# Investigation of vehicle technical parameters in built-up areas accidents

**Faculty of Mechanical Engineering and Design**

**Kaunas University of Technology**

MASTER THESIS

2013 / 2014

**Ludovic Cabezas Ibars**

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**Supervisor:** Assoc. prof. Martynas Starevičius

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# Abstract

This Master Thesis proposes to understand why Lithuania has one of the worst index of killed in traffic accidents in the European Union, especially pedestrians' deaths. In order to this, the project compares statistics in Lithuania, Spain and Sweden.

Most collisions occur due to a combination of factors such as the road infrastructure, the vehicle or the perpetrator.  This Master Thesis also tries to explain all of them but focusing on engineering part of the vehicle, built-up areas (urban roads) and one of the most vulnerable road user group: pedestrians. According to this, the main problem that this Thesis wants to solve is why cars cannot stop on time in order to avoid an accident. Trough analysis of resistance forces and traction between road and tyre the thesis gets an algorithm of vehicle for start and stop. Later, it is used for an experimental research about an accident that happened in Kaunas (Lithuania) between one car and two pedestrians to analyse and evaluate a possible maximal speed of this accident.

Finally, modelling the selected accident with different technical parameters and according engine power mass ratio (power-to-weight), Mater Thesis finds which type of vehicle is safest in urban conditions for pedestrians.

**Keywords:** Road traffic safety, power-to-weight, car crash, pedestrian accidents

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# Notations

| | |
|---|---|
| ***CARE*** | Community Road Accident Database |
| ***WHO*** | World Health Organization |
| ***IRTAD*** | International Traffic Safety Data and Analysis Group General |
| ***OECD*** | Organisation for Economic Co-operation and Development |
| ***TRRL*** | Transport and Road Research Laboratory |
| ***EU-27*** | European Union of 27 Member States |
| ***BE*** | Belgium |
| ***BG*** | Bulgaria |
| ***CZ*** | Czech Republic |
| ***DK*** | Denmark |
| ***DE*** | Germany |
| ***EE*** | Estonia |
| ***IE*** | Ireland |
| ***EL*** | Greece |
| ***ES*** | Spain |
| ***FR*** | France |
| ***IT*** | Italy |
| ***CY*** | Cyprus |

| | |
|---|---|
| ***LV*** | Latvia |
| ***LT*** | Lithuania |
| ***LU*** | Luxembourg |
| ***HU*** | Hungary |
| ***MT*** | Malta |
| ***NL*** | Netherlands |
| ***AT*** | Austria |
| ***PL*** | Poland |
| ***PT*** | Portugal |
| ***RO*** | Romania |
| ***SI*** | Slovenia |
| ***SK*** | Slovakia |
| ***FI*** | Finland |
| ***SE*** | Sweden |
| ***UK*** | United Kingdom |
| ***HR*** | Croatia |
| ***MK*** | Former Yugoslav Republic of Macedonia |
| ***TR*** | Turkey |
| ***IS*** | Iceland |
| ***LI*** | Liechtenstein |
| ***NO*** | Norway |

# Chapter 1

# Introduction

Nowadays the use of vehicle is very common and it has increased the last 20 years. Road transport is essential to human and societal development because people and goods need to move and access needs to be provided to jobs, education, health care and other services. However, it also exposes people to risk. Road traffic crashes still being one of the world's largest public health and injury prevention problems despite roads are better and the automotive industry is investing in new models and improving them in the issue of security.

According to the WHO more than a million people are killed on the world's roads each year. The daily deaths and injuries associated with road use represent a major public health problem in all countries, exacting huge human and economic costs. Nevertheless, many effective preventive strategies exist and countries that have invested in road safety for many decades have shown that effective strategies can reduce the size of the loss.

In Europe, despite the important decrease in number of deaths during the last decade, there are certainly many more actions to be taken in order to achieve a further decrease of road accident victims. Road safety is considered to be a high priority issue in all European countries although it is not equally distributed across Europe. The risk of being killed or injured in a road accident is much higher in some European countries than in others. A “North-South divide” exists in European transport safety: while North-Western European countries have developed and implemented plans and policies that have significantly improved road safety, Southern European countries generally suffer from greater road risk.

This contrast between safer and less safe Member States has become even more pronounced after the accession to the European Union of ten new countries in 2004. A good starting-point for this is to understand the baseline situation in different located countries, which is one propose of this Thesis.

This project also highlights the plight of vulnerable road users. Everyone has different preferences when it comes to transportation, but there is one that all road users share — everyone is a pedestrian. Unfortunately, pedestrians were one of the few groups of road users to experience an increase in fatalities. Pedestrians, cyclists and riders of motorized two-wheelers constitute 39% of all road traffic deaths in the WHO European Region. They are more likely to be more seriously injured. Rapid road traffic and urban design put these road users at increased risk.

In fact, it is known that road accidents are closely linked with the road infrastructure or environment (lack of sight distance, poor roadside clear zones, etc.), the vehicle (brake, steering, or throttle failures) and the perpetrator (such as driver error, illness or fatigue) or a combination between them. However, there are much more causes of accidents on the road and this hinders the investigation of accidents. Interventions may seek to reduce or compensate for contributing factors to highway crashes, or reduce the severity of crashes that do occur. In this case, vehicles technical parameters such as the engine power and the vehicle mass are studied to find the safest vehicle in urban conditions for pedestrian.

# Chapter 2

# Literature Review

This chapter will explore the literature that is relevant to understanding the development of, and interpreting the results of this convergent study. Firstly, it presents the definition of road traffic safety and some basic concepts about road accident's principal causes. Secondly, it explains the differences between Lithuania, Spain and Sweden's roads and park vehicles through analysis and comparisons of road accidents.

It is intended to familiarize the reader with the basic assumptions about problem solving that went into the design of this research and the interpretation of the results.

## 2.1 Definition of Road Traffic Safety

Road traffic safety refers to methods and measures for reducing the risk of a person using the road network being killed or seriously injured. The users of a road include pedestrians, cyclists, motorists, their passengers, and passengers of on-road public transport, mainly buses and trams. Best-practice road safety strategies focus upon the prevention of serious injury and death crashes in spite of human fallibility. Safe road design is now about providing a road environment which ensures vehicle speeds will be within the human tolerances for serious injury and death wherever conflict points exist.

Traffic safety is one of the fundamental qualities of the traffic system. Every traffic participant or road user wants to have a system which fulfils his needs and expectations. From this point of view, a safe road traffic is a responsibility of the state which has, with its institutions, an insight and control over traffic. It also has necessary means, beside the participants, which can directly or indirectly have an influence on this area.

In the complex system, road safety depends on participants' responsible behaviour, educational organizations, media, repressive and jurisdictional organs, civil society, companies, local self-government units and also state authorities. Each and every one of them has its own share of responsibility for a better safety and contributes to its realization. But the goals can be achieved only with coherent measures and collective efforts.

CARE is the EU's road accident database that collects information on accidents resulting in death and/or injury. The legal basis for CARE is Council Decision 93/704/EC on the creation of a database on road accidents. Its purpose is to provide information which makes it possible to: identify and quantify road safety problems; evaluate the efficiency of road safety measures; determine the relevance of EU actions; and facilitate the exchange of experiences. Road injury accidents are defined as any accident involving at least one road vehicle in motion on a public road or private road to which the public has right of access, resulting in at least one injured or killed person. Included are: collisions between road vehicles; between road vehicles and pedestrians; between road vehicles and animals or fixed obstacles and with one road vehicle alone. Included are collisions between road and rail vehicles. Road deaths are defined as any person killed immediately or dying within 30 days as a result of an injury accident, excluding suicides.

**Measuring mortality rate and fatality risk**

Comparison of road safety performance depends somewhat on what indicator is used as a measure of exposure to risk; population, number of registered vehicles or distance travelled by motorised vehicles. There has been considerable debate over which indicator is most appropriate to measure exposure to risk. Those in the health sector prefer the use of population as the denominator, since it permits comparisons with other causes of injury and death, including infectious diseases. As the health and transport sectors increase their level of co-operation, fatalities per 100 000 population is becoming more widely used as the standard indicator. In the transport sector it has been common, where data are available, to use fatalities per distance travelled (e.g. fatalities per million vehicle-kilometres) as a principal indicator, or fatalities per 10 000 vehicles.

**Fatalities per 100 000 head of population.** The number of inhabitants is the denominator most often used, as the figure is readily available in most countries. This rate expresses the mortality rate, or an overall risk of being killed in traffic, for the average citizen. It can be compared with other causes of death, like heart disease, HIV/Aids, etc. This is a particularly useful indicator to compare risk in countries with the same level of motorisation. It is, however, not at all adapted to comparing safety levels between industrialised countries and countries where the level of motorisation is very low.

**Fatalities per billion vehicle–kilometres** (or fatalities per billon person-kilometres, taking vehicle occupancy into account). This is the most objective indicator to describe risk on the road network. However, only a limited number of countries collect data on distance travelled.

**Fatalities per 10 000 registered (motorised) vehicles**. This rate can be seen as an alternative to the previous indicator, although it differs in that the annual distance travelled is unknown. This indicator can therefore only be used to compare the safety performance between countries with similar traffic and car-use characteristics. It requires reliable statistics on the number of vehicles.

In some countries, scrapped vehicles are not systematically removed from the registration database, thereby undermining accuracy. This indicator does not take into account non-motorised vehicles (such as bicycles), which can in some countries represent a large part of the vehicle fleet and of the fatalities figures. Most countries report their vehicle fleet without mopeds.

Ideally, it would be desirable to use all three indicators to make comparisons of performance between countries.

# 2.2 General causes of road accidents

The circulation of motor vehicles is based on three elements: the road, the vehicle and the driver. Each one of these elements, only or combined with others are susceptible to generate a specific risk of accident at any time.

### 2.2.1 Vehicle

The basis of vehicle safety is in the rigor of the manufacturers, who invest to ensure maximum safety (stability, brakes, steering, suspension, interior, lights, tires, etc.) for each new model hits the market.

Moreover, the best guarantee of security in the vehicle for manufacturers is the compliance with national and international regulations and, if it is possible, overcoming these requirements. Despite this, certainly the traffic accident can always have some shortcomings linked to the vehicle. Usually due to poor maintenance, especially in the case of vehicles with many kilometres driven component.

Tourism is the vehicle where drivers are injured, bikes which hurt more occupants and heavy vehicles injure more severely others.

**Type of vehicle**

• **Motorcar (M1):** motor vehicle intended for transporting persons, with a capacity of up to nine seats including that of the driver.

• **Bus (M2):** motor vehicle intended for transporting passengers, with more than nine seats including that of the driver.

• **Lorry:** motor vehicle intended for transporting goods, and for which a distinction is made between a light vehicle, with a maximum authorised weight not exceeding six tons, and a heavy vehicle with a maximum weight exceeding six tons.

• **Motorcycle:** two-wheeled, on-road motor vehicle, with or without a sidecar, including scooters, or any three-wheeler car, whose unladed weight does not exceed 400 Kg. and with a cylinder capacity not exceeding 50 c.c. This comprises motorcycles (not including mopeds, three-wheeler and invalid cars).

• **Tractor:** Rigid on-road motor vehicle designed for towing other non-motorised, on-road vehicles (articulated lorries are on-road goods transport vehicles with no forward axle, designed in such a way that part of the vehicle and part of the load rest on the tractor) and which does not include agricultural tractors, which are motor vehicles designed exclusively or primarily for agricultural use, regardless of whether they are authorised to drive on roads open to traffic.

• **Trailer:** On-road goods transport vehicle designed for being towed by an on road motor vehicle (not including agricultural vehicles which are designed for agricultural use, and regardless of whether they are authorised to drive on roads open to traffic).

• **Other vehicles:** The section "other vehicles" comprises those with a number plate and not included in the types described above, such as cranes, public works machinery, agricultural vehicles, cleaners and other on-road motor vehicles for special purposes other than transporting passengers or goods.

**<u>Type of fuel</u>**

• **Gas-oil:** Fuel extracted from the last fraction of atmospheric refining of crude oil.

• **Petrol:** Light hydrocarbons which are refined at between 35ºC and 215ºC in order to achieve a high octane index, and which are used as fuel in internal combustion engines, with the exception of aircraft.

**<u>Frequent Deficiencies</u>**

The station network of Vehicles Inspections, which makes the current mandatory vehicle safety under current regulations, is a reflection of the fact that not all vehicles have the proper conditions for driving.

Accident statistics are that irrefutably demonstrate that proportion involved in accidents the different elements, devices, and vehicle systems.

| Type of deficiency | Important deficiencies in vehicles % |
|---|---|
| **Brakes** | 49 |
| **Lights and signalling** | 30 |
| **Shafts and suspension** | 28 |
| **Frame, engine and transmission** | 24 |

***Table 1: Types of deficiencies found in one year in Vehicles Inspections***
*(Source: M11_Aula 2 José Luis Pedragosa)*

In general, the factor of the old park has a great importance for safety and as the *table 2* shows, it is more relevant in heavy vehicles (trucks and buses).

| Age of heavy vehicles | Trucks | Buses |
|---|---|---|
| **More than 20 years** | 2,9 % | 6,5 % |
| **20 years** | 9,0 % | 17,3 % |
| **10 years** | 26,0 % | 18,9 % |
| **5 years** | 32,0 % | 22,7 % |
| **1 year** | 11,1 % | 6,3 % |

***Table 2: Percent of age of heavy vehicles.***
*(Source: M11_Aula 2 José Luis Pedragosa)*

**Power and Speed**

Excessive speed is direct or indirect responsible for the cause of accidents and the level of impact. Finch et al. (1994) noted that reducing speed with 1 km/h could lead to a 3% less accidents risk. Accident frequencies and fatality rates increase more than proportionally when speed levels increase (Elvik, 2004), especially when certain speed limit is exceeded. Inappropriate speed is responsible for one-third of the accidents resulting in vehicle occupant fatalities (ETSC, 1995). Speed reduction is not only to the benefit of road safety but can also leads to a reduction of fuel consumption and CO2 emissions (Kroon, 1998; Auto Bild, 2006).

Vehicles, and especially cars, are developing all the time. This also affects the drivers' speed choice directly or indirectly.

In the first place, the driving comfort has substantially increased during the past decades. The noise level and vibrations inside the car at high speeds have decreased considerably. This is especially the case for larger and heavier cars, but it also applies to smaller vehicles. Therefore, such signals of driving too fast have almost completely disappeared.

In the second place, the engine power of cars has increased considerably over the years, making greater acceleration and higher top speeds possible (De Mol, 2001). In fact, the top speed of the vehicle can only determine the speed choice on roads where this top speed is also physically possible. This will only be the case on some parts of the motorway network, and only when little or no other traffic is around. However, there are indications that drivers of high-powered vehicles also drive faster on secondary roads (Horswell & Coster, 2002). These researchers found that this should be attributed partly to the fact that a car's greater power leads to choosing higher speeds and partly to the fact that 'speeders' simply choose a high-powered car.

The relation between speed and safety rests on two pillars. The first pillar is the relation between collision speed and the severity of a crash; the second pillar is the relation between speed and the risk of a crash. The higher the collision speed, the more serious the consequences in terms of injury and material damage.

Relatively many studies have examined the relation between absolute speed and crash rate. Irrespective of the research method used, practically all the studies concluded that the relation between speed and crash rate can best be described as a power function: the crash rate increases more rapidly when the speed increases and vice versa (see *Figure 1*).

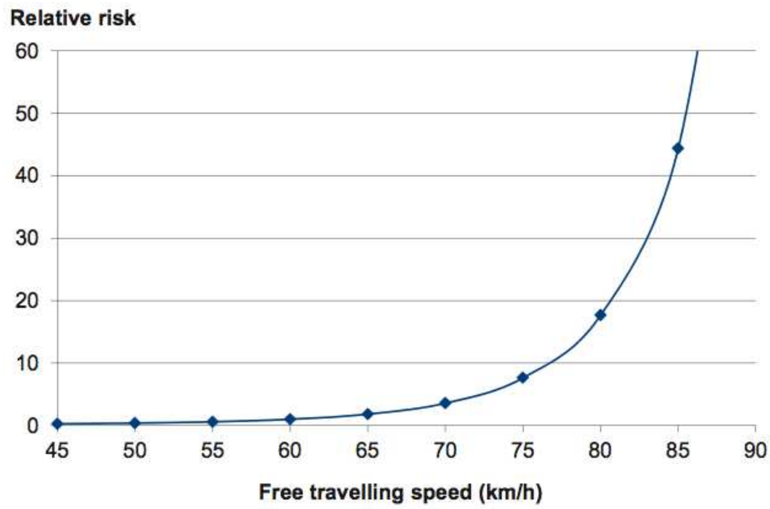



***Figure 1: Risk of involvement in a crash in a 60 km/h speed zone depending on speed***
*(Source: Victorian Auditor-General's Office based on data from the Road Accident Research Unit)*

During the past decades, vehicles have become ever better equipped (with crush areas, airbags and seatbelts) to absorb the energy released in a crash, thus protecting the occupants. However, the collision speed still is very important for the crash outcome.

**Weight and Size**

Besides speed, the mass of the vehicles involved is important for the outcome of a crash. In collisions between two vehicles of different mass, the occupants of the lighter vehicle are generally considerably worse off than those in the heavier vehicles. The difference in mass determines which vehicle absorbs which part of the released energy. Generally speaking, the energy absorption is inversely proportional to the masses of the vehicles.

Vehicle masses can differ enormously. This is particularly true for lorries and cars, between which the mass difference can amount to a factor of 10 or more.

Heavier vehicles can also influence the impact of accidents when vulnerable road users are involved. Roudsari et al. (2004) noted that the change in vehicle design and increase in the number of light truck vehicles (heavier vehicles, pickups, etc.) have led to changes in pedestrian injury profile. The risk of death when pedestrians were stroke by heavier vehicles was around 3 times higher than that for (normal) passenger vehicles

The incompatibility in collisions between vulnerable road users and practically any type of motor vehicle is of a completely different order. There are mass differences from a factor of 10 (light cars) to nearly 700 (lorries of 50 tons). In addition, pedestrians, cyclists and motorcyclists do not have an 'iron cage' around them that can absorb some of the energy released in a collision. For example, in a collision between a car and a cyclist or pedestrian, the survival rate of the latter two decreases enormously as the car's collision speed increases.

**Power to weight**

Power-to-weight ratio (or specific power or power-to-mass ratio) is a calculation commonly applied to engines to enable the comparison of one unit or design to another. It is also used as a measurement of performance of a vehicle as a whole, with the engine's power output being divided by the weight (or mass) of the vehicle, to give a metric that is independent of the vehicle's size.

Increasing the weight and the power of motor vehicles increases the emissions and has an important impact on road safety. Reducing the power to weight-ratios of motor vehicles is one of most effective ways to reduce vehicle fuel consumption. Putting limits on maximum power to weight ratios could also produce significant safety benefits (OECD 2004).

Power to weight ratios are important but within built up areas this alone will not solve all the speed related problems. Maximum vehicle speeds should be restricted to levels more consistent with highway and motorway speed limits (OECD, 2006).

### 2.2.2 Road infrastructure

For road traffic safety purposes it can be helpful to classify roads into ones in built-up area and non-built-up areas.

| Environment | Category of roads | Main functions |
|---|---|---|
| **Non built up areas** | Motorway (interurban) | Flow |
| | Main highways (principal interurban roads) | Flow |
| | Rural main roads | Flow/distribution |
| | Rural minor roads | Access |
| **built up areas** | Motorways (urban) | Flow |
| | Urban arterial roads and main roads | Flow/distribution |
| | Urban residential roads | Access |

***Table 3: Road categories and functions***
*(Source: OECD, 2006)*

Today, roads are without doubt safer than a few decades ago, despite the fact that the road transport performance has considerably increased. *Figure 2* outlines that the majority of the fatalities occur in accidents outside built-up areas, whereas motorways appear to be the safest.

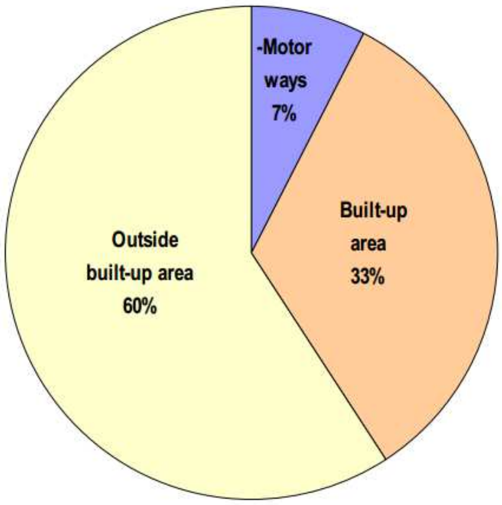



***Figure 2: Share of fatalities by type of road, 2002***
*(Source: Eurostat)*

**Built-up areas (Urban roads)**

In this environment there are many neighbourhood roads where many vulnerable road users, such as pedestrians (See *Figure* 3) and bicyclists can be found. **Traffic calming** measures are good solutions in order to slow down or reduce motor-vehicle traffic as well as to improve safety for these group of vulnerable road users.

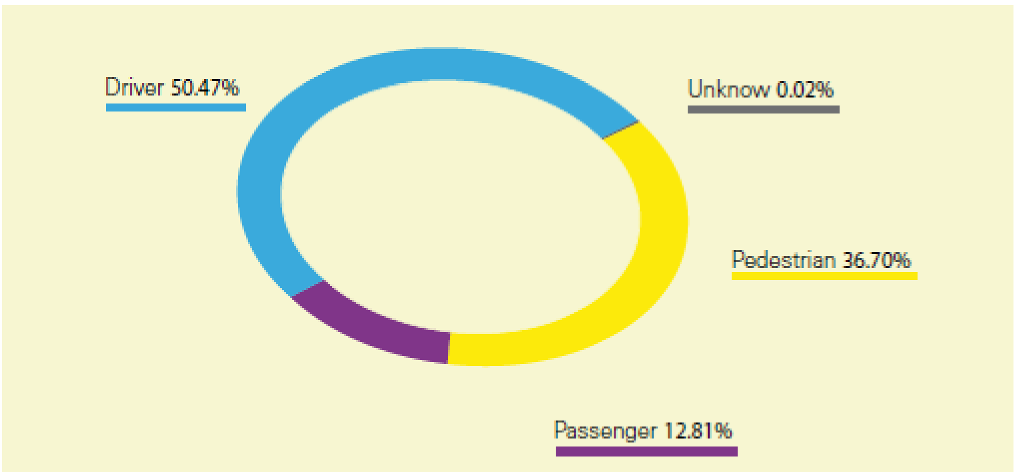



***Figure 3: Urban Roads. Fatalities at 30 days by road user type in EU countries***
*(Source: CARE)*

Often these measures have been implemented in response to conflicts between the needs of different groups of road users which led to an increase in accidents. The increase in such risks has inspired a lot of designers to re-design urban streets and spaces, in order to decrease the space dedicated to through traffic and to manage the speed of through-traffic on a scale much closer to the desires and needs of pedestrians, cyclists and other vulnerable road users.

Low speeds may be crucial for road safety in particularly sensitive locations. Examples include: in residential areas, near schools or homes for the elderly, at pedestrian crossings and/or at intersections. At such locations, physical speed-reducing measures such as speed humps, cushions, road narrowing's, plateaus in intersection areas and roundabouts, can help to ensure cars maintain safe speeds.

**Non-built-up areas (Motorways and Rural roads)**

Major highways, including **motorways** and freeways, are designed for safer high-speed operation and generally have lower levels of injury per vehicle km than other roads. Motorways are the safest road environment for fast moving traffic and, except for measures to ease congestion such as ramp metering and variable speed limits, they are not usually subject to additional infrastructure measures for speed management purposes.

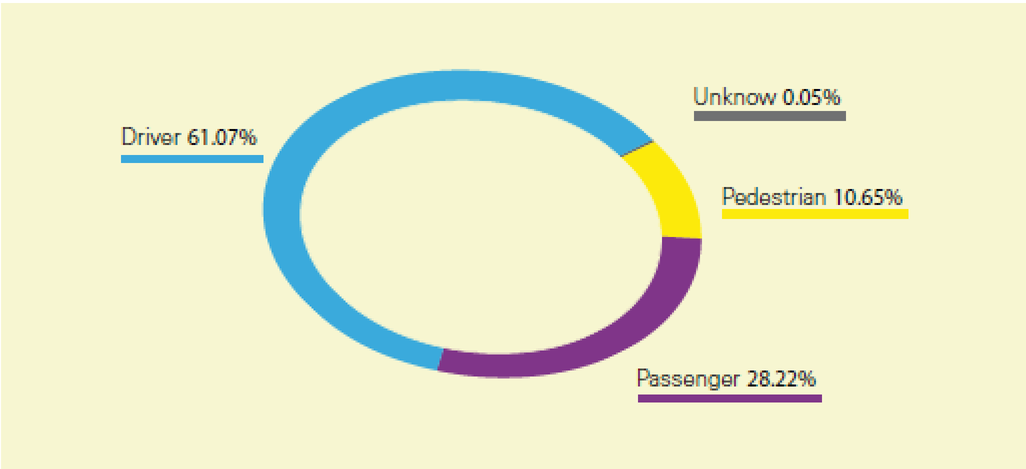



***Figure 4: Motorway. Fatalities at 30 days by road user type in EU countries***
*(Source: CARE)*

By contrast, in most industrialised countries, **rural roads** carry the greatest risk of death and injury. Drivers running off the road and colliding with road side objects in single vehicle accidents is a major problem on the rural network in many countries. It is expensive and impractical to apply infrastructure-based speed management measures to the entire network to prevent these accidents.

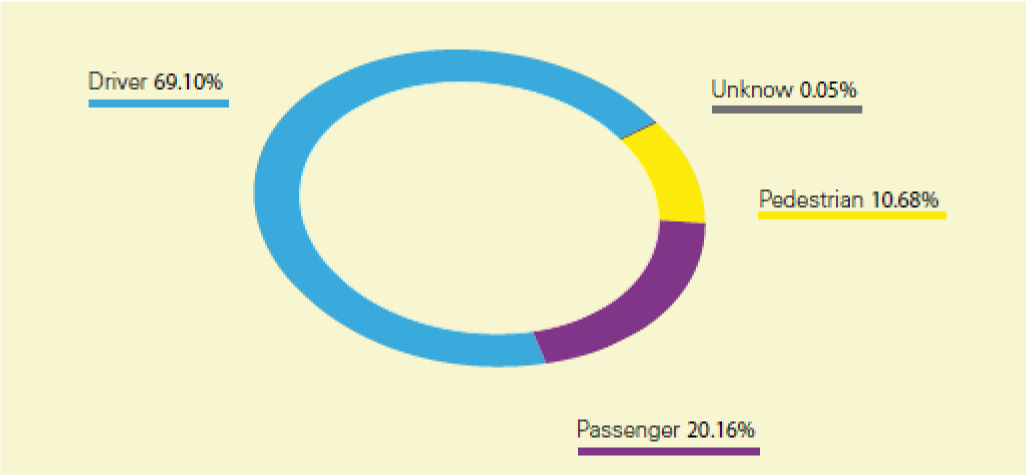



***Figure 5: Rural Road. Fatalities at 30 days by road user type in EU countries***
*(Source: CARE)*

However, local improvements to rural roads can be made by removing roadside obstacles such as trees, utility and sign poles, to make the road safer and more forgiving in the most dangerous locations. A highly effective solution for rural roads – which requires long-term planning – would be to separate traffic travelling in opposite directions, using for example median barriers. Some countries, such as Sweden, are progressively upgrading their highest risk rural roads to this standard. However, it is evident that for most countries resource constraints prevent this measure being carried out on a large scale.

**<u>Bad weather and night driving</u>**

Inclement weather, including heavy rain, hail, snowstorms, ice, high winds and fog can make driving more difficult. Drivers need more time to stop and may have trouble seeing the road clear. If the weather gets bad so do the roads. Car accidents happen very often in bad weather because it creates slick and dangerous surfaces for cars, trucks, and motorcycles and often causes automobiles to spin out of control or skid while braking.

Driving in the daylight can be hazardous, but driving at night nearly doubles the risk of a car accident occurring. Since your ability to perceive and judge distance is severely impaired at night — the human eye requires light to see — night driving is a top cause of car accidents. An estimated 90 percent of all driver decisions are made based on what they see. While your eyes are capable of seeing in limited light, the combination of headlights and road lights, with the darkness beyond them, can cause several problems for your vision. Therefore, car drivers must take extra precaution to avoid an auto accident during the night.

Car accident statistics are jarring at night. Despite 60 percent less traffic on the roads, more than 40 percent of all fatal car accidents occur at night. Driving either just before sunrise (dawn) or immediately after sunset (dusk) are also very dangerous time periods on the roadways, and many car accidents occur during these times. The problem is that while the sky is still well lit, the roads begin to get dark. This causes a disparity between light and dark and can cause vision problems for drivers.

There are relatively few studies that provide statistics on crash occurrence relative to time of day, and that also take into account distance driven. Swedish data from 1994 to 2000 on time distribution of crashes showed that 18–24 year-old drivers were over-represented at all times, but especially during night hours (Gregersen and Nyberg, 2002). In particular, 32% of 18-19 year-old drivers' crashes occurred during darkness, while the corresponding share for other ages was 22%. The difference was especially high on Friday nights between 19:00 and midnight, and Saturday nights between 19:00 and 2:00 am.

### 2.2.3 Driver

Almost unanimously the opinion of experts agrees to conclude that the person, with their flaws and limitations, is the main cause of the accident. It is justified, therefore, that the research effort and the formulation of preventive measures are oriented especially towards the conduct of users, which, as a result of their attitudes, is the factor that most can influence the generation of risks.

In a traffic accident, in most cases, the risk is consummated before either because drivers have not realized that it was about to occur or because they have not reacted in the time available to carry out the necessary evasive manoeuvre. Therefore, the immediate phase previous to the accident is what usually configure the degree of probability that this will occur and the level of severity of their consequences.

**Experience, age and gender**

Where experience-related factors are concerned, learning to drive takes time and needs extensive practice in order to reach a sufficient competence level – this is true for everyone, not just the young.

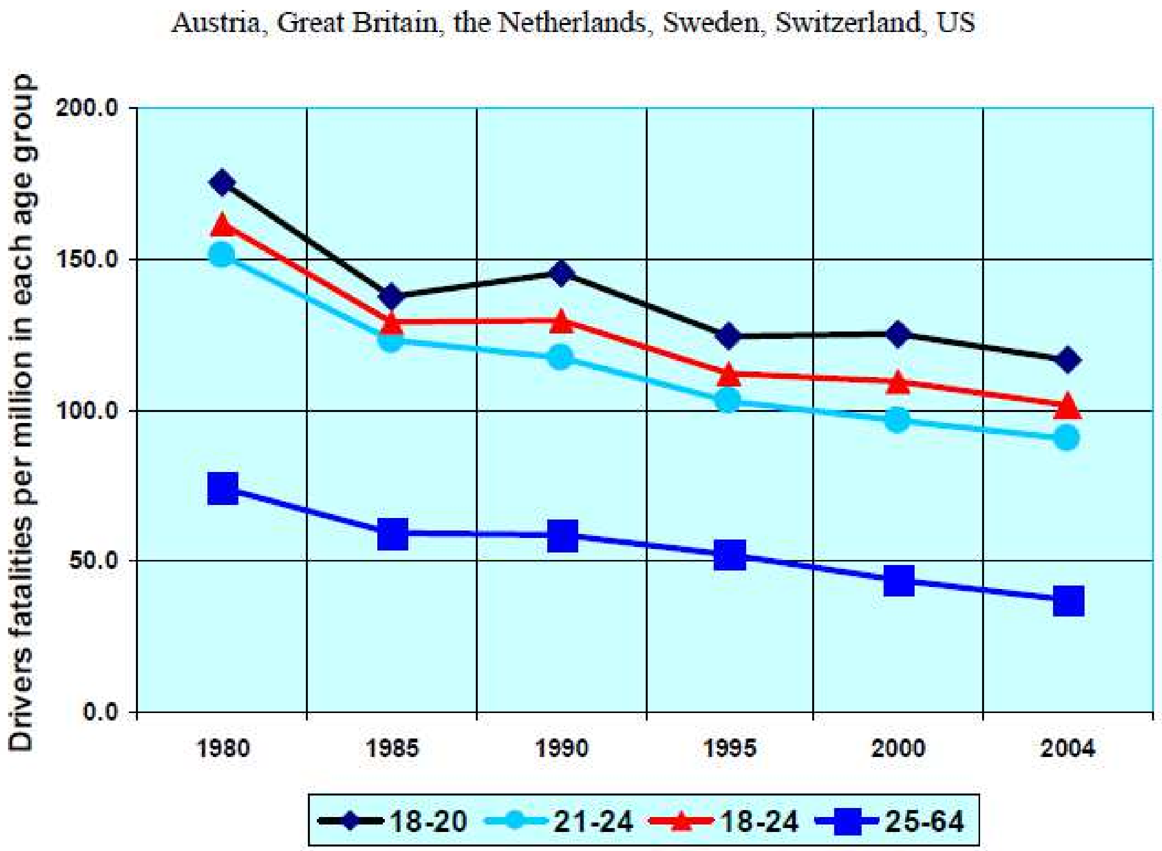



***Figure 6: Driver fatalities per million population for different age groups, over time***
*(Source: ITARD)*

With time, the actions of driving – changing gears, looking in the rear-view mirror, steering, correctly assessing situations, reacting appropriately, etc. – become automated. However, for the novice driver, these actions require consideration, increasing overall mental workload and possibly distracting attention from the road. Thus, novice drivers' attention is easily overloaded, and their ability to combine simultaneous actions is relatively poor. At the same time, because serious crashes are relatively rare events, new drivers are not provided with the sort of negative feedback that might induce them to drive more carefully, while they might also be motivated to arrive at a destination as quickly as possible, as well as by other factors, such as peer pressure or a desire to "show off".

Data show that driver crash involvement decreases as the licensing age for solo driving increases, indicating that age factors play a role in causing crashes. Indeed, physical and emotional immaturity, as well as the lifestyles associated with youth, can increase crash risk and severity. Young people are typically in a period of rapid maturation, whereby they test boundaries and assert independence. They are at a stage in life that is often intensely social, including being active at night and on weekends, in groups, and sometimes involving alcohol and/or drugs.

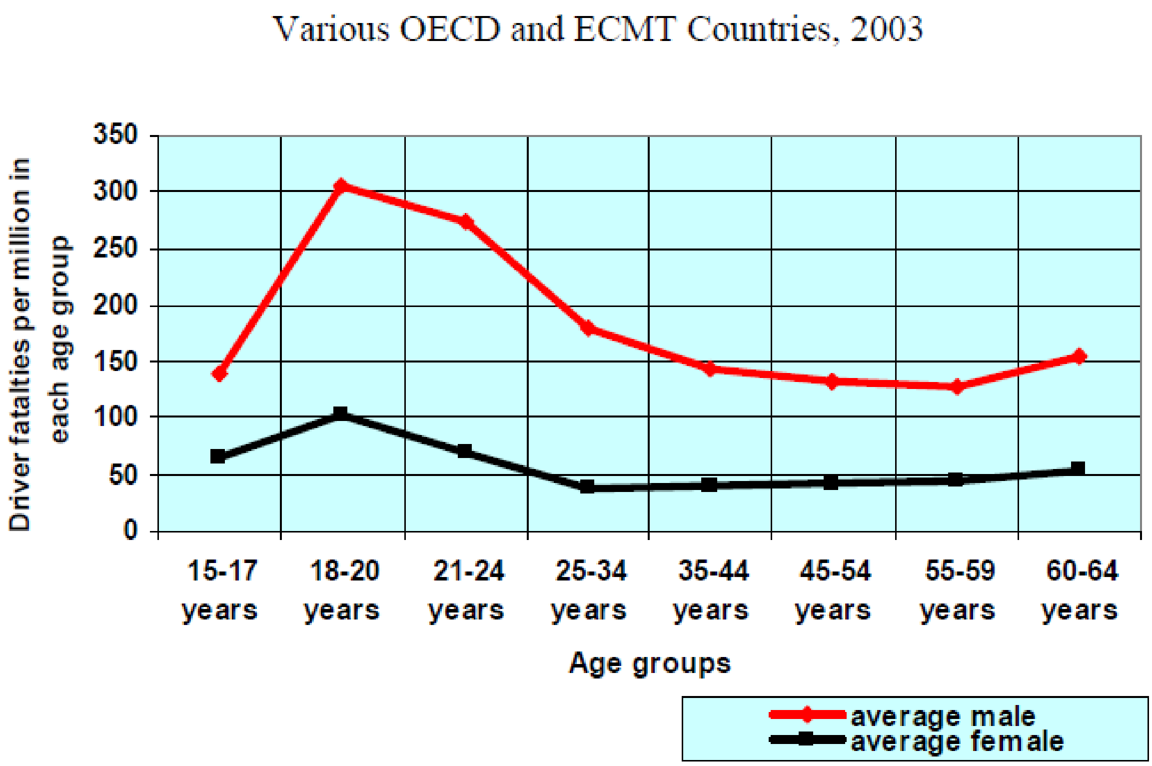



***Figure 7: Road-user fatalities by gender and age per million population***
*(Source: ITARD, OECD)*

Young male drivers' risk levels are much higher than those of young females, even when exposure is taken into account. Young males drive more than females. In Finland, for example, women drive half as much (Laapotti, 2003). However, the type of driving is also important. Qualitatively, females' driving exposure often includes less exposure to risk than that of males. Young females drive proportionally more in built-up areas, where crashes are likely to be less severe, and more often prefer to avoid bad weather conditions (Forsyth et al., 1995; Laapotti, 2003). Young males typically drive more during leisure time and at night, with friends and passengers, and have more crashes under these circumstances (Rolls et al., 1991, 1992; Begg and Langely, 2001; Laapotti, 2003).

According to Laapotti (2003), young males and females behave differently as drivers. Overall, female drivers tend to be more safety-oriented than males (Meadows and Stradling 1999; Laapotti 2003). Laapotti et al. (2001) conclude that gender differences in young drivers' behaviour may be explained by their different "goals for life and skills for living". The meaning of driving is different to females and males. While females tend to travel directly from one place to another, males spend more time simply driving for the sake of driving.

**Speed and reaction time**

The preconditions that the vehicle circulates (seniority, status, speed) and the conductor psychophysical condition, are those that determine the level of response that can resolve the conflict or not. Alterations reflexes and the reaction time of the driver are the main factors that cause accidents.

Speed is one of the basic risk factors in traffic (Wegman & Aarts, 2006). Higher driving speeds lead to higher collision speeds and thus to severer injury. Higher driving speeds also provide less time to process information and to act on it, and the braking distance is longer. Therefore the possibility of avoiding a collision is smaller.

The reaction time is the period which elapses between recognition of the object, the decision to brake and the time it takes for the foot to hit the brake pedal. The reaction time is not a fixed value: it ranges from 0.3 to 1.7 s, depending upon the driver and on external factors.

| | Reduction down to 0.3 s ← | → Extension up to 1.7 s |
|---|---|---|
| **A) Personal factors** | Trained, reflexive response | Inexperienced, uncoordinated response |
| | Good frame of mind; optimum performance potential | Poor frame of mind, e.g. fatigue |
| | Highly skilled driver | Lower level of driving skill |
| | Youth | Advanced age |
| | Anticipation | Inattentiveness, distraction |
| | Physical and mental health | Health disorders in response groups |
| | | Panic, alcohol |
| **B) Extraneous factors** Traffic situation | Uncomplicated, easily comprehended, predictable, familiar | Complicated, difficult to comprehend, unpredictable, rarely encountered |
| Type of perceived object | Explicit, conspicuous | Equivocal, inconspicuous |
| Location of perceived object | Within field of vision | At edge of field of vision |
| Nature of control element | Logical layout of mechanic controls | Poor layout of mechanical controls |

***Figure 8: Effect of personal and extraneous fact reaction time***
*(Source: BOSCH – Electronic Automotive Handbook, 2002)*

**Fatigue**

Fatigue is often ranked as a one of the factors in causing road crashes although its contribution to individual cases is hard to measure and is often not reported as a cause of crash. Driver fatigue is particularly dangerous because one of the symptoms is decreased ability to judge our own level of tiredness.

Fatigue is more likely to be a factor in crashes in rural areas as they can involve long trips and extensive periods of continuous driving, however anyone can be affected by fatigue.

If you don't get enough sleep you go in to sleep debt and you owe yourself more sleep. The only way to repay this debt is by sleeping. Until you catch up on your sleep, you will have a greater risk of having a fatigue related crash. Estimates suggest that fatigue is a factor in up to 30% of fatal crashes and 15% of serious injury crashes.

Research has shown that not sleeping for more than 17 hours has an effect on driving ability the same as a Blood Alcohol Concentration (BAC) of 0.05. Not sleeping for 24 hours has the same effect of having a BAC of 0.10, double the legal limit.

**Alcohol**

Alcohol is one of the leading causes of accidents, leading to many injuries and deaths. Because alcohol is a depressant, it slows down the brain and affects the body's responses. Drinking alcohol:

- affects driver judgement and reasoning
- slows down driver reactions
- upsets driver sense of balance and coordination
- impairs driver vision and hearing
- makes driver lose concentration
- makes driver drowsy.

Alcohol acts as a depressant of the central nervous system activity and decreases due to the skills of the driver. This deterioration of the ability to drive increases the risk of having an accident and likely even that it exists in rates of alcohol less than 0.2 grams of alcohol per litre in the blood. It is clear that the major causes of traffic accidents-producing are those that affect significantly the reaction time of the driver. They are widely two: alcohol (which extends this time exponentially depending on the volume and the graduation of ingested drinking) and speed (which subtracts possibilities for manoeuvring of avoidance or correction, and at the same time, in the event of a collision, aggravated damages to people and things).

People who have been drinking are more likely to take risks, further increasing the likelihood of accidents. Moreover, they suffer more serious injuries than those who haven't been drinking. As a result of research conducted in different countries, the average on the responsibility of the alcohol in the production of road accidents has been determined:

- 34 to 59% of fatal accidents.
- From 15 to 26% of accidents with serious injuries.
- 10% of accidents without victims.

Additionally, according to Waller, JA. (1990) people who have had an accident while drunk may be less likely to seek medical help. It's also harder for doctors to diagnose serious conditions like head injuries when a patient is drunk. Alcohol can interfere with anaesthetic and other medication, meaning operations and treatment may need to be delayed.

Alcohol, speed and fatigue are clearly three key risk factors and should therefore be addressed in risk assessments and the consequential preventive actions. The period of greatest risk in the 3 factors together is a weekend night.

## 2.3 Analysis of road accidents in EU (Lithuania, Spain and Sweden)

Despite the important decrease in the number of deaths in the European roads during the last decade (See *figure 4*), there are certainly many more actions to be taken in order to achieve a further decrease of road accident victims in Europe. Road safety is considered to be a high priority issue in all European countries and consequently many efforts have been made to implement safety measures that will contribute to improving the situation.

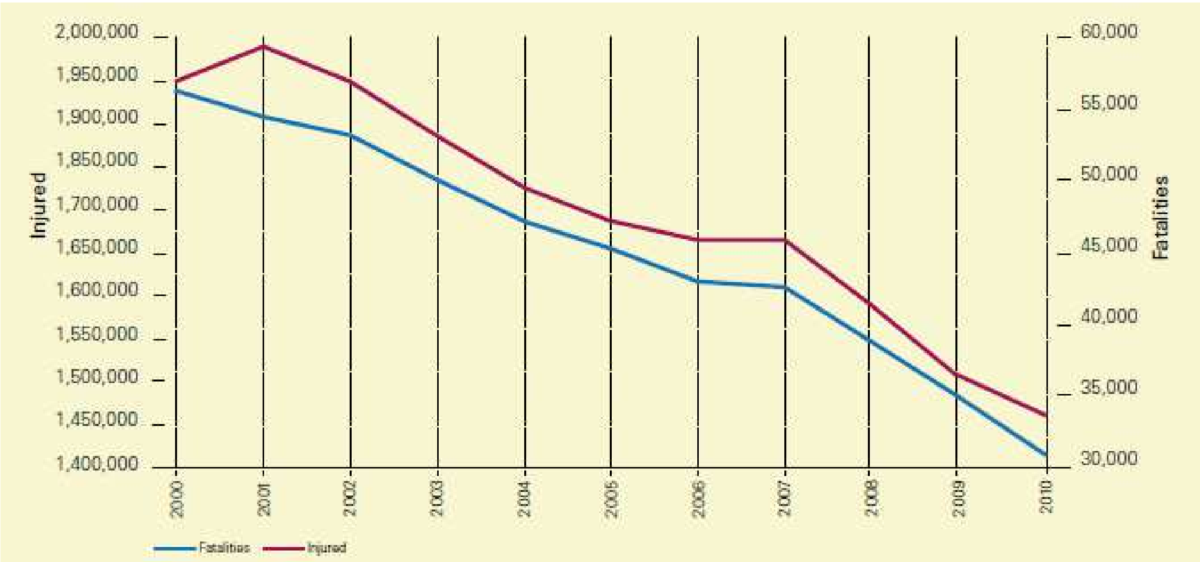



***Figure 9: Evolution of road fatalities and injured in EU-27 -2000-2010***
*(Source: CARE)*

Road safety is not equally distributed across Europe. The risk of being killed or injured in a road accident is much higher in some European countries than in others. A "North-South divide" exists in European transport safety: while North-Western European countries have developed and implemented plans and policies that have significantly improved road safety, Southern European countries generally suffer from greater road risk.

This contrast between safer and less safe Member States has become even more pronounced after the accession to the European Union of ten new countries in 2004. Several new Member States already suffered from low levels of traffic safety and an increase in the volume of road transport following their accession might well lead to an increase in accidents. In addition to a North-South divide in traffic safety, there is now also an East-West divide.

### 2.3.1 Comparison of road accidents

There is no reason to believe that these differences cannot be reduced or eliminated by improving traffic safety in the less safe countries. In this part, this thesis analyses Lithuania, Spain and Sweden to understand these dissimilarities due to geographical location.

| Road fatalities | | | | | |
|---|---|---|---|---|---|
| per million inhabitants | | per million passenger cars | | per billion pkm* | |
| LT | 224 | RO | 711 | RO | 39.8 |
| LV | 178 | BG | 590 | BG | 32.8 |
| EE | 152 | LV | 520 | HU | 27.1 |
| EL | 149 | LT | 498 | LV | 25.6 |
| PL | 137 | HU | 446 | PL | 23.5 |
| BG | 135 | SK | 439 | SK | 21.5 |
| SI | 131 | PL | 408 | LT | 19.1 |
| HU | 129 | EE | 389 | EE | 17.5 |
| RO | 115 | EL | 375 | EL | 17.4 |
| CY | 111 | SI | 270 | CY | 16.7 |
| SK | 107 | CZ | 264 | CZ | 14.6 |
| CZ | 104 | CY | 236 | PT | 13.1 |
| BE | 101 | PT | 228 | IE | 13.0 |
| IT | 96 | BE | 216 | ES | 11.7 |
| ES | 93 | IE | 211 | SI | 11.3 |
| PT | 92 | ES | 201 | AT | 10.0 |
| AT | 88 | EU-27 | 189 | BE | 9.6 |
| EU-27 | 87 | AT | 175 | EU-27 | 9.0 |
| IE | 86 | IT | 162 | IT | 7.4 |
| FR | 77 | DK | 154 | FR | 6.4 |
| LU | 76 | FR | 153 | DE | 5.7 |
| FI | 64 | FI | 136 | DK | 5.6 |
| DE | 62 | LU | 116 | LU | 5.4 |
| DK | 56 | UK | 116 | FI | 5.3 |
| UK | 54 | DE | 110 | MT | 4.9 |
| SE | 49 | SE | 107 | NL | 4.8 |
| NL | 45 | NL | 102 | UK | 4.8 |
| MT | 25 | MT | 46 | SE | 4.5 |

Note: All fatalities on the road: car drivers and passengers, bus and coach occupants, riders and passengers of powered two-wheelers, cyclists, pedestrians, commercial vehicle drivers.

* indicator based on passenger kilometres of cars and motorised two-wheelers only

***Table 4: Road fatality indicators, by country - 2006***

*(Source: DG Energy and Transport, Member States)*

According to road fatality indicators (See *table 4*) in 2006, among the EU-27 Member States and at national level, Latvia, Lithuania Romania and Bulgaria displayed the highest number of persons killed in road accidents. In Belgium, Estonia and France for example, the number of deaths has significantly dropped in recent years. These countries and several North-Western European countries could serve as examples of best practice to inspire other poorly performing countries.

North-West European urban regions were the safest as regards the number of fatalities in road accidents per million registered passenger cars. Thus, passenger car density in a region is inversely proportional to the number of fatalities in road accidents: the higher the passenger car density, the 'safer' the region.

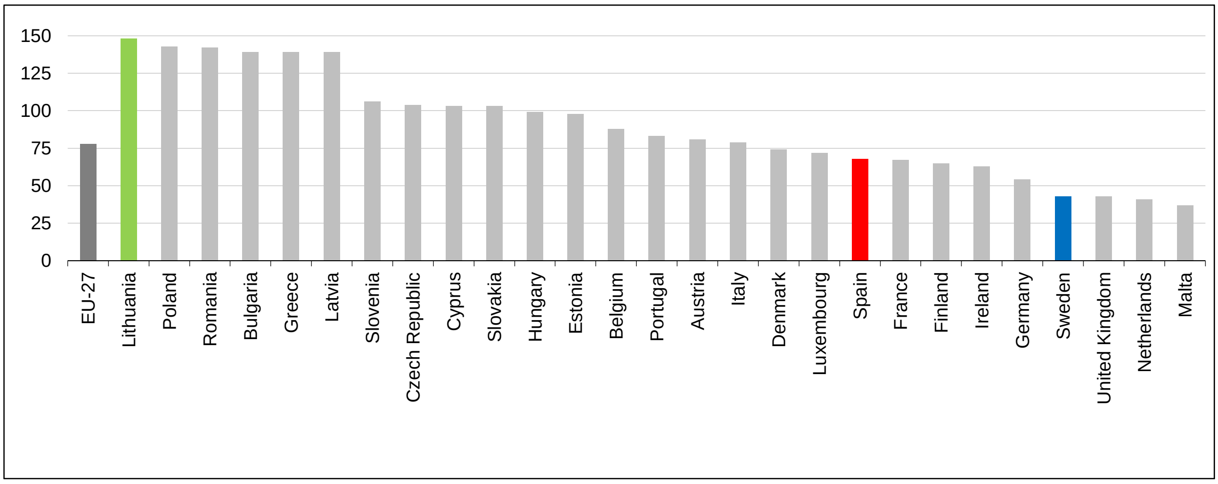



***Figure 10: People killed in road accidents per million inhabitants, 2008***
*(Source: Eurostat, CARE)*

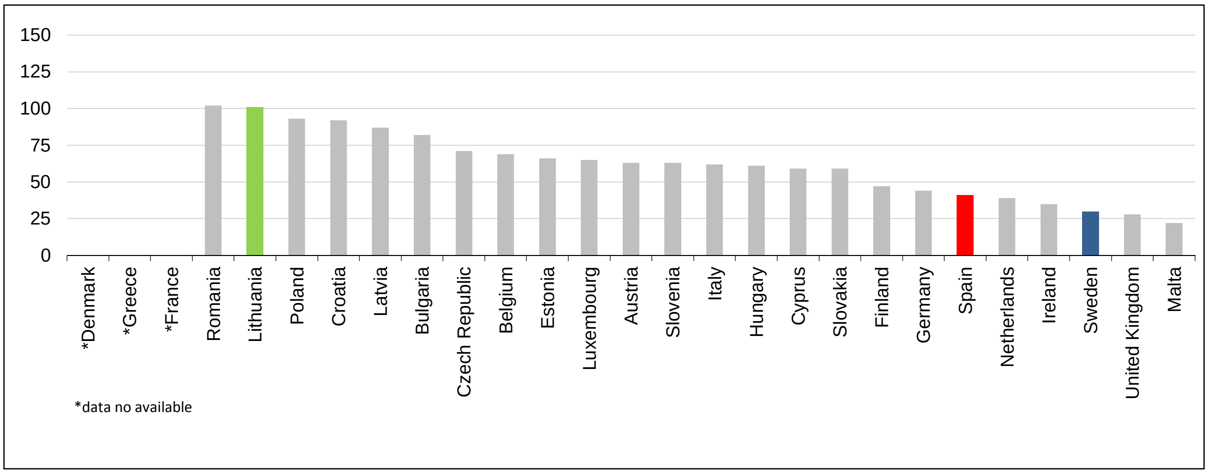



***Figure 11: People killed in road accidents per million inhabitants, 2012***
*(Source: Eurostat, CARE)*

During the last ten years, considerable progress in road safety was achieved in all countries for which data is available; in Lithuania, Spain and Sweden have decreasing road accidents tendency. The reasons for which numbers of road deaths have been declining are many and they include: safer cars and infrastructure, both stricter laws and a better perception of the risks connected with not wearing seat belts and helmets, speeding and drink-driving.

However, Lithuania still has the worst road indicators and the last two years they have increased. In contrast, Spain has a very good results due to it has been improving during the last ten years. Finally, Sweden has one of the best indicators in EU and the tendency is more flat.

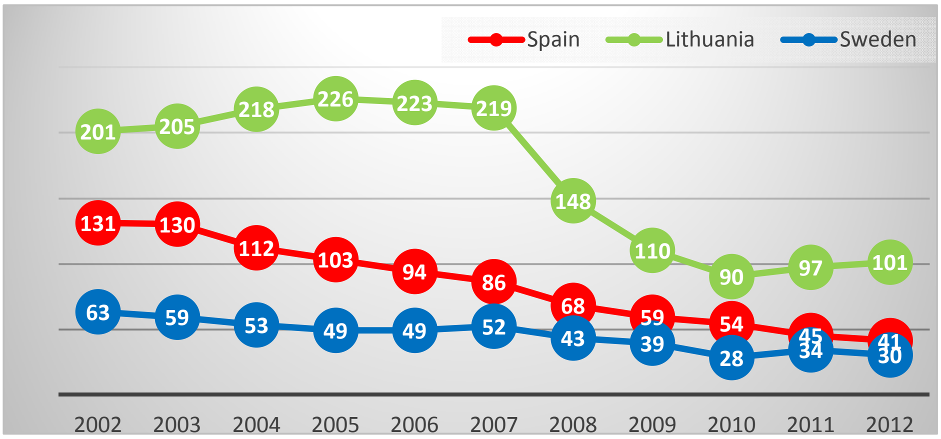



***Figure 12: People killed in road accidents per million inhabitants, 2002-2012***
*(Source: Eurostat, CARE)*

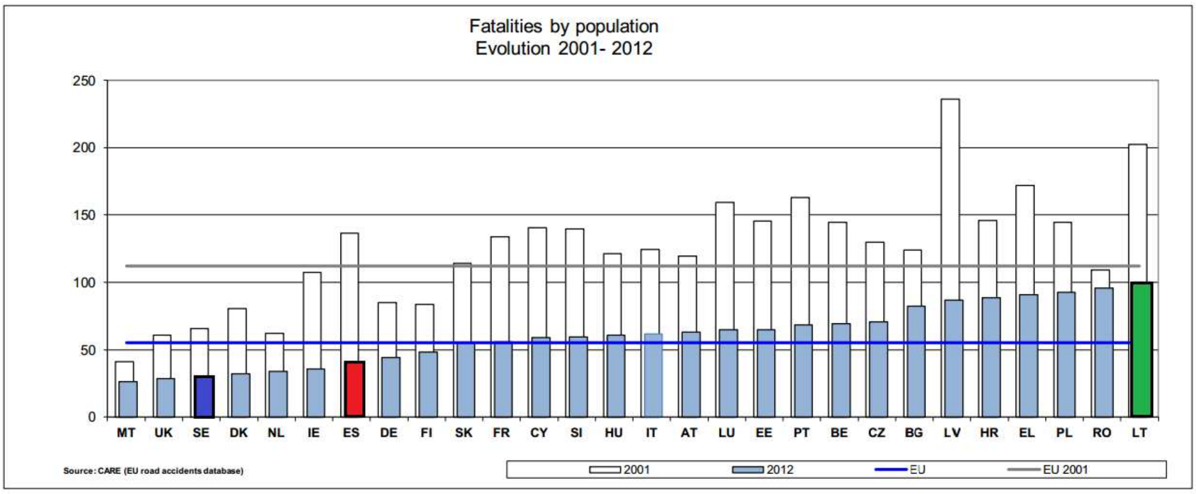



***Figure 13: Fatalities by population, evolution 2001-2012***
*(Source: CARE)*

Lithuania is the only of those three analysed countries that is still above the EU-27 average. However, it has reduced a half the fatalities in comparison to 2001 (See *figure 14*).

### 2.3.2 Lithuania

| Capital | Inhabitants | Vehicles/ 1.000 inhabitants | Road fatalities in 2012 | Fatalities/million inhabitants in 2012 |
|---|---|---|---|---|
| **Vilnius** | 3.0 million | 656 | 302 | 101 |

***Table 5: Summary table of Lithuania***
*(Source: Transport and Road Research Institute)*

**Risk and rates**

The number of road fatalities peaked in 1991. Since then it has decreased by more 70%. Between 1990 and 2011, the death rate (in terms of deaths per 100 000 population) decreased by more than 65%.

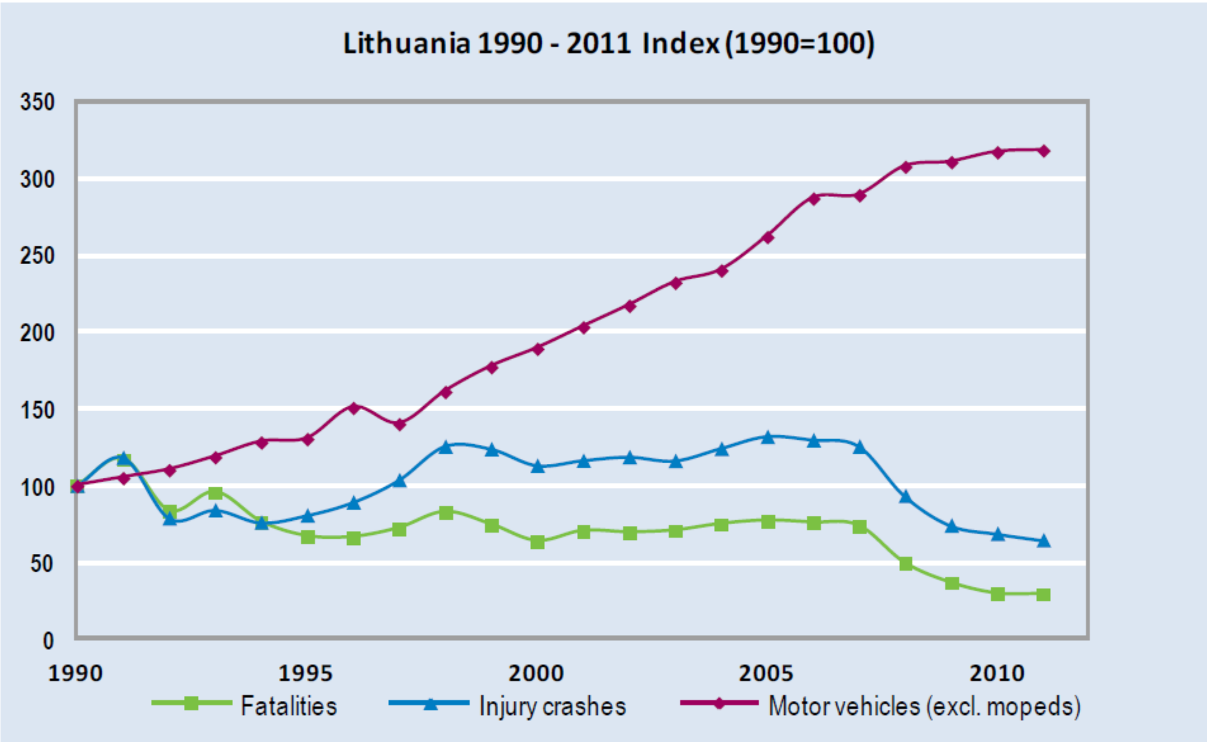



***Figure 14: Reported road fatalities, injury crashes and motorised vehicles in Lithuania 1990-2011***
*(Source: Transport and Road Research Institute)*

In 2011, the number of road fatalities and injury crashes on the roads of Lithuania was the lowest since 1980. In 2011, 3.312 fatal and injury crashes occurred in Lithuania, whereby 296 people were killed. These figures represent a 1% reduction in comparison to 2010. In comparison with year 2011, the number of fatalities (302) in 2012 has increased by 1%.

**Road users**

Despite the number of car occupants and drivers killed decreased, there was an increase in the number of pedestrians and cyclists killed.

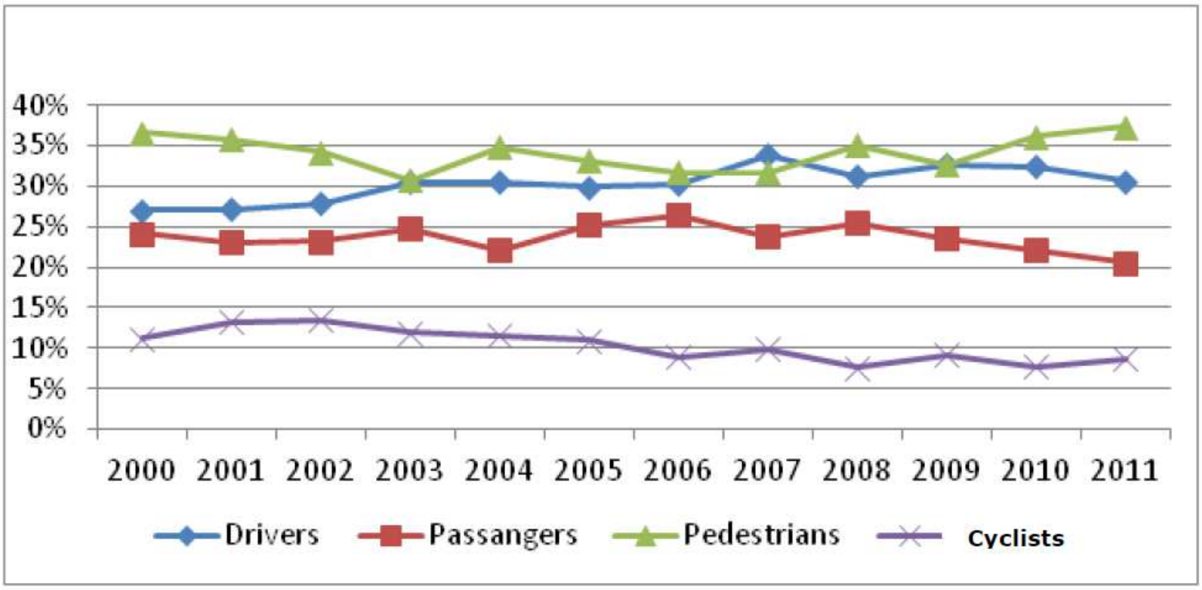



***Figure 15: Road fatalities by road user group in Lithuania year 2000-2011***
*(Source: Transport and Road Research Institute)*

Car drivers and pedestrians are the main victims of traffic crashes. Pedestrians in particular represent around one-third of casualties, a high share in comparison with other IRTAD countries.

| Traffic accidents during daylight hours | | |
|---|---|---|
| Traffic accidents | **2297** | 72,4% |
| Deaths | **166** | 55,1% |
| Injured | **2713** | 73,1% |

| Deaths | | |
|---|---|---|
| Pedestrian | **33** | 1,0% |
| Drivers | **71** | 23,6% |
| Passenger | **33** | 11,0% |
| cyclists | **22** | 7,3% |
| other | **7** | 2,3% |

| Injured | | |
|---|---|---|
| Pedestrian | **709** | 19,1% |
| Drivers | **792** | 21,3% |
| Passenger | **849** | 22,9% |
| cyclists | **253** | 6,8% |
| other | **110** | 3,0% |

| Traffic accidents during night hours | | |
|---|---|---|
| Traffic accidents | **876** | 27,6% |
| Deaths | **135** | 44,9% |
| Injured | **999** | 26,9% |

| Deaths | | |
|---|---|---|
| Pedestrian | **72** | 23,9% |
| Drivers | **32** | 10,6% |
| Passenger | **18** | 6,0% |
| cyclists | **10** | 3,3% |
| other | **3** | 1,0% |

| Injured | | |
|---|---|---|
| Pedestrian | **365** | 9,8% |
| Drivers | **282** | 7,6% |
| Passenger | **300** | 8,1% |
| cyclists | **31** | 0,8% |
| other | **21** | 0,6% |

***Figure 16: Road fatalities by road user group in Lithuania, deaths, injured and day-night 2012***
*(Source: Traffic accidents in Lithuania, 2012- Martynas Starevičius)*

## Age and Gender

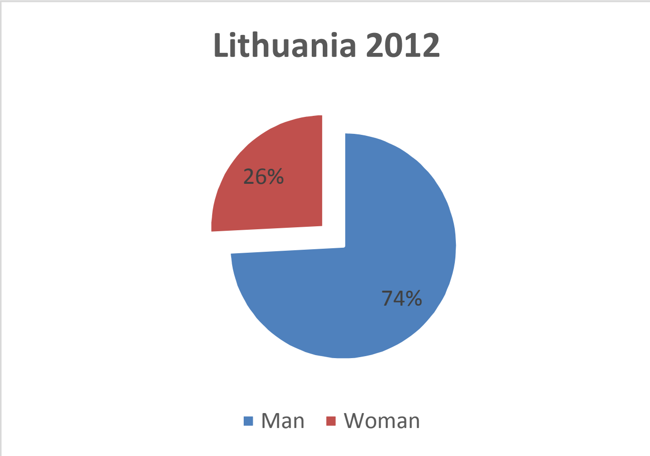



***Figure 17: Share of fatalities by gender in Lithuania, 2012***
*(Source: Personal compilation based on National sources)*

In 2012, men represented 74% of all road deaths. In contrast, women signified just the 26%.

| | 2010 | | 2011 | | 2012 | |
|---|---|---|---|---|---|---|
| **TOTAL** | **299** | **%** | **296** | **%** | **302** | **%** |
| **<6** | 1 | 0% | 3 | 1% | 2 | 1% |
| **6–9** | 2 | 1% | 4 | 1% | 2 | 1% |
| **10–14** | 4 | 1% | 6 | 2% | 8 | 3% |
| **15–17** | 10 | 3% | 6 | 2% | 2 | 1% |
| **18–20** | 18 | 6% | 21 | 7% | 28 | 9% |
| **21–24** | 25 | 8% | 27 | 9% | 29 | 10% |
| **25–34** | 40 | 13% | 30 | 10% | 45 | 15% |
| **35–44** | 35 | 12% | 37 | 13% | 43 | 14% |
| **45–54** | 55 | 18% | 50 | 17% | 50 | 17% |
| **55–64** | 44 | 15% | 44 | 15% | 43 | 14% |
| **>65** | 62 | 21% | 65 | 22% | 48 | 16% |
| **Unknown** | 3 | 1% | 3 | 1% | 2 | 1% |

| **2012** | **Men** | **Women** |
|---|---|---|
| **TOTAL** | **224** | **78** |
| **<6** | .. | **2** |
| **6–9** | .. | **2** |
| **10–14** | 6 | **2** |
| **15–17** | 2 | **..** |
| **18–20** | 24 | **4** |
| **21–24** | 25 | **4** |
| **25–34** | 42 | **3** |
| **35–44** | 31 | **12** |
| **45–54** | 37 | **13** |
| **55–64** | 31 | **12** |
| **>65** | 25 | **23** |
| **Unknown** | 1 | **1** |

***Table 6: Share of fatalities by age in Lithuania***
*(Source: Personal compilation based on National sources)*

During the last three years, the 15-24 age group increased their representation of road accidents. In 2010 represented 17% of all road deaths vs 20% in 2012. Moreover, the 86% deaths of this 20% were men.

**Speed and blood alcohol limits**

Excessive and inappropriate speed is the main cause of traffic crashes in Lithuania. Speeding by 30 km/h above the limit is considered a very serious violation with severe sanctions, including immediate licence withdrawal for novice drivers. In 2011, 16.7 % of the drivers exceeded the speed limit by more than 10 km/h.

| | Speed limit |
|---|---|
| **Urban roads** | 50 km/h |
| **Rural roads** | 90 km/h (70 km/h on gravel roads) |
| **Motorways** | 130 km/h (110 km/h in winter time) |

***Table 7: General speed limit – Passenger cars in Lithuania, 2013***
*(Source: Personal compilation based on National sources)*

The general maximum blood alcohol content authorised in Lithuania is 0.4 g/l and 0.2 g/l for novice drivers (driving experience of less than 24 months) and professional drivers.

**Road type**

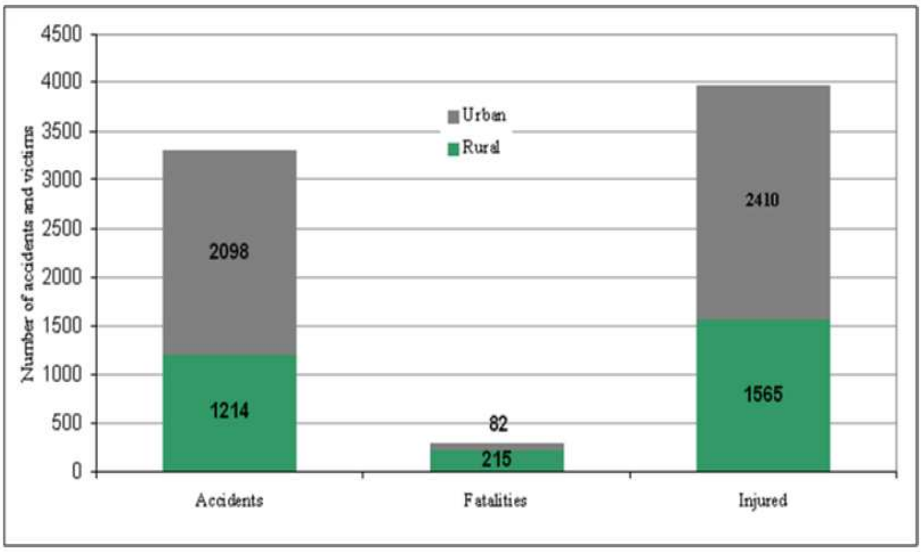



***Figure 18: Reported fatalities by road type in Lithuania***
*(Source: National sources)*

In 2012, most road crashes occurred in built-up areas. However, crashes are more severe on rural roads, where speeds are higher, cyclist and pedestrian infrastructure less developed and lighting only present on a small part of the network. The improvement in 2011 benefited both the rural and urban networks, whereas fatalities on motorways increased by 11%.

### 2.3.3 Spain

| Capital | Inhabitants | Vehicles/ 1.000 inhabitants | Road fatalities in 2012 | Fatalities/million inhabitants in 2012 |
|---|---|---|---|---|
| **Madrid** | 47.3 million | 1516 | 1903 | 41 |

***Table 8: Summary table of Spain***
*(Source: IRTAD, Dirección General de Tráfico)*

**Risk and rates**

The risk rate since 2000 has divided by three. In 2011, the number of road fatalities decreased by 16.9% compared to 2010. It is estimated that 3.6% of this important reduction can be attributed to the new methodologies to calculate road fatalities.

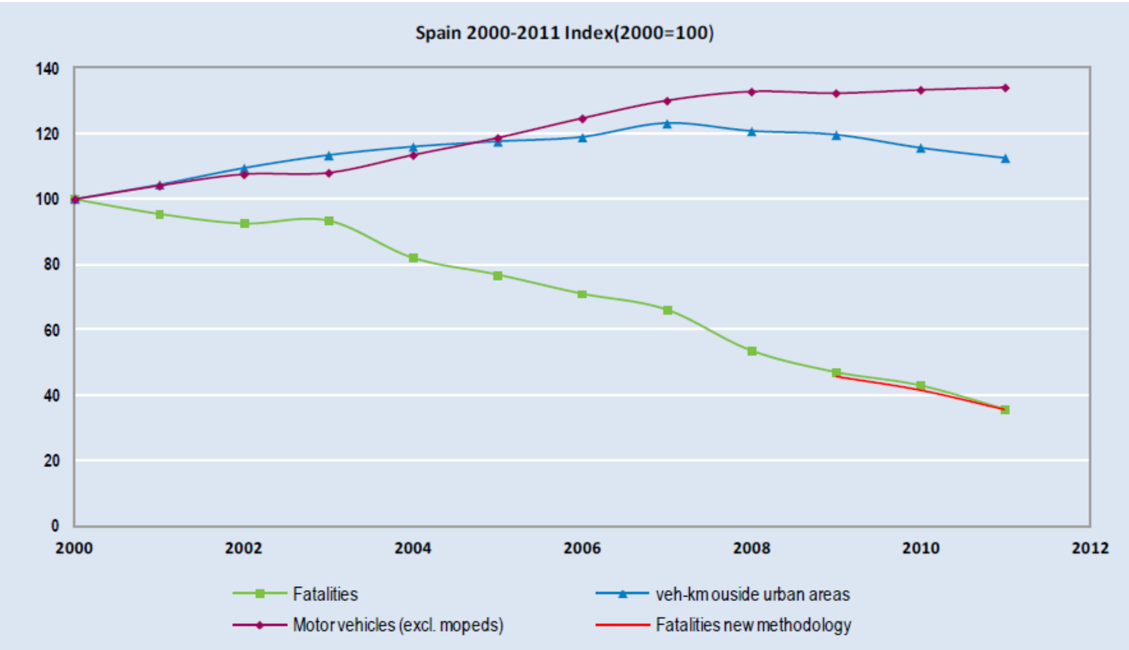



***Figure 19: Reported road fatalities, injury crashes and motorised vehicles in Spain 1990-2011***
*(Source: IRTAD, Dirección General de Tráfico)*

Data for 2012 suggest that the number of road fatalities dropped by about 11%, thus continuing the downward trend of previous years.

## Road users

In 2011, the decrease in fatalities benefited all road users, with the largest reduction for cyclists (-26.9%), moped riders (-26.0%) and pedestrians (-19.3%).

| | | | | | | | | | 2011% change over | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | | 2000 | | 2010 | | 2011* | | 2010 | 2000 | 1990 |
| **Bicyclists** | 160 | 2% | 84 | 1% | 67 | 3% | 49 | 2% | -26.9% | -41.7% | -69.4% |
| **Mopeds** | 683 | 8% | 474 | 8% | 100 | 4% | 74 | 4% | -26.0% | -84% | -89% |
| **Motorcycles and scooters** | 792 | 9% | 392 | 7% | 386 | 16% | 348 | 17% | -9.8% | -11% | -56% |
| **Passenger car occupants** | 5 034 | 56% | 3 289 | 57% | 1197 | 48% | 977 | 47% | -18.4% | -70.3% | -80.6% |
| **Pedestrians** | 1 542 | 17% | 898 | 16% | 471 | 19% | 380 | 18% | -19.3% | -57.7% | -75.4% |
| **Others** | 822 | 9% | 639 | 11% | 257 | 10% | 232 | 11% | -9.7% | -63.7% | -71.8% |
| **Total** | **9 032** | **100%** | **5 776** | **100%** | **2478** | **100%** | **2060** | **100%** | **-16.9%** | **-64.3%** | **-77.2%** |

* As of 2011, a new methodology was applied to calculate the number of road fatalities. The revised methodology explains the 3.6% (on average) of the decrease between 2011 and 2010.

***Table 9: Road fatalities by road user group in Spain year 1990-2011****

*(Source: IRTAD, Dirección General de Tráfico)*

Since 1990, all user groups, but especially car occupants and moped riders, have benefited from improvements in road safety. In recent years (2000-2011), motorcyclist fatalities showed strong increments until 2007, but this trend was broken in the following years with large reductions: by 22% in 2008, 12% in both 2009 and 2010 and 10% in 2011

## Age and Gender

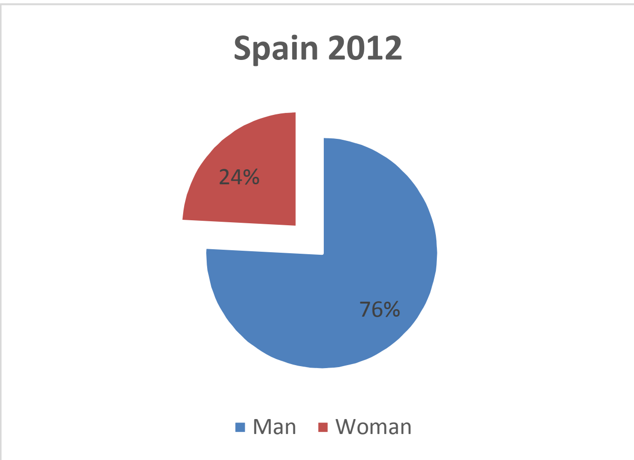



***Figure 20: Share of fatalities by gender in Spain, 2012***

*(Source: Personal compilation based on National sources)*

In 2012, men represented 76% of all road deaths. In contrast, women signified just the 24%.

| | 2010 | | 2011 | | 2012 | |
|---|---|---|---|---|---|---|
| **TOTAL** | **2478** | **%** | **2060** | **%** | **1903** | **%** |
| **<6** | 32 | 1% | 17 | 1% | 15 | 1% |
| **6–9** | 17 | 1% | 4 | 0% | 14 | 1% |
| **10–14** | 30 | 1% | 21 | 1% | 23 | 1% |
| **15–17** | 50 | 2% | 29 | 1% | 32 | 2% |
| **18–20** | 139 | 6% | 100 | 5% | 54 | 3% |
| **21–24** | 174 | 7% | 134 | 7% | 120 | 6% |
| **25–34** | 453 | 18% | 333 | 16% | 298 | 16% |
| **35–44** | 442 | 18% | 378 | 18% | 350 | 18% |
| **45–54** | 346 | 14% | 313 | 15% | 274 | 14% |
| **55–64** | 248 | 10% | 229 | 11% | 200 | 11% |
| **>65** | 529 | 21% | 484 | 23% | 507 | 27% |
| **Unknown** | 18 | 1% | 18 | 1% | 16 | 1% |

| 2012 | Men | Women |
|---|---|---|
| **TOTAL** | **1440** | **458** |
| **<6** | 9 | **6** |
| **6–9** | 7 | **7** |
| **10–14** | 17 | **6** |
| **15–17** | 23 | **9** |
| **18–20** | 34 | **20** |
| **21–24** | 99 | **21** |
| **25–34** | 248 | **50** |
| **35–44** | 301 | **49** |
| **45–54** | 225 | **48** |
| **55–64** | 148 | **52** |
| **>65** | 321 | **185** |
| **Unknown** | 8 | **5** |

***Table 10: Share of fatalities by age in Spain***
*(Source: Personal compilation based on National sources)*

During the last three years, the 15-24 age group decreased their representation of road accidents. In fact, in almost all groups of age has improve. As we can see on the *table 10,* a group of risk could be people older than 65 where the majority are men.

## Speed and blood alcohol limits

Speeding is a major concern in Spain and a contributory factor in about 24% of fatal crashes. The Directorate-General for Traffic (DGT) conducted two studies in speed on Spanish roads in 2009 and 2010. The indicators obtained describe the speed-choosing drivers in ideal conditions: very little traffic, no police presence or surveillance, good weather and favourable road sections. The measurements distinguish between daytime and night-time behaviour. For light vehicles, the average speeds are very high, especially on rural roads and at night-time, where the average speed exceeds the specified limit.

| | Speed limit | Comments |
|---|---|---|
| **Urban roads** | 50 km/h | |
| **Rural roads** | 90/100 km/h | 90 km/h (roads with no hard shoulder or with one of less than 1.5 m. width). 100 km/h (roads with hard shoulder, at least 1.5 m. wide or with two lanes or more in each direction). |
| **Motorways** | 120 km/h | |

***Table 11: General speed limit in Spain – Passenger cars, 2013***
*(Source: Personal compilation based on National sources)*

In Spain, the legal BAC limit is 0.5 g/l for general drivers and 0.3 g/l for novice and professional drivers.

**Road type**

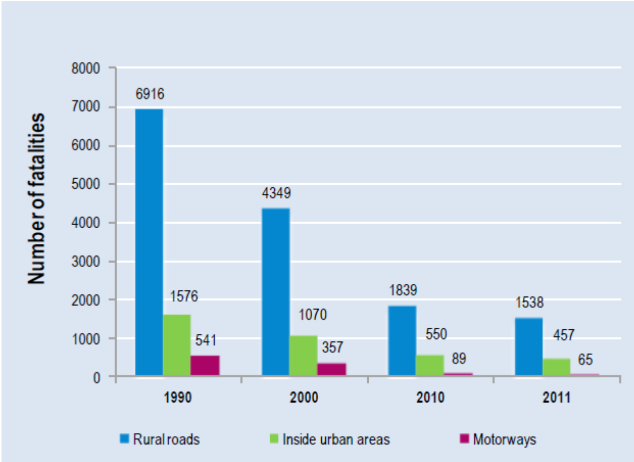



***Figure 21: Reported fatalities by road type in Spain - 1990, 2000, 2010 and 2011***
*(Source: National sources)*

In 2011, 75% of fatal crashes occurred on rural roads, 22% on urban roads and 3% on motorways. Since 2000, there have been reductions on all type of roads; the biggest being on motorways (82%), and on rural roads (65%). In urban areas the reduction was 57%.

### 2.3.4 Sweden

| Capital | Inhabitants | Vehicles/ 1.000 inhabitants | Road fatalities in 2012 | Fatalities/million inhabitants in 2012 |
|---|---|---|---|---|
| **Stockholm** | 9,5 million | 597 | 302 | 30 |

***Table 12: Summary table of Sweden***
*(Source: IRTAD, Swedish Traffic Agency, Swedish Transport Administration, VTI)*

**Risk and rates**

In 2011, 319 people were killed in a traffic crash — a 20% increase in comparison with 2010. This sharp increase needs to be interpreted with care however, as in 2010, Sweden observed a 26% decrease in road fatalities. The number of fatalities increased for all road users except for car drivers and cyclists. The relative increase was highest for the number of deceased pedestrians.

The fact that the 2011 fatality figure was higher than in 2010 does not represent a break in the overall downward trend of the past years; instead, the fatality figure for 2010 can be regarded as lower than expected in view of the risk level at the time. The low result for 2010 can also be explained by the unusually severe winter — which meant lower than usual speeds — and by a delayed recession effect.

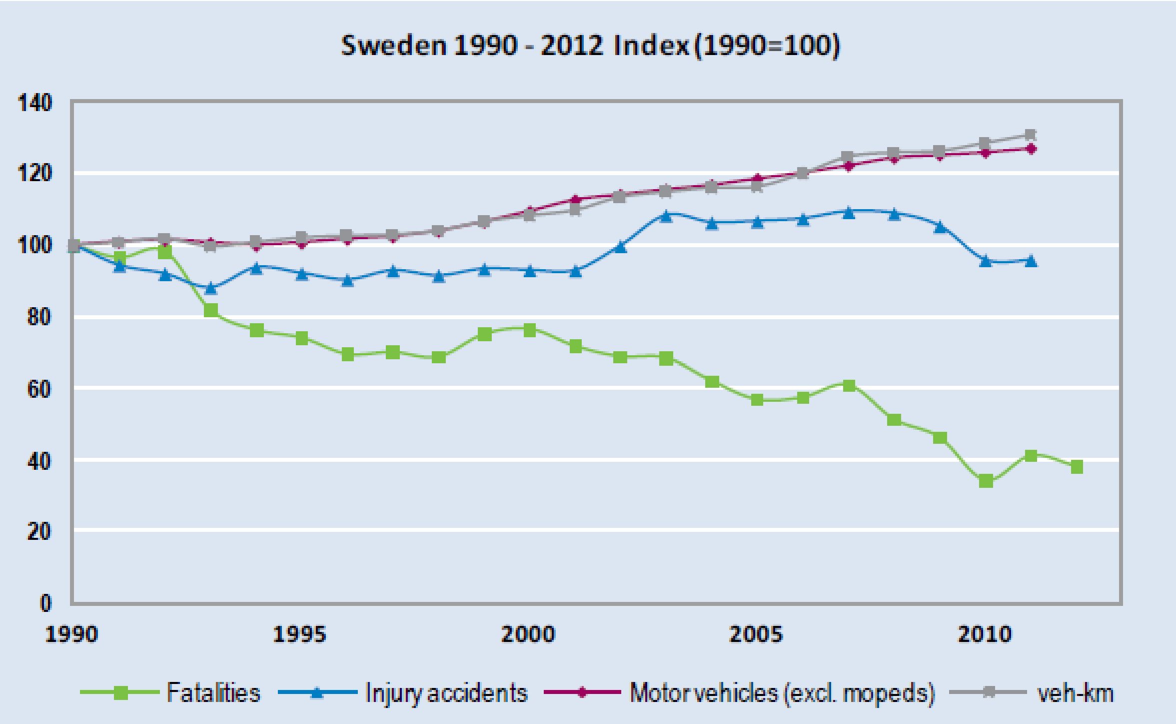



***Figure 22: Reported road fatalities, injury crashes and motorised vehicles in Sweden 1990-2012***
*(Source: IRTAD, Swedish Traffic Agency, Swedish Transport Administration, VTI)*

Between 1990 and 2011, the number of road fatalities decreased by nearly 60%, while the number of injury crashes was reduced by only 4%. The positive trend can partly be explained by the gradual improvements in infrastructure, vehicle population and an increased focus on injury prevention. Both the safe national roads and safe vehicles indicators are improving at a sufficient rate, and road design in the municipal road network has also long been developing towards greater safety. The positive development can also be explained by the fact that most safety measures have targeted the severest crashes, aided by much better reporting of injury crashes in recent years.

## Road users

In 2010, on the basis of distance travelled, riders of motorised-two wheelers had a risk 20 times higher than a car occupant to be killed in a car crash. In 2011, the increase in fatalities concerned all road users, with the sharpest increase for pedestrians — from 31 killed in 2010, to 53 in 2011. The reasons behind this negative outcome are not clear, but in part explained by the very low number of pedestrians killed in 2010 – probably due to the hard winter in that year — resulting in less exposure for both pedestrians and motor vehicles, and a level slightly higher than expected in 2011.

| | | | | | | | | | 2011% change over | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | | 2000 | | 2010 | | 2011 | | *2010* | *2000* | *1990* |
| Bicyclists | 68 | 9% | 47 | 8% | 21 | 8% | 21 | 7% | 0% | -55.3% | -69.1% |
| Mopeds | 22 | 3% | 10 | 2% | 8 | 3% | 11 | 3% | 38% | 10% | -50% |
| Motorcycles | 46 | 6% | 39 | 7% | 37 | 14% | 46 | 14% | 24% | 18% | 0% |
| Passenger car occupants | 468 | 61% | 393 | 66% | 151 | 57% | 159 | 50% | 5.3% | -59.5% | -66.0% |
| Pedestrians | 134 | 17% | 73 | 12% | 31 | 12% | 53 | 17% | 71.0% | -27.4% | -60.4% |
| Others | 34 | 4% | 29 | 5% | 18 | 7% | 29 | 9% | 61.1% | 0% | -14.7% |
| **Total** | **772** | **100%** | **591** | **100%** | **266** | **100%** | **319** | **100%** | **19.9%** | **-46%** | **-58.7%** |

***Table 13: Road fatalities by road user group in Sweden year 1990-2011****
*(Source: IRTAD, Swedish Traffic Agency, Swedish Transport Administration, VTI)*

Overall since 1990, all user groups, with the exception of motorcyclists, benefited from the improvements in safety. Regarding motorcyclists, the relative lack of progress is explained by the explosion in the motorcycle fleet, which doubled between 1996 and 2011. To respond to this trend, in April 2010, the Swedish Transport Administration presented a new national strategy on motorcycle and moped safety.

## Age and Gender

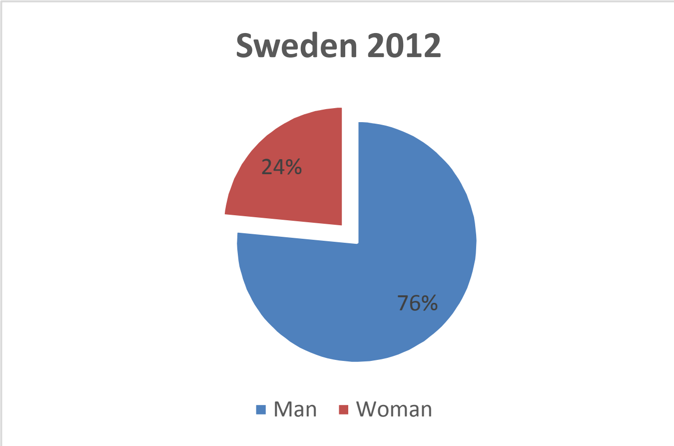



***Figure 23: Share of fatalities by gender in Sweden, 2012***
*(Source: Personal compilation based on National sources)*

In 2012, men represented 76% of all road deaths. In contrast, women signified just the 24%.

| | | | | | 2011% change over | | |
|---|---|---|---|---|---|---|---|
| | 1990 | 2000 | 2010 | 2011 | *2010* | *2000* | *1990* |
| 0-5 | 10 | 2 | 3 | 5 | 67% | 150% | -50% |
| 6-9 | 12 | 3 | 3 | 1 | -67% | -67% | -92% |
| 10-14 | 13 | 14 | 4 | 4 | 0% | -71% | -69% |
| 15-17 | 34 | 16 | 9 | 9 | 0% | -44% | -74% |
| 18-20 | 88 | 52 | 20 | 29 | 45% | -44% | -67% |
| 21-24 | 66 | 50 | 26 | 28 | 8% | -44% | -58% |
| 25-64 | 357 | 300 | 137 | 152 | 11% | -49% | -57% |
| >65 | 192 | 154 | 64 | 91 | 42% | -41% | -53% |
| Total | 772 | 591 | 266 | 319 | 20% | -46% | -59% |

***Table 14: Share of fatalities by age in Sweden***
*(Source: IRTAD, Swedish Traffic Agency, Swedish Transport Administration, VTI)*

The increase in fatality hit more particularly the 18-20 and 65+ age groups.

Since 1990, the reduction in fatalities has benefited all age groups, but the highest reduction concerns the younger groups. Child (0-14) fatalities have been halved since 2000, partly due to the legislation on child-restraint systems, but also to work on separating traffic modes in urban areas.

Young people (18-20) constitute a high-risk group, with a mortality rate twice as high as the older age groups. On the other hand, the mortality rate of the 21-24 age group reduced considerably in 2008-2009, perhaps due to the economic downturn and its impact on the mobility patterns of this age band.

**Speed and blood alcohol limits**

Speeding is a major problem in Sweden and the percentage of drivers exceeding speed limits was increasing at the beginning of the decade; however there are now indications that compliance with speed limits is somewhat better, primarily due to road safety cameras.

In 2012, the Swedish Road Administration measured the average speed and compared the results with the average speed in 2004. These showed that the average speed has decreased by 3.4. The trend is therefore positive from a road safety perspective. Sweden has also adopted tighter speed limits and introduced new speed limits in 10 km/h steps, ranging from 30 km/h to 120 km. In some specific areas, speed limits of 5, 10 and 20 km/h are also used.

| | Speed limit |
|---|---|
| **Urban roads** | 50 km/h |
| **Rural roads** | 90 or 70 km/h |
| **Motorways** | 110 km/h |

***Table 15: General speed limit in Sweden– Passenger cars, 2013***
*(Source: Personal compilation based on National sources)*

In Sweden, the legal BAC limit is 0.2 g/l. In 2011, 18% of motor vehicle drivers killed in crashes were under the influence of alcohol.

**Road type**

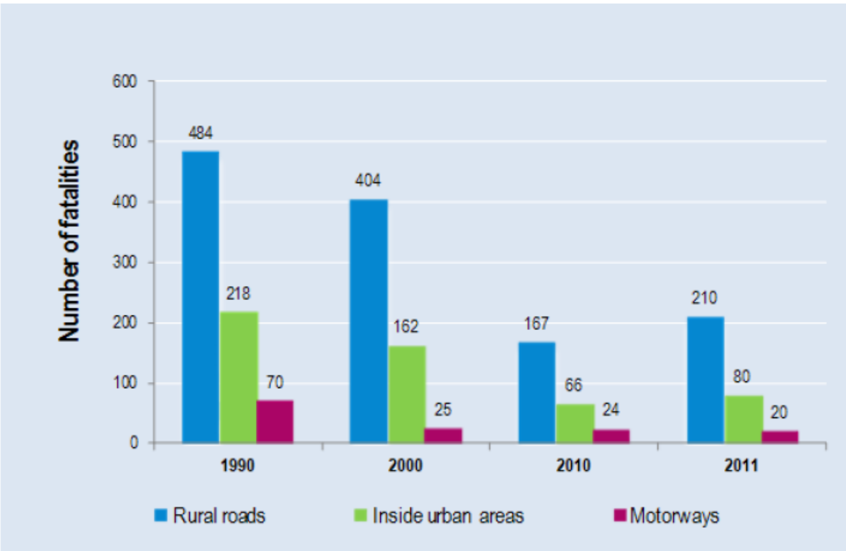



***Figure 24: Reported fatalities by road type in Sweden - 1990, 2000, 2010 and 2011***
*(Source: National sources)*

In 2011, 68% of fatal crashes occurred on rural roads, 26% on urban roads and 6% on motorways. The increase in fatalities hit both rural and urban roads but did not affect motorways, where the number of fatalities continued to decrease (-17%).

Over the past twenty years there has been a major improvement over the whole network, but the decrease in fatalities, in particular for pedestrians and cyclists, has been achieved mainly through the improvement of urban road conditions, i.e. construction of mini-roundabouts, bicycle lanes and other countermeasures in infrastructure.

On rural roads, improvements in road safety since 2000 are in part due to the implementation of speed cameras and the generalisation of the "2+1" roads, which has been very cost effective in reducing head-on collisions on rural roads. In 2011, 210 kilometres of road with median barriers were added, of which 20 kilometres were motorways.

### 2.3.5 Conclusions

Through the analysis we can conclude the number of vehicles has increased during the last decade that in all three countries and, in contrast, the number of fatalities and injuries has reduced. As the figure 25 shows, Lithuania has increased by 50% the number of registered vehicles and probably this fast vehicles growth and the road safety management on this new big park of vehicles could be a strong reason of high rates of fatalities.

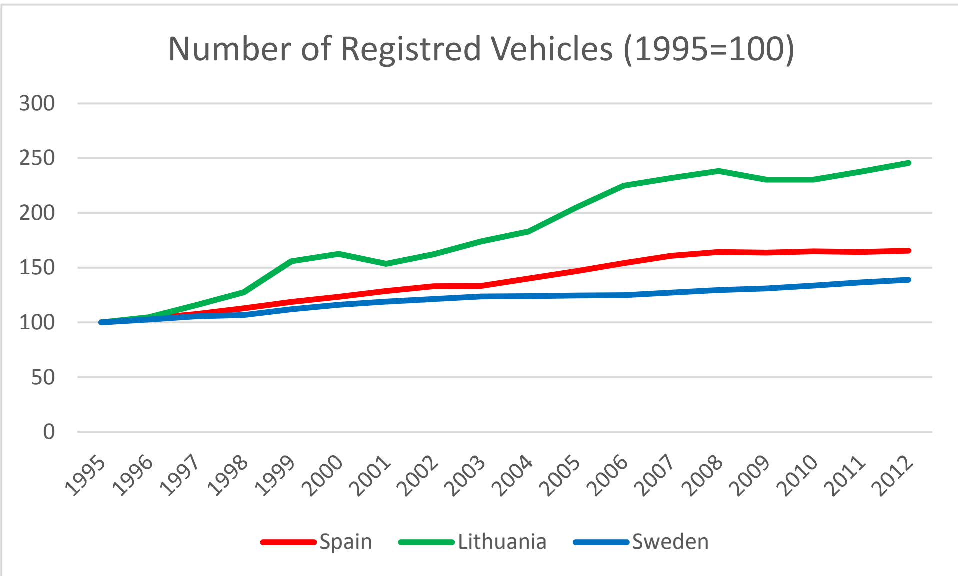



***Figure 25: Comparison of number of vehicles between Spain, Lithuania and Sweden – 1995-2012***
*(Source: Personal compilation based on National sources)*

In the following figures we can see the important decrease in number of fatalities and injuries during this last decade in Lithuania (-50%; -40%) and Spain (-70%; -20%). However, Sweden has just decreased the number of fatalities (-50%) because the number of injuries is almost the same than ten years ago.

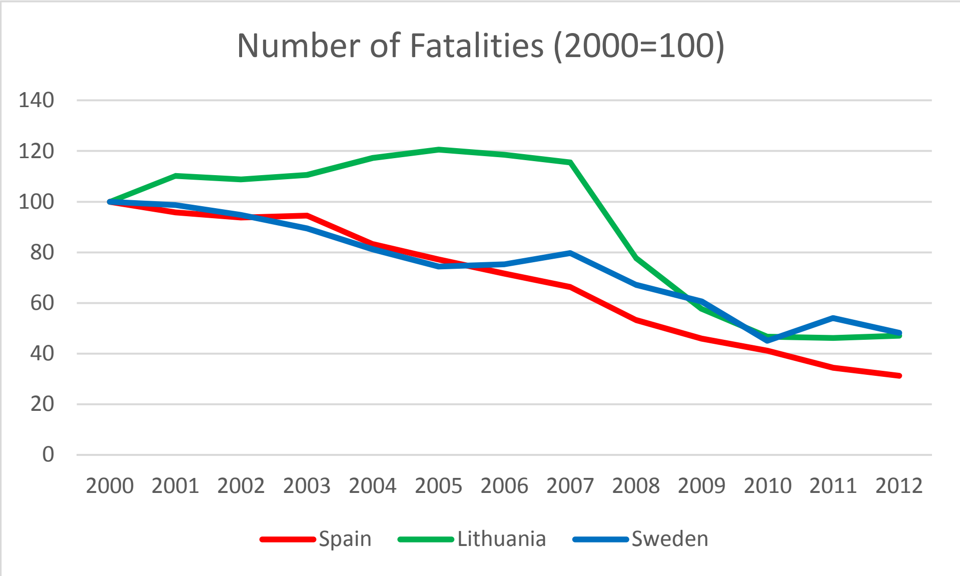



***Figure 26: Comparison of number of vehicles between Spain, Lithuania and Sweden – 2000-2012***
*(Source: Personal compilation based on National sources)*

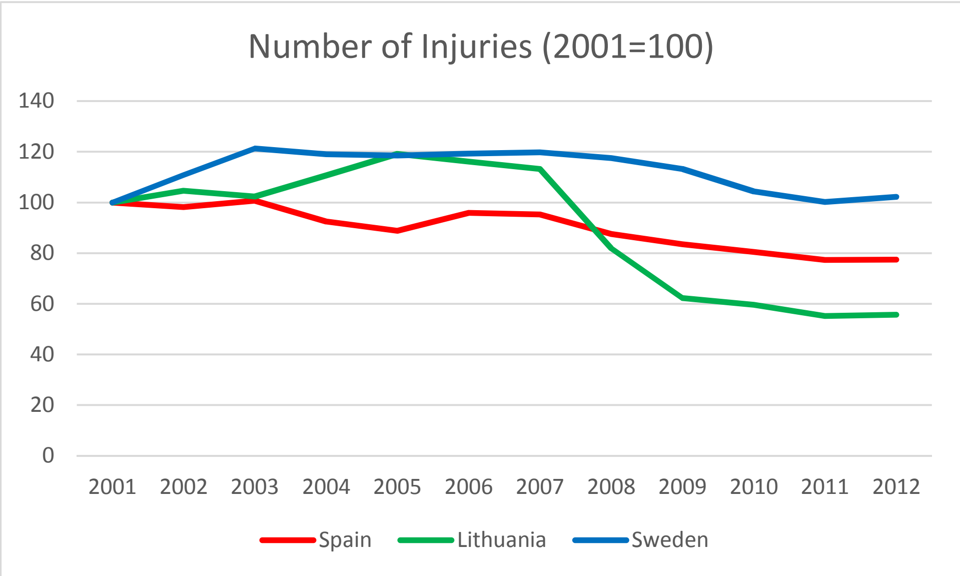



***Figure 27: Comparison of number of injuries between Spain, Lithuania and Sweden –2000-2012***
*(Source: Personal compilation based on National sources)*

In addition, the number of fatalities in urban areas also decreased by 50% approximately (See *Figure 28*). At the same time, most of the crashes occurred in built-up areas and for that reason, it is very important to protect with some measures the road user group more vulnerable, such as pedestrians. The high number of fatalities and serious injuries faced by vulnerable road users such as riders of motorcycles, mopeds, cyclists and pedestrians are significant and in some European States still increasing.

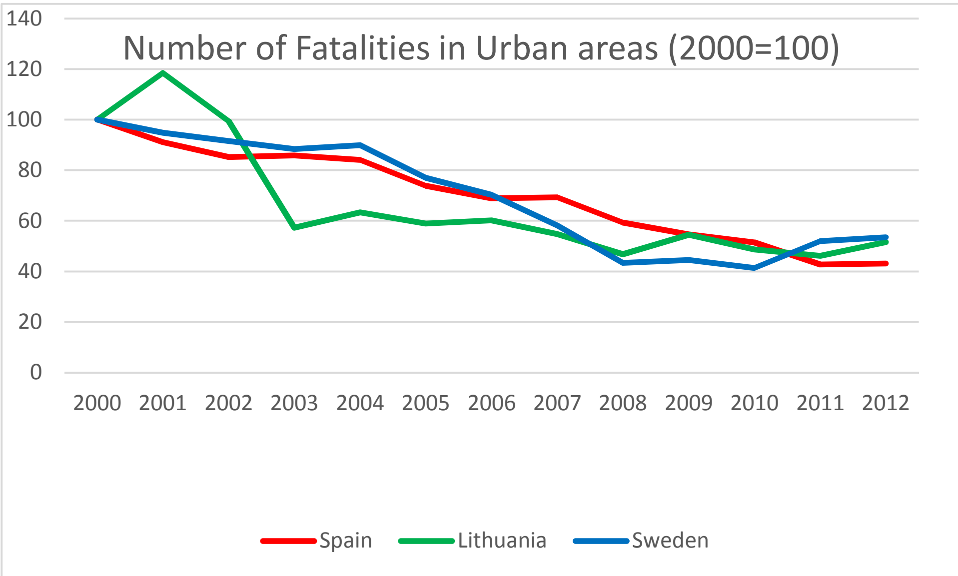



***Figure 28: Comparison of number of fatalities in urban areas between SP, LT and SE – 2000-2012***
*(Source: Personal compilation based on National sources)*

From the analysis of each country we can also extract the profile of death people in road accidents: a man between 18-25 years old or older than 65. In fact, young and novice drivers (with less than one year's experience) are responsible for a big amount of the total number of crashes.

Another problem is the speed, a very important variable to take into account. One of the principal's causes of accidents is the speed. As we can see in the following table, the most restrictive country in speed and blood alcohol limits between Lithuania, Spain and Sweden is definitely Sweden. It is zero tolerant with blood alcohol (0.2 g/L alcohol) and has lower speed limits. For instead, in Lithuania is allowed in some motorways to reach 130 km/h but it is not possible neither in Spain nor Sweden.

| | Speed limit, cars (in general), km/h: | | | Blood alcohol limit, grams of alcohol in 1 litre of blood |
|---|---|---|---|---|
| | Built-up areas | Outside built-up areas | Motorways | |
| BE | 30-50 | 90-120 | 120 | 0.5 |
| BG | 50 | 90 | 130 | 0.5 |
| CZ | 50 | 90 | 130 | 0.0 |
| DK | 50 | 80 | 110-130 | 0.5 |
| DE | 30-50 | 100 | (130) | 0.5 |
| EE | 50 | 90-110 | 110 | 0.0 |
| IE | 50 | 80-100 | 120 | 0.8 |
| EL | 50 | 90-110 | 130 | 0.5 |
| ES | 50 | 90-100 | 120 | 0.5 |
| FR | 50 | 80-110 | 110-130 | 0.5 |
| IT | 50 | 90-110 | 130 | 0.5 |
| CY | 50 | 80 | 100 | 0.5 |
| LV | 50 | 90 | 110 | 0.5 |
| LT | 50 | 70-90 | 110-130 | 0.4 |
| LU | 50 | 90 | 130 | 0.5 |
| HU | 50 | 90-110 | 130 | 0.0 |
| MT | 50 | 60-80 | - | 0.8 |
| NL | 30-50-70 | 80-100 | 100-120 | 0.5 |
| AT | 50 | 100 | 130 | 0.5 |
| PL | 50-60 | 90-110 | 130 | 0.2 |
| PT | 50 | 90-100 | 120 | 0.5 |
| RO | 50 | 90-100 | 130 | 0.0 |
| SI | 30-50 | 90-100 | 130 | 0.5 |
| SK | 50 | 90 | 130 | 0.0 |
| FI | 40-50 | 80-100 | 100-120 | 0.5 |
| SE | 30-50 | 70-90 | 100-120 | 0.2 |
| UK | 32-48 | 96-112 | 112 | 0.8 |

***Table 16: Speed limits, blood alcohol limits in EU-27***
*(Source: National sources, ITF)*

In Sweden, Spain and Lithuania the number of deaths has significantly dropped in recent years. The reasons for which numbers of road deaths have been declining are many and they include: safer cars and infrastructure, both stricter laws and a better perception of the risks connected with not wearing seat belts and helmets, speeding and drink-driving.

Sweden has the best results and could serve as example of best practice to inspire Spain or Lithuania who has the worst rates in EU. In 1997 the Swedish parliament wrote into law a "Vision Zero" plan, promising to eliminate road fatalities and injuries altogether. Planning has played the biggest part in reducing accidents. Roads in Sweden are built with safety prioritised over speed or convenience. Low urban speed-limits, pedestrian zones and barriers that separate cars from bikes and oncoming traffic have helped. Building 1,500 kilometres (900 miles) of "2+1" roads—where each lane of traffic takes turns to use a middle lane for overtaking—is reckoned to have saved around 145 lives over the first decade of Vision Zero. And 12,600 safer crossings, including pedestrian bridges and zebra-stripes flanked by flashing lights and protected with speed-bumps, are estimated to have halved the number of pedestrian deaths over the past five years. Strict policing has also helped: now less than 0.25% of drivers tested are over the alcohol limit.

Since reaching a peak in road deaths in the 1970s, rich countries have become much better at reducing the number of traffic accidents. The following table shows the gross investment spending in road infrastructure.

| GEO/TIME | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|
| Albania | 253 | 497 | 486 | 242 |
| Bulgaria | 134 | 169 | 101 | 281 |
| Czech Republic | 1,493 | 2,043 | 1,987 | 1,720 |
| Denmark | 1,029 | 936 | 714 | 937 |
| Germany | n.a. | n.a. | n.a. | n.a. |
| Estonia | 131 | 162 | 133 | 140 |
| Ireland | 1,425 | 1,319 | 1,173 | 841 |
| Spain | 7,770 | 8,099 | 8,692 | 6,858 |
| France | 12,489 | 12,623 | 12,648 | 11,942 |
| Italy | 13,664 | 13,051 | 5,641 | n.a. |
| Cyprus | n.a. | n.a. | n.a. | n.a. |
| Latvia | 241 | 265 | 135 | 140 |
| Lithuania | 312 | 437 | 448 | 422 |
| Luxemburg | 157 | 138 | 138 | n.a. |
| Hungary | 646 | 979 | 1,566 | 840 |
| Austria | 802 | n.a. | n.a. | n.a. |
| Poland | 3,443 | 4,508 | 5,340 | 6,510 |
| Portugal | 1,453 | 1366 | 951 | 1,511 |
| Romania | 2,806 | 3,891 | 3,105 | 2,850 |
| Slovenia | 666 | 694 | 406 | 221 |
| Slovakia | 520 | 567 | 662 | 342 |
| Finland | 802 | 973 | 922 | 890 |
| Sweden | 1,423 | 1,604 | 1,574 | 1,653 |
| United Kingdom | 6,341 | 6,137 | 6,610 | 6,555 |
| Iceland | 187 | 216 | 121 | 79 |
| Norway | 1,719 | 1,993 | 2,399 | n.a. |
| Switzerland | 2,674 | 2,840 | 2,997 | n.a. |
| Croatia | 1,066 | 1,101 | 909 | 515 |
| FYROM* | 39 | 45 | 43 | 32 |
| Turkey | 1,947 | 2,233 | 2,918 | 5,419 |

***Table 17: Gross investment spending in road infrastructure in selected countries – 2007-2010 (at current prices and exchange rates – million €)***
*(Source: National sources, ITF)*

In conclusion, one of the reasons of having high rates of accidents in Lithuania, is that a new member states (2004) already suffered from low levels of traffic safety and an increase in the volume of road transport following their accession might well lead to an increase in accidents.

Nevertheless, Lithuania successfully implemented the target set in the EU White Paper of reducing, by 50%, the number of traffic deaths in the period 2001-2010. The number of fatalities was reduced from 706 to 299 – i.e. a 58% reduction. However, it has to develop more strategies to continue with the encouraging results in the past decade. To achieve this objective, it is planned to:

• Further improve road users' education in the field of traffic safety;

• increase road users' and vehicle enforcement;

• improve the rescue service quality;

• improve the crash data collection system.

In the complex system, road safety depends on participants' responsible behaviour, educational organizations, media, repressive and jurisdictional organs, civil society, companies, local self-government units and also state authorities. Each and every one of them has its own share of responsibility for a better safety and contributes to its realization. But the goals can be achieved only with coherent measures and collective efforts.

# Chapter 3

# Problem Statement and Methodology

---

This chapter presents in detail the main problem investigated during this project. It also finds the algorithms that are going to be used to analyse this issue in the following chapter.

## 3.1 Problem Description

According to *Literature Review* crashes are more severe on rural roads, where speeds are higher. However, most road crashes occurred in built-up areas and in this environment there are many neighbourhood roads where many vulnerable road users, such as pedestrians and bicyclists can be found.

In Lithuania, despite the number of car occupants and drivers killed decreased, there is an increase in the number of pedestrians and cyclists killed. Traffic calming measures are good solutions in order to slow down or reduce motor-vehicle traffic as well as to improve safety for these group of vulnerable road users.

The problem studied is that cars cannot stop before running over a pedestrian. In other words, the vehicles don't reduce their speed enough because injures to the pedestrian at least are less. For instance, according to an overview of recent studies (Rósen et al., 2011): at a collision speed of 20 km/h nearly all pedestrians survive a crash with a passenger car; about 90% survive at a collision speed of 40 km/h, at a collision speed of 80 km/h the number of survivors is less than 50%, and at a collision speed of 100 km/h only 10% of the pedestrians survive (see *Figure 26*).

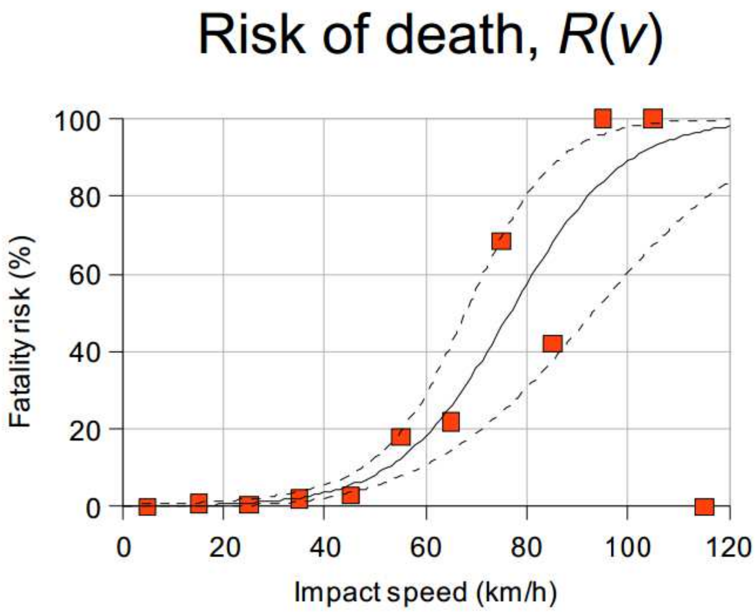



***Figure 29: The fatality rate of pedestrians in crashes with passenger cars as function of the collision speed***
*(Source: Rosén et al., 2011)*

For that reason, low speeds may be crucial for road safety in particularly sensitive locations. Examples include: in residential areas, near schools or homes for the elderly, at pedestrian crossings and/or at intersections. At such locations, physical speed-reducing measures such as speed humps, cushions, road narrowing's, plateaus in intersection areas and roundabouts, can help to ensure cars maintain safe speeds.

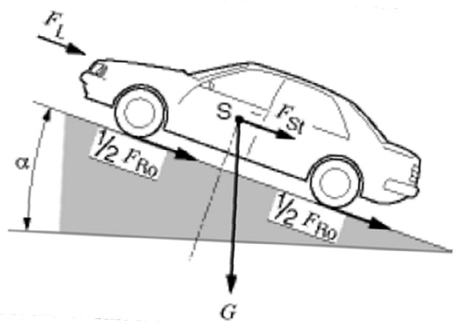
Nevertheless, in order to know these safe speeds, it is necessary to study the acceleration of the car and braking (deceleration). Through analysis of the different involved forces this thesis presents an algorithm to find these safe speed and parameters of the vehicle. And later, it will be useful to do the experimental and analytic research and evaluate the risk of death.

# 3.2 Analysis of resistance forces

### 3.2.1 Total Running-resistance

The running resistance is calculated as:

$$Fw = Fro + FL + Fst$$




$Fw = Running\ resistance$ [N]
$Fro = Rolling\ resistance$ [N]
$FL = \ Aerodinamic\ drag$ [N]
$Fst =$ Climbing resistance [N]

### 3.2.2 Rolling resistance

The rolling resistance *F*ro is the product of deformation processes which occur at the contact patch between tire and road surface.

$$Fro = f \cdot m \cdot g$$

$Fro = Rolling\ resistance$ [N]
$f = \ Coefficient\ of\ rolling\ resistance$
$m = mass$ [kg]
$g = gravity$[m/s²]

An approximate calculation of the rolling resistance can be made using the coefficients provided in the following table:

| **Road surface** | **Coefficient of rolling resistance *f*** |
|---|---|
| Pneumatic car tires on : | |
| **Large sett pavement** | 0.015 |
| **Small sett pavement** | 0.015 |
| **Concrete, asphalt** | 0.013 |
| **Rolled gravel** | 0.02 |
| **Tarmacadam** | 0.025 |
| **Unpaved road** | 0.02 |
| **Field** | 0.1…0.35 |
| Pneumatic truck tires on: **Concrete, asphalt** | 0.006…0.01 |
| Strake wheels in: **field** | 0.14…0.24 |
| Track-type tractor in: **field** | 0.07…0.12 |
| Wheel on rail | 0.001…0.002 |

***Table 18: Coefficient of rolling resistance "f" depending on road surface***
*(Source: Automotive Handbook, Bosch - 2008)*

The increase in the coefficient of rolling resistance f is directly proportional to the level of deformation, and inversely proportional to the radius of the tire. The coefficient will thus increase in response to greater loads, higher speeds and lower tire pressure.

### 3.2.3 Aerodynamic drag

Aerodynamic drag is calculated as:

$$FL = 0{,}386 \cdot \delta \cdot Cw \cdot A \cdot (v1 + vo)^2$$

Where:

$FL = Aerodynamic\ drag$ *[N]*
$\delta = Air\ density\ (at\ 200\ m\ altitude\ \delta = 1.202\ kg/m^3)$
$Cw = Drag\ coefficient$
$A = Cross\ section$ *[m²]*
$vo = Initial\ speed$ *[km/h]*
$v1 = Final\ speed$ *[km/h]*

### 3.2.4 Climbing resistance

Climing resistance is calculated as:

$$Fst = m \cdot g \cdot \sin \alpha$$

Where:

$Fst = Climbing\ resistance$ *[kW]*
$m = mass$ *[kg]*
$g = gravity$ *[m/s²]*
$\alpha = Gradient\ angle$ *[º]*

### 3.2.5 Adhesion to road surface

Coefficients of static friction (ur) depending on speed:

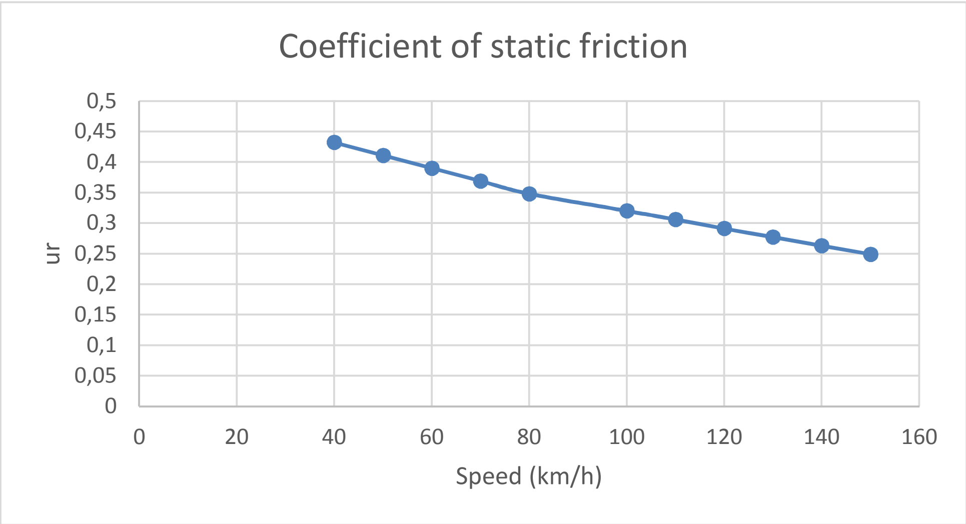



***Figure 30: Coefficient of static friction (ur) depending on speed***
*(Source: Norma Española de trazado de carreteras 3.1-IC (1999))*

# 3.3 Acceleration

### 3.3.1 Acceleration distance

$$da = \frac{v1^2}{25{,}92 \cdot a}$$

Where:

$da = Acceleration\ distance$ [m]
$v1 = Final\ speed$ [km/h]
$a = Acceleration$ [m/s²]
$Pa = Power\ available\ for\ acceleration$ [kW]
$km = Rotational\ inertia\ coefficient$
$n = efficiency$
$Pw = motive\ power$ [kW]
$Fw = Running\ resistance$ [N]

$$a = \frac{3600 \cdot \mathrm{Pa}}{v1 \cdot km \cdot m}$$

$$Pa = P \cdot \eta - Pw$$

$$Pw = \frac{Fw \cdot v1}{3600}$$

# 3.4 Braking (deceleration)

### 3.4.1 Lost time: reaction time, brake response time

The periods in which no braking occurs are combined to form the so-called lost time:

$$tvz = tr + tu + ta + ts/2$$

Where:

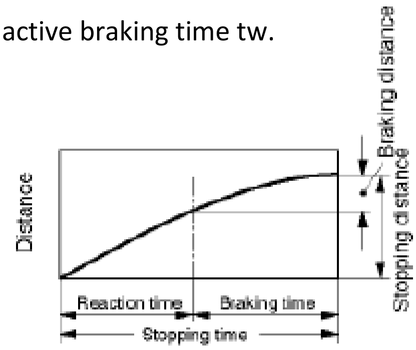
$tvz = Lost\ time$ [s]
$tr = reaction\ time$ [s]
$tu = active\ braking\ time$ [s]
$ta = brake\ response\ time$ [s]
$ts/2 = Rotational\ inertia\ coefficient$ [s]

The **reaction time** is the period which elapses between recognition of the object, the decision to brake and the time it takes for the foot to hit the brake pedal. The reaction time is not a fixed value: it ranges from 0.3 to 1.7 s.

The condition of the brakes at the moment at which they are applied (e.g. wet brake disks) is one factor influencing brake **response time ta and pressure build-up** time ts; others are the designs of the actuation and force-transmission mechanism and linkage. Consult ECE R13 for legal regulations concerning ta and ts on tightly adjusted brakes. The applicable regulation for testing braking-system effectiveness uses figures of 0.36 s (vehicle class M1) and 0.54 s (vehicle classes M2, M3, N1...N3) in the braking-distance equation ta + ts/2.

### 3.4.2 Stopping distance: reaction and brake distance

This is the distance covered between the moment when a hazard is recognized and the time when the vehicle comes to a complete stop. It is the sum of the distances travelled during the reaction time tr, the brake response time ta (at constant vehicle speed v), and the active braking time tw.




$$db = \frac{v1}{3,6} \cdot tvz + \frac{v1^2}{25,92 \cdot amax}$$

$$a\,max = k \cdot g \cdot ur$$

$$ur = f(v1)$$

Where:

$db = stopping\ distance\ [m]$
$v1 = inicial\ speed\ [km/h]$
$tvz = Lost\ time\ [s]$
$amax = reaction\ time\ [s]$
$k = ratio\ between\ the\ load\ on\ driven\ or\ braked\ wheels\ and\ the\ total\ weight$
$g = gravity\ \ [m/s^2]$
$ur = coefficient\ of\ static\ friction$

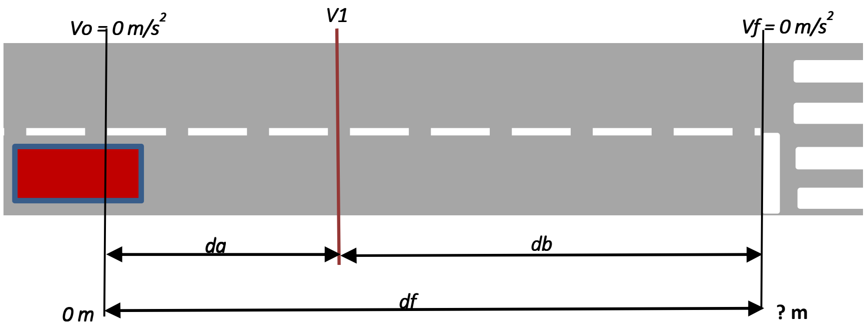
# 3.5 Algorithm of vehicle: start and stop

In this section, there are presented the algorithm that is used to solve the problem related to stop on time the vehicle, find safe speed depending on the type of car (power-to-weight ratio) and calculate different scenarios. Find the implemented algorithm in the annexes of this project.

### 3.5.1 Assumptions

| | | |
|---|---|---|
| tvz = | 1,96 | s |
| tr = | 1,2 | s (0,3-1,7) |
| tu = | 0,2 | s |
| ta = | 0,36 | s (M1=0,36;M2=0,54) |
| ts/2 = | 0,2 | s |
| | f = | 0,015 |
| | km = | 1,3 (1-1,4) |
| Fst = | 0 | N |
| FL = | 371 | N |
| | d = | 1,20 $kg/m^3$ |
| | Cw = | 0,4 |
| | A = | 2 $m^2$ |

### 3.5.2 Final distance travelled (df)

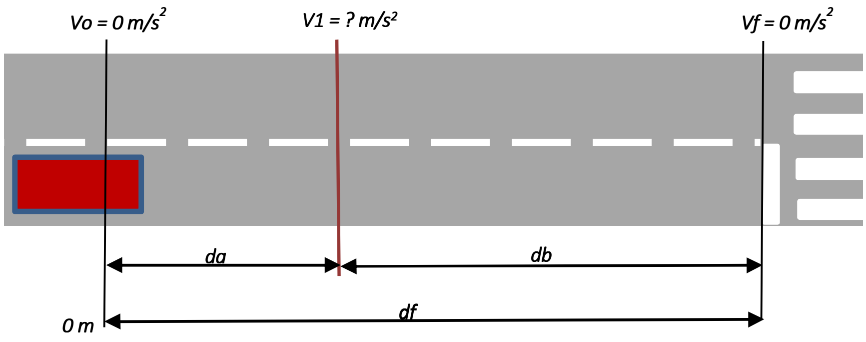



(1) $$df = da + db$$

(2) $$db = \frac{v1}{3{,}6} \cdot tvz + \frac{v1^2}{25{,}92 \cdot amax}$$

(3) $$da = \frac{v1^2}{25{,}92 \cdot a}$$

### 3.5.3 Speed limit of the road to stop on time (v1)

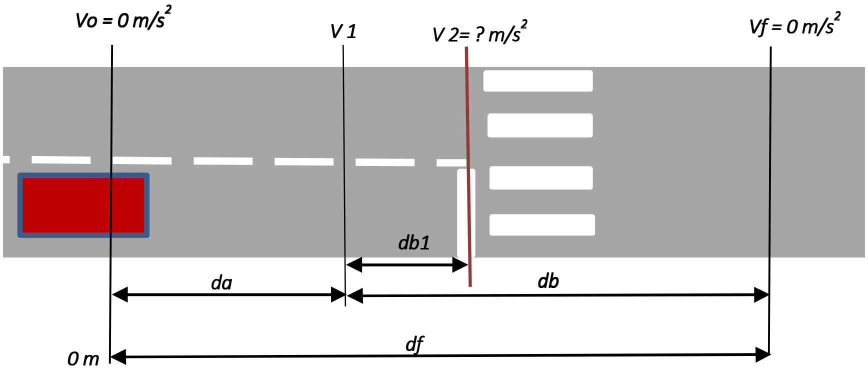



(1) $$df = da + db$$

(2) $$db = \frac{\boldsymbol{v1}}{3{,}6} \cdot tvz + \frac{\boldsymbol{v1}^2}{25{,}92 \cdot amax}$$

(3) $$da = \frac{\boldsymbol{v1}^2}{25{,}92 \cdot a}$$

### 3.5.4 Speed of the vehicle if it is not able to stop on time




(1) $$df = da + db$$

(2) $$db = \frac{v1}{3{,}6} \cdot tvz + \frac{v1^2}{25{,}92 \cdot amax}$$

(3) $$da = \frac{v1^2}{25{,}92 \cdot a}$$

If **da<250** then:

the vehicle is breking

If **df < d** then:

the vehicle stop on time.

If **(dr + da) > d** then:

the vehicle cannot reduce the speed.

If **df>d** and **(dr+da)<d** then:

$$d = da + db1 \tag{4}$$

$$db1 = \frac{v1}{3,6} \cdot tvz + \frac{\boldsymbol{v2}^2 - v1^2}{25,92 \cdot amax} \tag{5}$$

If **da>250** then:

the vehicle is still accelerating

$$da = \frac{\boldsymbol{v2}^2}{25,92 \cdot a} \tag{4}$$

Where:

df = final distance [m]

d = distance to stop [m]

dr = reaction distance [m]

da = accelerating distance [m]

# Chapter 4

# Experimental and analytic research

This chapter presents the experimental research about a real accident happened in Kaunas (Lithuania). There is also an analytic research with different scenarios through the algorithms found in the previous chapter. Then, it will show all the results obtained and the way to evaluate them to decide which type of vehicle (technical parameters) is safest in urban conditions for pedestrians.

# 4.1 Analysis of accident

The accident took place the third of July of 2013 in Baltų pr. (Kaunas) about 17:30 pm. A BMW 525D ran over two pedestrians, a woman and her ten-year-old daughter, when they were crossing the road on a zebra crossing. Both of them died due to the terribly impact.

### 4.1.1 Road infrastructure: speed limit and features of the road

The driver of this car was twenty years old and he was driving at 100 km/h, much faster than the speed limit of 60 km/h.


***Figure 31: Speed limit on Baltų pr. (Kaunas)***
*(Source: http://www.delfi.lt)*

The car started to accelerate from the interseccion between Baltų pr. and Žiemgalių g. and continue throug the Baltų pr. where it reached 100 km/h speed and went over 250 m. before crossing over the two pedestrians.

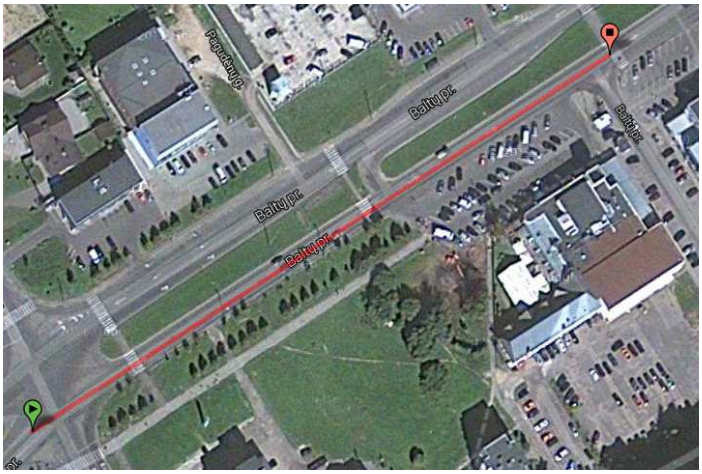



***Figure 32: 250 m. Distance from intersection (v=0) to zebra crossing where accident occur***
*(Source: http://www.delfi.lt)*

The street where accident occur is flat (α=0), so there won't be climbing resistance. Moreover, the road is a large sett pavement then the coefficient of rolling resistance would be f = 0.015.

***Figure 33: Zebra Crossing of the accident***
*(Source: http://www.delfi.lt)*

### 4.1.2 Vehicle: technical specifications

**BMW 525D**

| | |
|---|---|
| **Power** | 160 kW |
| **Weight** | 1725 kg |
| **No. Of cylinders** | 6 cylinders |
| **No. Of gears** | 6 speed |
| **Engine swept** | 1995 cc |
| **Torque (NM)** | 45 N·m |
| **Fuel type** | Diesel |

***Table 19: technical specifications***
*(Source:www.coches.net)*


***Figure 34: BMW 525D crashed***
*(Source: http://www.delfi.lt)*

# 4.2 Evaluation of the vehicle and maximal speed

### 4.2.1 Final distance *(df)* depending on reached speed and the power-to-weight ratio

The following results show the final distance (df=da+db) for different types of cars, after the acceleration from v0= 0 km/h to reached speed (v1=100, 90, 80, 70, 60 km/h), reaction and breaking until stop (vf=0). In others words, driver try to stop the car when he realizes pedestrians' presence. To solve this scenario, it has been used the algorithm from *chapter 3 – 3.5.2.*

**v1=100 km/h**

| MODEL | | POWER [kW] | WEIGHT [kg] | POWER-TO-WEIGHT RATIO | da [m] | db [m] | FINAL DISTANCE *(df)* [m] |
|---|---|---|---|---|---|---|---|
| **BMW** | **525D** | **160** | **1725** | **0,093** | **195** | **177** | **372** |
| VOLKSWAGEN | POLO (STD) | 40 | 1113 | 0,036 | 762 | 177 | 940 |
| CITROEN | BERLINGO (STD) | 51 | 1297 | 0,039 | 617 | 177 | 795 |
| RENAULT | MEGANE (STD) | 63 | 1245 | 0,051 | 433 | 177 | 611 |
| BMW | 3 (STD) | 90 | 1420 | 0,063 | 314 | 177 | 491 |
| PEUGEOT | 407 (STD) | 100 | 1530 | 0,065 | 298 | 177 | 476 |
| TOYOTA | COROLLA (TOP) | 130 | 1700 | 0,076 | 244 | 177 | 421 |
| VOLKSWAGEN | PASSAT (TOP) | 184 | 1627 | 0,113 | 156 | 177 | 334 |
| MERCEDES | C (TOP) | 200 | 1785 | 0,112 | 157 | 177 | 334 |
| AUDI | A6 (TOP) | 320 | 2070 | 0,155 | 110 | 177 | 287 |

***Table 20: Final distance for different car models (0-100-0 km/h)***
*(Source: personal compilation)*

**v1=90 km/h**

| MODEL | | POWER [kW] | WEIGHT [kg] | POWER-TO-WEIGHT RATIO | da [m] | db [m] | FINAL DISTANCE *(df)* [m] |
|---|---|---|---|---|---|---|---|
| **BMW** | **525D** | **160** | **1725** | **0,093** | **138** | **144** | **282** |
| VOLKSWAGEN | POLO (STD) | 40 | 1113 | 0,036 | 479 | 144 | 624 |
| CITROEN | BERLINGO (STD) | 51 | 1297 | 0,039 | 404 | 144 | 549 |
| RENAULT | MEGANE (STD) | 63 | 1245 | 0,051 | 292 | 144 | 436 |
| BMW | 3 (STD) | 90 | 1420 | 0,063 | 217 | 144 | 361 |
| PEUGEOT | 407 (STD) | 100 | 1530 | 0,065 | 208 | 144 | 352 |
| TOYOTA | COROLLA (TOP) | 130 | 1700 | 0,076 | 172 | 144 | 316 |
| VOLKSWAGEN | PASSAT (TOP) | 184 | 1627 | 0,113 | 111 | 144 | 256 |
| MERCEDES | C (TOP) | 200 | 1785 | 0,112 | 112 | 144 | 256 |
| AUDI | A6 (TOP) | 320 | 2070 | 0,155 | 79 | 144 | 223 |

***Table 21: Final distance for different car models (0-90-0 km/h)***
*(Source: personal compilation)*

In any of different type of cars the final distance is 250 m or less (except Audi A6 at 90 km/h). Accelerating distance is higher when the reaching speed is higher as well. Stopping distance in both cases is long. From that distance it is very difficult to see if anyone is crossing or guess it.

**v1=80 km/h**

| MODEL | | POWER [kW] | WEIGHT [kg] | POWER-TO-WEIGHT RATIO | da [m] | db [m] | FINAL DISTANCE *(df)* [m] |
|---|---|---|---|---|---|---|---|
| **BMW** | **525D** | **160** | **1725** | **0,093** | **95** | **116** | **211** |
| VOLKSWAGEN | POLO (STD) | 40 | 1113 | 0,036 | 302 | 116 | 418 |
| CITROEN | BERLINGO (STD) | 51 | 1297 | 0,039 | 262 | 116 | 378 |
| RENAULT | MEGANE (STD) | 63 | 1245 | 0,051 | 193 | 116 | 309 |
| BMW | 3 (STD) | 90 | 1420 | 0,063 | 146 | 116 | 262 |
| PEUGEOT | 407 (STD) | 100 | 1530 | 0,065 | 140 | 116 | 256 |
| TOYOTA | COROLLA (TOP) | 130 | 1700 | 0,076 | 117 | 116 | 233 |
| VOLKSWAGEN | PASSAT (TOP) | 184 | 1627 | 0,113 | 77 | 116 | 193 |
| MERCEDES | C (TOP) | 200 | 1785 | 0,112 | 77 | 116 | 193 |
| AUDI | A6 (TOP) | 320 | 2070 | 0,155 | 55 | 116 | 171 |

***Table 22: Final distance for different car models (0-80-0 km/h)***
*(Source: personal compilation)*

**v1=70 km/h**

| MODEL | | POWER [kW] | WEIGHT [kg] | POWER-TO-WEIGHT RATIO | da [m] | db [m] | FINAL DISTANCE *(df)* [m] |
|---|---|---|---|---|---|---|---|
| **BMW** | **525D** | **160** | **1725** | **0,093** | **62** | **90** | **153** |
| VOLKSWAGEN | POLO (STD) | 40 | 1113 | 0,036 | 187 | 90 | 277 |
| CITROEN | BERLINGO (STD) | 51 | 1297 | 0,039 | 165 | 90 | 255 |
| RENAULT | MEGANE (STD) | 63 | 1245 | 0,051 | 123 | 90 | 213 |
| BMW | 3 (STD) | 90 | 1420 | 0,063 | 95 | 90 | 185 |
| PEUGEOT | 407 (STD) | 100 | 1530 | 0,065 | 91 | 90 | 182 |
| TOYOTA | COROLLA (TOP) | 130 | 1700 | 0,076 | 77 | 90 | 167 |
| VOLKSWAGEN | PASSAT (TOP) | 184 | 1627 | 0,113 | 51 | 90 | 141 |
| MERCEDES | C (TOP) | 200 | 1785 | 0,112 | 51 | 90 | 141 |
| AUDI | A6 (TOP) | 320 | 2070 | 0,155 | 36 | 90 | 127 |

***Table 23: Final distance for different car models (0-70-0 km/h)***
*(Source: personal compilation)*

When the reached speed is low, stopping distance is also lower. It is shorted approximately 25 m every 10 km/h reduced. However, in such as speed some vehicles aren’t still not able to stop before 250 m due to acceleration distance.

**v1=60 km/h**

| MODEL | | POWER [kW] | WEIGHT [kg] | POWER-TO-WEIGHT RATIO | da [m] | db [m] | FINAL DISTANCE *(df)* [m] |
|---|---|---|---|---|---|---|---|
| **BMW** | **525D** | **160** | **1725** | **0,093** | **39** | **69** | **108** |
| VOLKSWAGEN | POLO (STD) | 40 | 1113 | 0,036 | 111 | 69 | 180 |
| CITROEN | BERLINGO (STD) | 51 | 1297 | 0,039 | 99 | 69 | 168 |
| RENAULT | MEGANE (STD) | 63 | 1245 | 0,051 | 75 | 69 | 144 |
| BMW | 3 (STD) | 90 | 1420 | 0,063 | 58 | 69 | 127 |
| PEUGEOT | 407 (STD) | 100 | 1530 | 0,065 | 56 | 69 | 125 |
| TOYOTA | COROLLA (TOP) | 130 | 1700 | 0,076 | 47 | 69 | 116 |
| VOLKSWAGEN | PASSAT (TOP) | 184 | 1627 | 0,113 | 31 | 69 | 100 |
| MERCEDES | C (TOP) | 200 | 1785 | 0,112 | 32 | 69 | 101 |
| AUDI | A6 (TOP) | 320 | 2070 | 0,155 | 23 | 69 | 92 |

***Table 24: Final distance for different car models (0-60-0 km/h)***
*(Source: personal compilation)*

In this table, where the reached speed is 60 km/h (road speed limit) all the vehicles can stop before 250 m and the stopping distance is 69m.

### 4.2.2 Speed limit of the road to stop on time (df ≤250) depending on power-to-weight ratio

In this scenario, we analyse the maxim speed that each type of car can reach to stop on time at 250 m (final distance). It is considered that the car starts from 0 km/h and reach this speed limit and after react and brake to stop at 250 m. To solve this scenario, it has been used the algorithm from *chapter 3 – 3.5.3.*

| MODEL | | POWER [kW] | WEIGHT [kg] | POWER-TO-WEIGHT RATIO | FINAL DISTANCE *(df)* [m] | Speed limit to stop [km/h] |
|---|---|---|---|---|---|---|
| **BMW** | **525D** | **160** | **1725** | **0,093** | **250** | **86** |
| VOLKSWAGEN | POLO (STD) | 40 | 1113 | 0,036 | 250 | 68 |
| CITROEN | BERLINGO (STD) | 51 | 1297 | 0,039 | 250 | 70 |
| RENAULT | MEGANE (STD) | 63 | 1245 | 0,051 | 250 | 74 |
| BMW | 3 (STD) | 90 | 1420 | 0,063 | 250 | 79 |
| PEUGEOT | 407 (STD) | 100 | 1530 | 0,065 | 250 | 79 |
| TOYOTA | COROLLA (TOP) | 130 | 1700 | 0,076 | 250 | 82 |
| VOLKSWAGEN | PASSAT (TOP) | 184 | 1627 | 0,113 | 250 | 89 |
| MERCEDES | C (TOP) | 200 | 1785 | 0,112 | 250 | 89 |
| AUDI | A6 (TOP) | 320 | 2070 | 0,155 | 250 | 94 |

***Table 25: Speed limit for different car models to stop at 250 m***
*(Source: personal compilation)*

### 4.2.3 Speed *v2* of the car at 250 m depending on speed *v1* and power-to-weight ratio

In this case, it is found the speed of the car when this is on zebra crossing at 250 m (d) from the intersection. Depending on power-to-weight ratio and the reached speed, the car could be accelerating (a) o braking (b) at 250 m point. To solve this scenario, it has been used the algorithm from *chapter 3 – 3.5.4.*

**v1=100 km/h**

| MODEL | | POWER [kW] | WEIGHT [kg] | P/W | db1 [m] | df [m] | dr [m] | da [m] | Speed v2 [km/h] |
|---|---|---|---|---|---|---|---|---|---|
| **BMW** | **525D** | **160** | **1725** | **0,093** | **55,31** | **372** | **54,4** | **195** | **99,65 (b)** |
| VOLKSWAGEN | POLO (STD) | 40 | 1113 | 0,036 | - | 940 | 54,4 | 762 | 52,26 (a) |
| CITROEN | BERLINGO (STD) | 51 | 1297 | 0,039 | - | 795 | 54,4 | 617 | 63,64 (a) |
| RENAULT | MEGANE (STD) | 63 | 1245 | 0,051 | - | 611 | 54,4 | 433 | 75,97 (a) |
| BMW | 3 (STD) | 90 | 1420 | 0,063 | - | 491 | 54,4 | 314 | 89,29 (a) |
| PEUGEOT | 407 (STD) | 100 | 1530 | 0,065 | - | 476 | 54,4 | 298 | 91,53 (a) |
| TOYOTA | COROLLA (TOP) | 130 | 1700 | 0,076 | 6,19 | 421 | 54,4 | 244 | 100(Cannot red) |
| VOLKSWAGEN | PASSAT (TOP) | 184 | 1627 | 0,113 | 93,63 | 334 | 54,4 | 156 | 82,54 (b) |
| MERCEDES | C (TOP) | 200 | 1785 | 0,112 | 93 | 334 | 54,4 | 157 | 82,85 (b) |
| AUDI | A6 (TOP) | 320 | 2070 | 0,155 | 140,28 | 287 | 54,4 | 110 | 54,93 (b) |

***Table 26: Speed at 250 m if the driver wants to reach 100 km/h***
*(Source: personal compilation)*

**v1=90 km/h**

| MODEL | | POWER [kW] | WEIGHT [kg] | P/W | db1 [m] | df [m] | dr [m] | da [m] | Speed v2 [km/h] |
|---|---|---|---|---|---|---|---|---|---|
| **BMW** | **525D** | **160** | **1725** | **0,093** | **111,98** | **282** | **49** | **138** | **52,43 (b)** |
| VOLKSWAGEN | POLO (STD) | 40 | 1113 | 0,036 | - | 624 | 49 | 479 | 65,01 (a) |
| CITROEN | BERLINGO (STD) | 51 | 1297 | 0,039 | - | 549 | 49 | 404 | 70,78 (a) |
| RENAULT | MEGANE (STD) | 63 | 1245 | 0,051 | - | 436 | 49 | 292 | 83,15 (a) |
| BMW | 3 (STD) | 90 | 1420 | 0,063 | 33 | 361 | 49 | 217 | 90(Cannot red.) |
| PEUGEOT | 407 (STD) | 100 | 1530 | 0,065 | 42,41 | 352 | 49 | 208 | 90(Cannot red.) |
| TOYOTA | COROLLA (TOP) | 130 | 1700 | 0,076 | 78,42 | 316 | 49 | 172 | 74,84 (b) |
| VOLKSWAGEN | PASSAT (TOP) | 184 | 1627 | 0,113 | 138,66 | 256 | 49 | 111 | 21,96 (b) |
| MERCEDES | C (TOP) | 200 | 1785 | 0,112 | 138,04 | 256 | 49 | 112 | 23,13 (b) |
| AUDI | A6 (TOP) | 320 | 2070 | 0,155 | - | 223 | 49 | 78,9 | STOP on time |

***Table 27: Speed at 250 m if the driver wants to reach 90 km/h***
*(Source: personal compilation)*

Those tables show some cars which have power-to-weight ratios lowers and at 250 m are still accelerating (a). Others cannot reduce the speed due to the reaction distance (dr) plus accelerating distance (da) is more than 250 m. Finally, we can see some models that can reduce their speed and even stop before 250 m.

**v1=80 km/h**

| MODEL | | POWER [kW] | WEIGHT [kg] | P/W | db1 [m] | df [m] | dr [m] | da [m] | Speed v2 [km/h] |
|---|---|---|---|---|---|---|---|---|---|
| **BMW** | **525D** | **160** | **1725** | **0,093** | **-** | **211** | **43,56** | **94,7** | **STOP on time** |
| VOLKSWAGEN | POLO (STD) | 40 | 1113 | 0,036 | - | 418 | 43,56 | 302 | 72,78 (a) |
| CITROEN | BERLINGO (STD) | 51 | 1297 | 0,039 | - | 378 | 43,56 | 262 | 78,2 (a) |
| RENAULT | MEGANE (STD) | 63 | 1245 | 0,051 | 57,3 | 309 | 43,56 | 193 | 71,99 (b) |
| BMW | 3 (STD) | 90 | 1420 | 0,063 | 103,8 | 262 | 43,56 | 146 | 32,71 (b) |
| PEUGEOT | 407 (STD) | 100 | 1530 | 0,065 | 109,6 | 256 | 43,56 | 140 | 23,63 (b) |
| TOYOTA | COROLLA (TOP) | 130 | 1700 | 0,076 | - | 233 | 43,56 | 117 | STOP on time |
| VOLKSWAGEN | PASSAT (TOP) | 184 | 1627 | 0,113 | - | 193 | 43,56 | 76,7 | STOP on time |
| MERCEDES | C (TOP) | 200 | 1785 | 0,112 | - | 193 | 43,56 | 77,2 | STOP on time |
| AUDI | A6 (TOP) | 320 | 2070 | 0,155 | - | 171 | 43,56 | 54,8 | STOP on time |

***Table 28: Speed at 250 m if the driver wants to reach 80 km/h***
*(Source: personal compilation)*

**v1=70 km/h**

| MODEL | | POWER [kW] | WEIGHT [kg] | P/W | db1 [m] | df [m] | dr [m] | da [m] | Speed v2 [km/h] |
|---|---|---|---|---|---|---|---|---|---|
| **BMW** | **525D** | **160** | **1725** | **0,093** | **-** | **153** | **38,11** | **62,3** | **STOP on time** |
| VOLKSWAGEN | POLO (STD) | 40 | 1113 | 0,036 | 63,25 | 277 | 38,11 | 187 | 50,41 (b) |
| CITROEN | BERLINGO (STD) | 51 | 1297 | 0,039 | 85,31 | 255 | 38,11 | 165 | 21,31 (b) |
| RENAULT | MEGANE (STD) | 63 | 1245 | 0,051 | - | 213 | 38,11 | 123 | STOP on time |
| BMW | 3 (STD) | 90 | 1420 | 0,063 | - | 185 | 38,11 | 94,8 | STOP on time |
| PEUGEOT | 407 (STD) | 100 | 1530 | 0,065 | - | 182 | 38,11 | 91,3 | STOP on time |
| TOYOTA | COROLLA (TOP) | 130 | 1700 | 0,076 | - | 167 | 38,11 | 76,6 | STOP on time |
| VOLKSWAGEN | PASSAT (TOP) | 184 | 1627 | 0,113 | - | 141 | 38,11 | 50,6 | STOP on time |
| MERCEDES | C (TOP) | 200 | 1785 | 0,112 | - | 141 | 38,11 | 51 | STOP on time |
| AUDI | A6 (TOP) | 320 | 2070 | 0,155 | - | 127 | 38,11 | 36,3 | STOP on time |

***Table 29: Speed at 250 m if the driver wants to reach 70 km/h***
*(Source: personal compilation)*

**v1=60 km/h**

| MODEL | | POWER [kW] | WEIGHT [kg] | P/W | db1 [m] | df [m] | dr [m] | da [m] | Speed v2 [km/h] |
|---|---|---|---|---|---|---|---|---|---|
| **BMW** | **525D** | **160** | **1725** | **0,093** | **-** | **108** | **32,67** | **38,6** | **STOP on time** |
| VOLKSWAGEN | POLO (STD) | 40 | 1113 | 0,036 | - | 180 | 32,67 | 111 | STOP on time |
| CITROEN | BERLINGO (STD) | 51 | 1297 | 0,039 | - | 168 | 32,67 | 98,9 | STOP on time |
| RENAULT | MEGANE (STD) | 63 | 1245 | 0,051 | - | 144 | 32,67 | 74,7 | STOP on time |
| BMW | 3 (STD) | 90 | 1420 | 0,063 | - | 127 | 32,67 | 58,1 | STOP on time |
| PEUGEOT | 407 (STD) | 100 | 1530 | 0,065 | - | 125 | 32,67 | 56,1 | STOP on time |
| TOYOTA | COROLLA (TOP) | 130 | 1700 | 0,076 | - | 116 | 32,67 | 47,4 | STOP on time |
| VOLKSWAGEN | PASSAT (TOP) | 184 | 1627 | 0,113 | - | 100 | 32,67 | 31,4 | STOP on time |
| MERCEDES | C (TOP) | 200 | 1785 | 0,112 | - | 101 | 32,67 | 31,7 | STOP on time |
| AUDI | A6 (TOP) | 320 | 2070 | 0,155 | - | 92 | 32,67 | 22,7 | STOP on time |

***Table 30: Speed at 250 m if the driver wants to reach 60 km/h***
*(Source: personal compilation)*

# 4.3 Analysis of the results and evaluation of risk

From the experimental research we can extract several conclusions:

- Stopping distance ($dr+d_{brake}$) is longer when speed car is higher

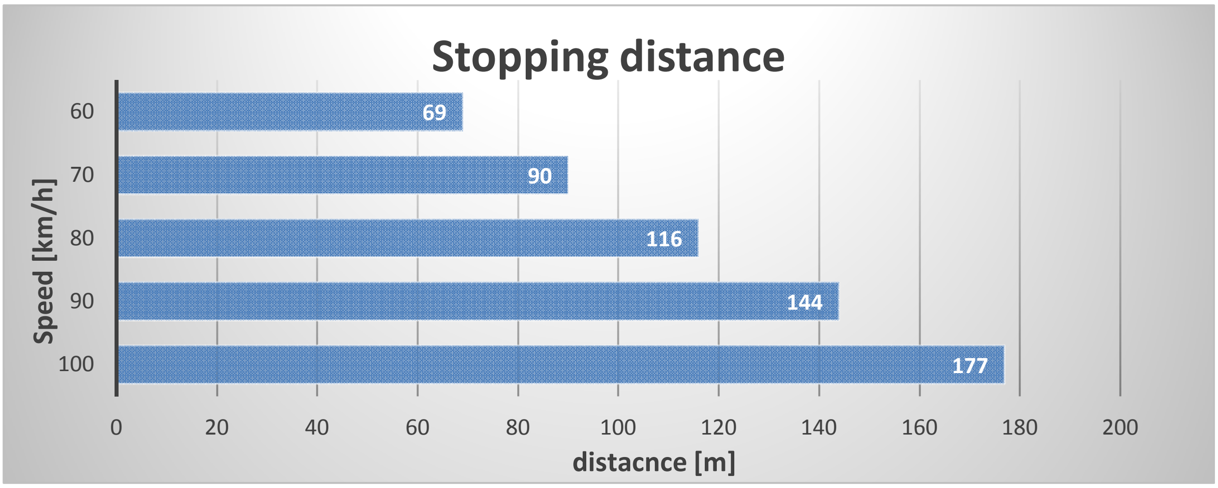



***Figure 35: Stopping distance travelled by the car depending on its speed***

*(Source: personal compilation)*

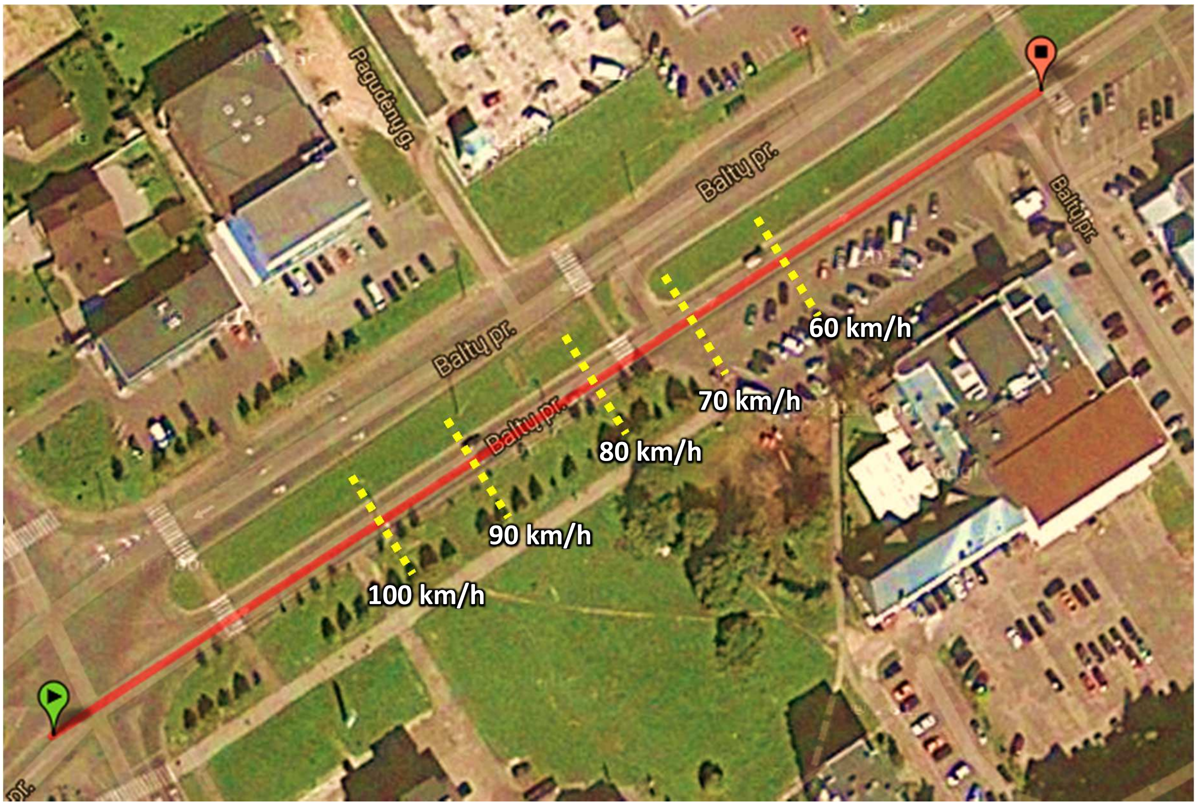



***Figure 36: Point where driver should react to stop on time (250 m) depending on his speed***

*(Source: personal compilation)*

- Final distance it's much longer when power-to-ratio is smaller. That means that cars with less power sometimes couldn't reach the speed assigned before 250 m so their speed is lower and driver can react before and breaking distance will be less. If we consider that driver doesn't stop, fatality risk of pedestrian would be much higher with powerful cars or with a high power-to-weight ratio.

- Even when the scenario is that the driver try to stop the car, we notice that this one is no able to stop the vehicle in a high speed. In this case, the most powerful car analysed (Audi A6) can reach easily high speeds in shorter distance and is able to reduce speed before the crash from 100 km/h to 55 km/h. However other powerful cars which are able to reach 100 km/h before 250 m would be the worst ones in urban environment to safe pedestrian lives because they cannot reduce their speed less than 18%. So it means that if they reach 100 km/h speed (real condition of the accident), their speed at 250 m point will be between 82-100 km/h and the fatality risk of pedestrian would be between 70-90%.

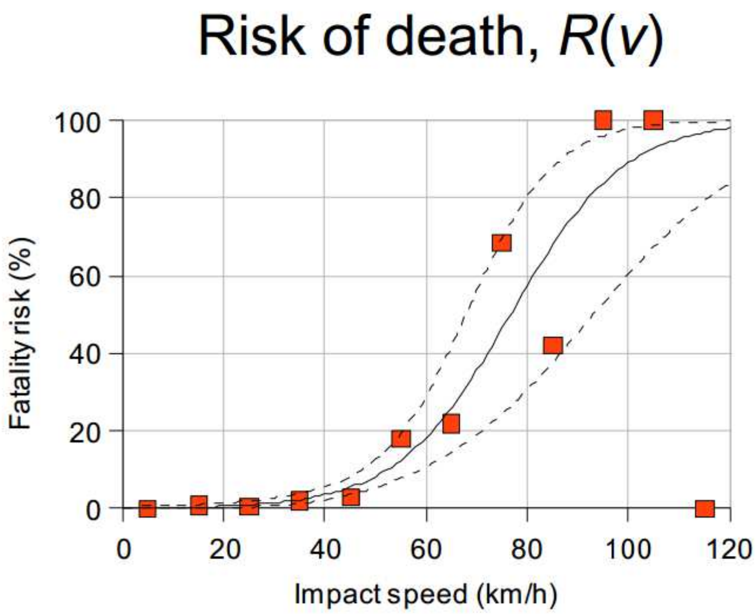



***Figure 37: The fatality rate of pedestrians in crashes with passenger cars as function of the collision speed***
*(Source: Rosén et al., 2011)*

- To sum up, the next table shows the evaluation of risk of death depending of type of car, at 100 km/h speed and considering two scenarios: driver not try to stop and driver try to stop.

| MODEL | | P/W | Driver not try to stop | | Driver try to stop | |
|---|---|---|---|---|---|---|
| | | | Accident speed [km/h] | Risk of death [%] | Accident speed [km/h] | Risk of death [%] |
| **BMW** | **525D** | **0,093** | **100** | **90 %** | **99,65 (b)** | **90 %** |
| VOLKSWAGEN | POLO (STD) | 0,036 | 52,26 (a) | 10 % | 0 | 0 % |
| CITROEN | BERLINGO (STD) | 0,039 | 63,64 (a) | 20 % | 0 | 0 % |
| RENAULT | MEGANE (STD) | 0,051 | 75,97 (a) | 40 % | 0 | 0 % |
| BMW | 3 (STD) | 0,063 | 89,29 (a) | 70 % | 30 | 5 % |
| PEUGEOT | 407 (STD) | 0,065 | 91,53 (a) | 70 % | 40 | 5 % |
| TOYOTA | COROLLA (TOP) | 0,076 | 100 | 90 % | 100 | 90 % |
| VOLKSWAGEN | PASSAT (TOP) | 0,113 | 100 | 90 % | 82,54 (b) | 60 % |
| MERCEDES | C (TOP) | 0,112 | 100 | 90 % | 82,85 (b) | 60 % |
| AUDI | A6 (TOP) | 0,155 | 100 | 90 % | 54,4 (b) | 10 % |

***Table 31: Risk of pedestrian death if the driver wants to reach 100 km/h***
*(Source: personal compilation)*

- In contrary, the different cars who are not able to reach such as speed (100 km/h) in this distance will impact the pedestrians accelerating (scenario where the driver don't stop). In fact, the speed of impact it depends on the power-to-weight ratio, where lowest ratio will impact at 52 km/h. So the fatality risk will increase from 15% to 90%.

- From this last analysis we can also say that the best relation power-to-weight for urban roads (speed limit: 60 km/h) and to protect pedestrian would be between 0.05 and 0.06 maximum because the risk of fatality is very low (0%-5%) if the driver wants to reach 100 km/h and tries to stop when realizes of the pedestrians presence. In the case that the driver don't stop, the maximum ratio should be 0.04 because the risk of death would be 20% and just 1,1% power-to-speed more  increase till 40% the risk.

- Another important conclusion that we can find is that the best speed limit for this road should be 60 km/h because all the cars, even that ones with higher power-to-weight ratios, are able to stop on time. Moreover, as we can see in this following figure, the risk of involvement in a crash in a 60 km/h speed zone depends on speed.

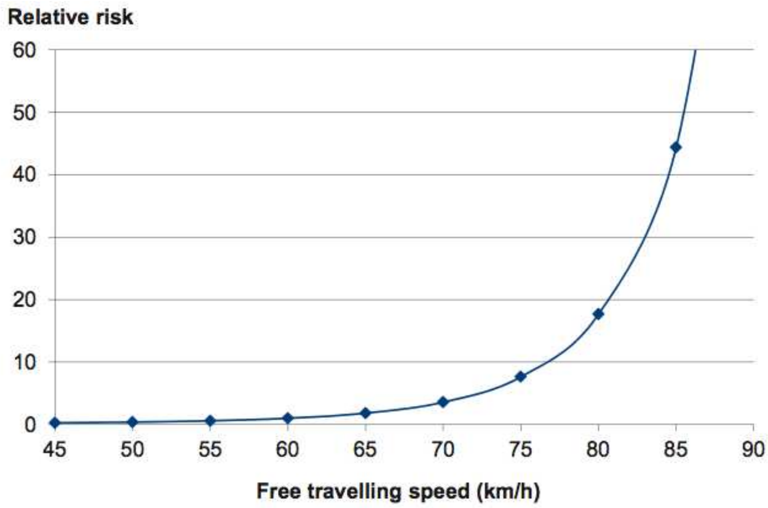



***Figure 38: Risk of involvement in a crash in a 60 km/h speed zone depending on speed***
*(Source: Victorian Auditor-General's Office based on data from the Road Accident Research Unit)*

| MODEL | | P/W | Driver not try to stop | | Driver try to stop | |
|---|---|---|---|---|---|---|
| | | | Accident speed [km/h] | Risk of crash [%] | Accident speed [km/h] | Risk of crash [%] |
| **BMW** | **525D** | **0,093** | **100** | **90 %** | **99,65 (b)** | **90 %** |
| VOLKSWAGEN | POLO (STD) | 0,036 | 52,26 (a) | 10 % | 0 | 0 % |
| CITROEN | BERLINGO (STD) | 0,039 | 63,64 (a) | 20 % | 0 | 0 % |
| RENAULT | MEGANE (STD) | 0,051 | 75,97 (a) | 40 % | 0 | 0 % |
| BMW | 3 (STD) | 0,063 | 89,29 (a) | 70 % | 30 | 0 % |
| PEUGEOT | 407 (STD) | 0,065 | 91,53 (a) | 70 % | 40 | 0 % |
| TOYOTA | COROLLA (TOP) | 0,076 | 100 | 90 % | 100 | 90 % |
| VOLKSWAGEN | PASSAT (TOP) | 0,113 | 100 | 90 % | 82,54 (b) | 20 % |
| MERCEDES | C (TOP) | 0,112 | 100 | 90 % | 82,85 (b) | 20 % |
| AUDI | A6 (TOP) | 0,155 | 100 | 90 % | 54,4 (b) | 1 % |

***Table 32: Risk of crash in a 60 km/h sped zone if the driver wants to reach 100 km/h***
*(Source: personal compilation)*

- What we can see in this last table is that risk of involvement in a crash follows an exponential graph where as much speed much more risk. Look, there is a huge increment risk from 80 km/h to 100 km/h: four times.

# Chapter 5

# Conclusions

This Master Thesis proposed to understand why Lithuania has one of the worst index of killed in traffic accidents in the European Union, especially pedestrians' deaths. In order to this, the project compares statistics in Lithuania, Spain and Sweden and analyses a real accident occurred in Kaunas (Lithuania).

Through the comparison of these countries we can conclude the number of vehicles has increased during the last decade in all three countries and, in contrast, the number of fatalities and injuries has reduced. Due to the entrance of Lithuania in the European Union (2004), it has increased by 50% the number of registered vehicles and probably this fast vehicles growth and the road safety management on this new big park of vehicles could be a strong reason of high rates of fatalities.

However, most collisions and accidents occur in built up areas and the high number of fatalities and serious injuries faced by vulnerable road users such as riders of motorcycles, mopeds, cyclists and pedestrians are significant and in some European States still increasing. In Lithuania, pedestrians are the most vulnerable road user group and it is one of the highest issues in road safety in this country.

From the analysis of each country we can also extract the profile of death people in road accidents: a man between 18-25 years old or older than 65. In fact, young and novice drivers (with less than one year's experience) are responsible for a big amount of the total number of crashes. Moreover, this young group usually is who drives more powerful vehicles or with a higher power-to-weight ratio and they can reach higher speeds in less distance. Speed is another important variable to take into account which is closely related with power-to-weight ratio.

Modelling the selected and real accident between two pedestrians and a BMW drove by novice driver the final thesis concludes that could be interesting to restrict power-to-weight ratio vehicles for these group and proposes that the maximum ratio should be 0.04 because the risk of pedestrians' death would be in the worst scenario the 20%.

However, another possible solution could be being zero tolerant with high speed in urban zones and implementing different measures such as low urban speed-limits, pedestrian zones and barriers that separate cars from bikes and oncoming traffic. Building safer crossings, including pedestrian bridges and zebra-stripes flanked by flashing lights and protected with speed-bumps. Finally, strict policing can also help: much control in drivers with alcohol tests and speed cameras.

To sum up, Lithuania successfully implemented the target set in the EU White Paper of reducing, by 50%, the number of traffic deaths in the period 2001-2010. The number of fatalities was reduced from 706 to 299 – i.e. a 58% reduction. However, it has to develop more strategies to continue with the encouraging results in the past decade. Apart from those ones already explained, to achieve this objective it could be interesting to:

• Further improve road users' education in the field of traffic safety;

• increase road users' and vehicle enforcement;

• improve the rescue service quality and crash data collection system.

In the complex system, road safety depends on participants' responsible behaviour, educational organizations, media, repressive and jurisdictional organs, civil society, companies, local self-government units and also state authorities. Each and every one of them has its own share of responsibility for a better safety and contributes to its realization. But the goals can be achieved only with coherent measures and collective efforts.

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