters and thus total accidents and fatalities per vehicle class and age were also examined with respect to different road conditions. We again note that the analysis was separately undertaken for buses and trucks.

5. RESULTS

Mean annual risk index estimates for trucks and buses covering the entire study period (1996-2004) appear in Table 1. A normalised factor on a ‘0-5 years’ class baseline was calculated in order to better illustrate the analysis results. Trucks were involved in a higher number as well as more severe accidents in comparison with buses even though their main function was to transport passengers. Similarities can also be observed among bus and truck normalised values, partly verifying the anticipated connection between the two vehicle categories with respect to the influence of age. With respect to the two accidents indices, age factors were almost equal, whereas for the two fatality indices there were small differences.

As can be seen, vehicle age greatly influences the rate of crash involvement; 16-20-year-old CMV vehicles demonstrate a 4.5 times higher probability of getting involved in accidents compared with new vehicles (less than 6 years of age). Furthermore, in comparison with newer vehicles they also have an approximately four times higher probability of resulting in a fatality when involved in an accident. It has to be pointed out that these results are consistent for both bus and truck accidents. From these indications it can be inferred that CMV age strongly affects the risk and the severity of accident occurrence.

In a time series graph (Figure 1), the evolution of CMV risk indices is shown for the entire study period. Even though the general safety level seems to improve over time - reflecting various efforts towards improving safety - the annual age factor remains highly independent of other conditions. This could be seen as an indication that commonly used safety measures do not seem to be able to dampen the effects of ageing trucks and buses on accident involvement and severity. It could equally be interpreted as a need to differentiate and develop specific measures to target the problem of an ageing fleet.

The results of the TRIA analysis, combined with secondary analysis variables, are shown in Figure 2 (results are normalised with respect to the '0-5' age class). In all index cases (TRIA, TRIF, BRIA, BRIF), the classes '11-15' and '16-20' have higher risk values in comparison with the mean index for the 9 years of observations, whereas the classes '0-5' and '6-10' are consistently below the 9-year median value. The age impact seems stable and independent of road conditions in contrast to reports indicating that even in normal conditions (daylight, dry pavement) older vehicles demonstrate higher accident implication rates.

6. COST

Although important to the economy, CMV transport creates certain adverse impacts which are generally not borne by those who generate them. The four main determinants of these externalities are considered to be emissions, noise, hidden costs associated with service provision and accidents. In a study for intercity freight transportation in the USA (Forkenbrock, 1999), it was found that user fees would need to be increased threefold to internalise externalities while it was also estimated that accidents account for 53%

of total external costs. Secondary accidents, delays in the shipment of freight and passengers, and supplementary congestion generated could increase the above estimation.

The economic impact of large truck and bus crashes is significant; the average cost of crashes involving large trucks was US$59,153 in 2000 dollars (Zaloshnja and Miller, 2002). These costs included medical and emergency services, property damage, lost productivity, and monetary valuation for pain, suffering and quality-of-life loses associated with these crashes. The average cost of crashes involving transit or intercity buses was US$32,548. For crashes with injuries these costs rose to US$164,730 for large trucks and US$77,043 for buses. Annual total US costs for large truck crashes averaged more than US$19.6 billion for 1997-1999, whereas bus crashes averaged far less at US$0.7 billion (Knipling, 2007).

Based on the findings presented earlier in this paper, we the total cost for CMV accidents for the period 1996-2004 was quantified and the extra cost due to vehicle age was further estimated. The estimation for the total 9-year cost values for CMV accidents appears in Table 3 (calculations are based on values presented in Table 2). The monetary cost of accidents in Greece was estimated in a recent study (Yannis *et al.*, 2005b) and includes the lost production cost.

The cost of each accident was estimated according to its outcome and the corresponding monetary cost. Thus, a two-vehicle collision resulting in the death of both drivers and in property damage for both vehicles would have a total cost of ((fatality cost + property damage cost)*2). Supposing one of the vehicles was a truck, 8 years of age, this cost would be assigned to the 'truck accidents cost' column and to the '6-10years' row of table 3. This assignment is not made on a driver-being-at-fault basis.

Performing a comparison between bus and truck accident costs (as they appear in Table 3), it was observed that for almost all age classes, their ratio was around 1/3. This result could be anticipated as the main cost component is fatality cost. The only exception to the above is the 6-10 age group, whose ratio equals 0.6; this maybe reflecting the lower age of the bus fleet. However, this finding needs further examination.

The cost attributed to both trucks and buses in the ‘16-20 years’ age group accounts for over 45% of the total cost and is four times higher than the cost associated with newer vehicles (0-5 years of age). The total CMV accidents’ cost divided by the number of Greek tax payers results in a corresponding cost of almost €100 per capita per year. The mean annual income reported per tax payer for 2003 (in Greece) was of €13,972 (NSSG, 2005).

7. CONCLUSIONS

Practitioners and researchers have shown significant interest in CMV transportation. Accident statistics indicate that CMV vehicles present a serious safety problem, particularly with regard to the severity of accidents in which they are involved. In this paper, previous research involving CMVs and their implications for safety was reviewed. Using a large Greek accident database, the present study focused on the effects of vehicle age on accident occurrence and severity.

The impact of CMV age was shown to be significant and rather independent of road conditions. The 16-20-year-old CMV vehicles showed a 4.5 times higher probability of being involved in accidents in comparison with new vehicles (less than 6 years of age). The same age group was also found to have an approximately four times higher probability of suffering a fatality when involved in an accident. These results were verified on both urban and rural networks, under all daylight conditions considered (daylight, dusk, night) and independently to the road condition (normal, wet or other). In an attempt to estimate the social cost attributed to CMV accidents, it was found that the mean annual burden to tax payers is over €100 per capita, half of which is attributed to older vehicles.

Even when the overall benefits to society probably outweigh the costs, little effort is generally to investigate fleet renewal, and economic or other incentives are rarely given to carriers for fleet renewal. Such incentives could include annual licensing fees and toll payments that would vary by age. Age restrictions on the use of trucks in city centres could prove helpful and offer environmental gain as well. The annual technical inspection of CMVs should be upgraded and further certified as a procedure, and enforcement could drastically reduce the number of possible offenders.

The effects of vehicle age on accident occurrence and severity deserve more attention in the literature as preliminary evidence of a strong correlation connecting age and accidents was found. However, it must be mentioned that this correlation does not necessarily imply a simple cause-and-effect relationship. Other secondary parameters should also be investigated along with vehicle age, such as road environment, driver's age and training. The most frequent mechanical failures related to motor ageing have to be identified, while the relationship between mechanical failure probability and technical inspection frequency has to be quantified. Future research could also cover the issue of transferability of results to other networks and to different vehicle types.

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TABLE 1 Mean annual risk rates per vehicle age and category

	TRIA		TRIF		BRIA		BRIF	
	(acc/10^8 vehkm)	normalised factor	(fat/10^8vehkm)	normalised factor	(acc/10^8 vehkm)	normalised factor	(fat/10^8vehkm)	normalised factor
0-5 years	9.4	1.0	2.2	1.0	4.1	1.0	0.5	1.0
6-10 years	11.8	1.3	2.5	1.1	6.4	1.6	1.0	2.0
11-15 years	24.6	2.6	5.5	2.5	10.1	2.5	0.9	1.8
16-20 years	42.7	4.5	8.8	4.0	18.7	4.6	2.1	4.2

TABLE 2 Monetary Cost of Accidents (data for Greece, 2003 constant values)

	Cost (euro)
Fatality	1,433,899
Severe injury	137,313
Slight injury	12,623
Property damage	18,212

Source: National Technical University of Athens

TABLE 3 Total CMV Accidents costs per age class and for the period 1996-2004

	Truck Accidents Cost (10^6 €)*	Bus Accidents Cost (10^6 €)*	Total Cost (10^6 €)*

	Total	Mean annual	Total	Mean annual	Total	Mean annual
0-5 years	400	44.4	131	14.6	531	59.0
6-10 years	443	49.2	261	29.0	704	78.2
11-15 years	968	107.6	255	28.3	1,223	135.9
16-20 years	1,571	174.6	558	62.0	2,129	236.6
Total	3,382	375.8	1,205	133.9	4,587	509.7

[*a]2003 constant values

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