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School of Transportation Sciences

Master of Transportation Sciences

Master's thesis

Analysis of Road Safety Indicators for crashes involving heavy goods vehicles: Road Safety Monitoring & Benchmarking in Europe

Tinsaye Tefera Yishak

Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences, specialization Traffic Safety

SUPERVISOR :
Prof. dr. Elke HERMANS

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PREFACE

This thesis is the culmination of my research on analyzing road safety indicators for crashes involving heavy goods vehicles: road safety monitoring & benchmarking in European countries. The topic is certainly relevant today because heavy good vehicles pose serious risks, especially to vulnerable road users, due to their large mass. Even though no exposure indicator can be used globally to assess a country's performance in HGV safety accurately, this study examined the data already available to gain more insightful knowledge into each country's HGV safety situation.

My prior knowledge and the knowledge I acquired while attending Hasselt University were put to use as I worked on this thesis. Additionally, I've learned valuable facts about the subject and improved my research abilities. Since monitoring and benchmarking have caught my attention to assist with comparing HGVs safety performance across countries, I am passionate about and intend to be involved in research on related topics.

I express my sincere gratitude to the Flemish Interuniversity Council, VLIR-UOS, for granting me a scholarship and enabling me to pursue this master's degree. Next, I would like to sincerely thank my thesis promotor, Prof. Elke Hermans, for her help, inspiration, and guidance throughout my studies. This work is only possible because of her thoughtful steering, unreserved and unsurpassed knowledge of the research. I would also like to thank my co-promoter Prof. Evelien Polders, for her timely and constructive feedback. Last but not least, I want to express my sincere gratitude to my family and friends for their fantastic kindness, patience, love, and respect.

I hope this thesis will aid in understanding HGV safety policies and practices in Europe and other continents. More importantly, I hope it will encourage researchers, transportation experts, and policymakers to consider a detailed study on HGV safety.

SUMMARY

The potential severity of injuries and economic impact of HGV crashes have grown in recent years due to their large mass. The study's main objective is to examine available data on HGVs involved in road traffic crashes in European countries to assess the HGV safety performance in selected countries based on a set of indicators and to benchmark their performance against best performers. The intended result is to recommend countermeasures to reduce the identified problems. In this study, eight risk domains (problem areas) are explored to develop HGV safety performance indicators: seatbelts, speed, alcohol and drugs, driver distraction, driver fatigue, vehicle-related indicators, permissible maximum weights, and post-impact care. The limited availability of disaggregated data focusing on HGV limited the final selection of basic indicators. Based on the availability of data over a period of time, a selection of European countries for which a complete data set for the most recent year is obtained from several sources.

The initial analysis of the composite index's construction process is performed using 15 indicators for the 28 European countries. The second analysis of the composite index's construction process is performed using all 17 indicators for 9 European countries. Data analysis is carried out on the gathered indicator dataset to gain more understanding of each indicator individually (univariate analysis) and the structure and relationships of the entire indicator set (multivariate analysis). For each country and groups of countries with comparable values of the composite HGVs index are created. Three types of index scores are obtained using EW (linear and geometric) and Poison regression analysis technique, using cross-sectional data for 2018. Variations are seen in the rankings of the countries obtained using various methods.

Additionally, a reference ranking of the average annual change in deaths involving HGVs for all countries from 2010 to 2018 is used to ensure that the rankings are not solely based on 2018. Spearman's correlation analysis between the rankings and the reference ranking reveals that the linear aggregation ranking provided a more appropriate description of a country's HGV safety performance. Using groups of countries with comparable levels of HGV safety performance, the 'best-in-class' is then identified. The study's findings confirm differences in the safety performance of HGVs between the countries under investigation and made an effort to determine why. Therefore, benchmarking HGV safety performance results in recommendations that support best practices, encourage the adoption of effective HGV safety strategies and measures, and, more importantly, inspire researchers, transport experts, and transportation policymakers on the concept of developing the HGV safety index.

Key Words: Heavy Goods Vehicles, Road Safety Indicator, Composite Index, Monitoring, Benchmarking, European Countries.

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LIST OF ABBREVIATIONS

ABS	Anti-Lock Braking System
ACEA	The European Automobile Manufacturers' Association
ADAS	Advanced Driver Assistance Systems
AEB	Autonomous Emergency Braking
AIC	Akaike Information Criterion
BAC	Blood Alcohol Concentration
CI	Composite Index
DALY	Disability-Adjusted Life-Years
DUI	Driving Under Influence
DG ECFIN	Directorate-General for Economic and Financial Affairs
ECR	Euro Contrôle Route
EMS	Emergency Medical Services
ERF	European Union Road Federation
ESC	Electronic Stability Control
ETSC	European Transport Safety Council
EU	European Union
EW	Equal Weight (ing)
GBD	Global Burden of Diseases
GDP	Gross Domestic Product
GSR	General Safety Regulation
HGV	Heavy Goods Vehicles
IBM	International Business Machines
IRF	International Road Federation
IRTAD	International Traffic Safety Data and Analysis
ISA	Intelligent Speed Assistance
ISO	International Organization for Standard
ITF	International Transport Forum
KMO	Kaiser-Meyer-Olkin
LGV	Light Goods Vehicles
LRT	Likelihood-Ratio test
OECD	The Organization for Economic Co-operation and Development
PCA	Principal component analysis
PIN	Road Safety Performance Index panelist
PTW	Powered Two Wheelers
SPI	Safety Performance Indicators
SPSS	Statistical Package for the Social Sciences
SUN	Sweden, the United Kingdom and the Netherlands
SWOV	Dutch Institute for road safety research
UNECE	United Nations Economic Commission for Europe
USA	United States of America
VRU	Vulnerable Road Users
WHO	World Health Organization

CHAPTER ONE

1. INTRODUCTION

This master's thesis investigates available data on Heavy Goods Vehicles (HGVs) (goods vehicles of over 3,5 tons maximum permissible gross weight) involved in road traffic crashes in a number of European countries and their best practices in order to monitor HGV's safety performance based on a set of indicators. This section gives an introduction of the thesis research project and includes the background, problem statement, research objectives and questions, organization of the research, as well as the conceptual framework of the study.

1.1 Background

According to the global report on road safety in 2018 by the World Health Organization (WHO), road traffic crashes claim more than 1.35 million lives yearly and cause 20-50 million injuries. The report also identified road traffic crashes as the leading cause of death for people between 5 and 29 years of age (World Health Organization, 2018). According to Global Burden of Diseases (GBD) and Injuries Collaborators (2020), the ranking of road injury rose from number 8 cause of Disability-Adjusted Life-Years (DALY) in 1990 to number 7 in 2019, considering all age and gender levels. In 2019 road injury was the number one cause of DALY in the world for the 10-49 age group (GBD 2019 Diseases and Injuries Collaborators, 2020). Furthermore, from previous reports, it has been shown that road traffic crashes are severe for vulnerable road users, pedestrians, cyclists, and riders of motorbikes and their passengers accounting for a staggering 50% of global road crash fatalities (World Bank, 2019).

The International Traffic Safety Data and Analysis (IRTAD) database collects and aggregates international data on road crashes from several countries. Thus it provides an empirical basis for international comparisons and more effective road safety policies (IRTAD, 2019). IRTAD (IRTAD, 2019), confirmed that the years 2017 and 2018 have been encouraging for road safety in the majority of IRTAD countries. This is because, among the 26 countries the number of road deaths decreased in 16 countries, while it increased in 10 countries. On average, traffic fatalities were down by 5.7% in 2017 compared to 2010 and decreased by 1.7% in 2018 compared to 2017. Similarly, the 14th road safety performance index (PIN) report by the European Transport Safety Council (ETSC, 2020) ranked EU progress on road safety: out of the 32 countries, 16 countries reduced road deaths in 2019 compared to 2018 in which Luxembourg achieved the best results with a 39% decrease, Sweden with 32%, and Estonia with 22%. On the other hand, road deaths increased in 12 countries, while progress stagnated in four countries.

The number of road fatalities dropped significantly in the early months of 2020 because of the lockdown imposed in many countries in response to the Covid-19 pandemic. A decrease in economic activity and the movement of people reduced the number of road casualties. Sweden (21.6%) reported the highest reduction, followed by Switzerland (17.4%). However, some countries registered increases in average speed and in the severity of road crashes. Taking into account the type and scale of lockdown measures and their impact on traffic, driving behavior and the traffic composition (the increase in the number of pedestrians and cyclists), some countries registered increases in the number of road deaths such as Denmark (+7.2%), the Netherlands (+3.3%) and Belgium (+2.9%) (IRTAD, 2020).

Likewise, the number of fatalities in crashes involving HGVs in the European Union decreased from about 7,200 in 2006 to 3,800 in 2015 (almost 50% reduction). Also, the total share of HGV fatalities in the EU fell to some extent from 17% in 2006 to 14% in 2015. The share was highest in Finland and Poland, whereas it was lowest in Estonia and Italy (European Road Safety Observatory, 2017). Between 2016 and 2007, the total number of fatalities involving HGVs in the EU fell by almost 40%, however, it slightly increased afterwards (European Road Safety Observatory, 2008). Around 3310 people were killed in road collisions that involving HGV in the EU in 2018, representing 14% of all road deaths. The number of deaths in collisions involving HGVs has decreased by 1.8% on average each year in the EU over the period 2010 to 2018 (European Transport Safety Council, 2020). Sweden had an exceptionally massive increase in the number of road fatalities involving HGVs in 2018. Estonia and Romania recorded an average annual reduction in the number of deaths involving HGVs (European Transport Safety Council, 2020).

These kinds of reports are very encouraging for the majority of countries and, show that countries work on their road safety issues to tackle their road safety problems. A comparison between countries based on crash data and the number of casualties can be used to set up a ranking between countries. Sharing the road safety experiences from country to country and from region to region can be the ideal solution to achieve the desired goal as a whole. According to Shen et al. (2015), even though the final solutions or priorities could be different from one country to another, close cooperation between countries within the same region or between countries that have similar challenges and development can identify common problems and improvement can be anticipated by learning lessons from existing best practices in other countries. Thus, country benchmarking is a useful tool, used in many regions in many areas, to compare countries and learn from each other.

Benchmarking is a process in which countries or jurisdictions (states, provinces, etc.) evaluate various aspects of their performance with other, so-called 'best-in-class' jurisdictions. The benchmark results provide countries or jurisdictions with information from others that can be used to develop measures and programs to increase their performance (Wegman et al., 2008). However, conducting road safety benchmarking successfully is a difficult task because there is currently no universally accepted practice. It consists of a series of core activities such as selecting a set of appropriate road safety performance indicators (SPIs), structuring them logically, and then combining them into a composite index in a concise and comprehensive manner, which is the key foundation for successful benchmarking (Shen et al., 2015).

1.2 Problem Statement

Road transportation that is effective increases economic competitiveness. In order to offer safe and sustainable freight mobility, it must be supported by an integrated, multimodal freight transportation system which is a vital component of any prospering and growing economy. It is the basis for many supply-chain and logistical systems. In 2017, in the road transport sector, 571,795 companies were active in the EU-28; mainly in Spain (18%), Poland (15%), Italy (11%), and the United Kingdom (8%) (De Smedt & De Wispelaere, 2020). In 2020, road freight transport accounted for more than three-quarters (77.4%) of total inland freight transport (based on ton-kilometers performed) (Eurostat, 2022a). Because of their geographical location or economic activity, some countries experience more international freight transport by road than others. Germany accounts for approximately 27% of total EU freight transport volume (in ton km), while France accounts for 16%, Poland and Spain account for 10% (Eurostat, 2022a). A safe system that moves freight reliably and efficiently should be competitive, relieve traffic congestion, increase the safety, security, and resilience of the system, maintain infrastructure, be environmentally-friendly, and use cutting-edge technology and practices (Znidaric, 2015).

In all countries that collect distance travelled data by HGVs on their roads, HGVs pose a greater risk to other road users than non-goods vehicles (European Transport Safety Council, 2020). In Switzerland, for example, the risk of death in a collision involving an HGV per km travelled by HGVs is four times greater than the risk of death in a collision involving a non-goods vehicle per km travelled by non-goods vehicles. The danger is three times higher in the United Kingdom, Estonia, Sweden, France, the Netherlands, and Austria. HGVs are involved in twice as many fatal collisions per km traveled in Poland and Norway as non-goods vehicles. In Slovenia, HGVs are involved in 1.5 times as many fatal collisions per billion kilometers traveled as non-goods vehicles (European Transport Safety Council, 2020).

Because of their large mass, growing concerns related to HGVs crashes have increased in recent years owing to the potential level of injury severity and economic impact (European Road Safety Observatory, 2008). Most of the fatalities resulting from collisions involving HGVs are not HGV occupants but other road users. According to the European Transport Safety Council (2020), most of the fatalities are car occupants accounting for 50% of all deaths in collisions involving HGVs. Vulnerable road users account for nearly 28% (13% are pedestrians, 7% are cyclists and 8% are motorized two-wheelers). Occupants of HGVs make up 12% of all road deaths, 11% are drivers and 1% passengers (European Transport Safety Council, 2020).

In general, although countries may have had different HGVs safety performance in the past years and for the future, countries need to learn and improve road safety not only from their own experiences but also from systematic comparison with other countries of both their safety performance and their safety interventions and policies. Several studies have popularized the concept of road safety indicators to overcome the difficulty of making international comparisons of road safety performance and to allow for a sufficient understanding of the processes that lead to road crashes and casualties (e.g. Nardo et al., 2005, Hakkert et al., 2007, Wegman et al., 2008, Hermans et al., 2008, Bax et al., 2012, Shen et al., 2015). Usually, there is a bias to investigate the overall/aggregated performance of a country by means of road safety performance indicators. However, benchmarking the road safety performance of a specific transport mode, such as the HGV using specific road safety performance indicators, can add value to evaluating and monitoring the progress of HGV's safety from country to country. Although there is no universally accepted set of indicators that accurately describes the HGV safety performance of a country, more estimable insight into the HGVs safety situation of countries can be acquired by studying the existing data and comparing them to benchmark countries.

1.3 Objective

The main objective of the study is to examine available data on HGVs involved in road traffic crashes in European countries to assess the HGV's safety performance in selected countries based on a set of indicators and to benchmark their performance against best performers. The intended result is to recommend countermeasures to reduce the identified problems.

The specific objectives of the study are to:

1. Assess the trend of traffic crashes and casualties involving HGVs in selected European countries;
2. Identify the major contributing factors and road safety indicators related to crashes involving HGVs;
3. Develop a composite HGV index for the selected European countries;
4. Compare and benchmark countries based on the composite HGVs index;
5. Recommend effective interventions and countermeasures that could be applied to improve the HGV's safety performance.

1.4 Research Questions

The study focuses on the following research questions to achieve the aforementioned objectives:

1. What is the trend of HGV traffic crashes and casualties in selected European countries?
2. What are the major contributing factors and relevant road safety indicators related to crashes involving HGVs?
3. What is the composite HGV index of the selected European countries?
4. Which countries are the benchmark in HGVs safety performance?
5. What possible countermeasures could be recommended to improve the HGV's safety performance?

1.5 Organization of the Research

This study is organized into five chapters. In the first chapter, the study background, definition of the problem and purpose of the study, research objectives, and questions are included. Chapter 2 covers a review of related literature to understand state-of-the-art of benchmarking and the process of benchmarking. Furthermore, the section attempts to review the literature on the recommended road safety performance indicators for HGV before presenting the final set of selected available road safety indicators of HGV in this study. Finally, the selected available HGV road safety indicators in this study are presented. Chapter 3 describes the study area, study design, data collection methodology, and data analysis techniques and how they address the research questions. Chapter 4 involves the research findings and interpretations. A detailed discussion of the findings linked with previous findings, the limitations, and recommendations for future study are presented in chapter 5. Lastly, the study's conclusion is provided in chapter 6.

1.6 Conceptual Framework of the study

The study's conceptual framework shows the steps and major methods used to meet the stated objectives.

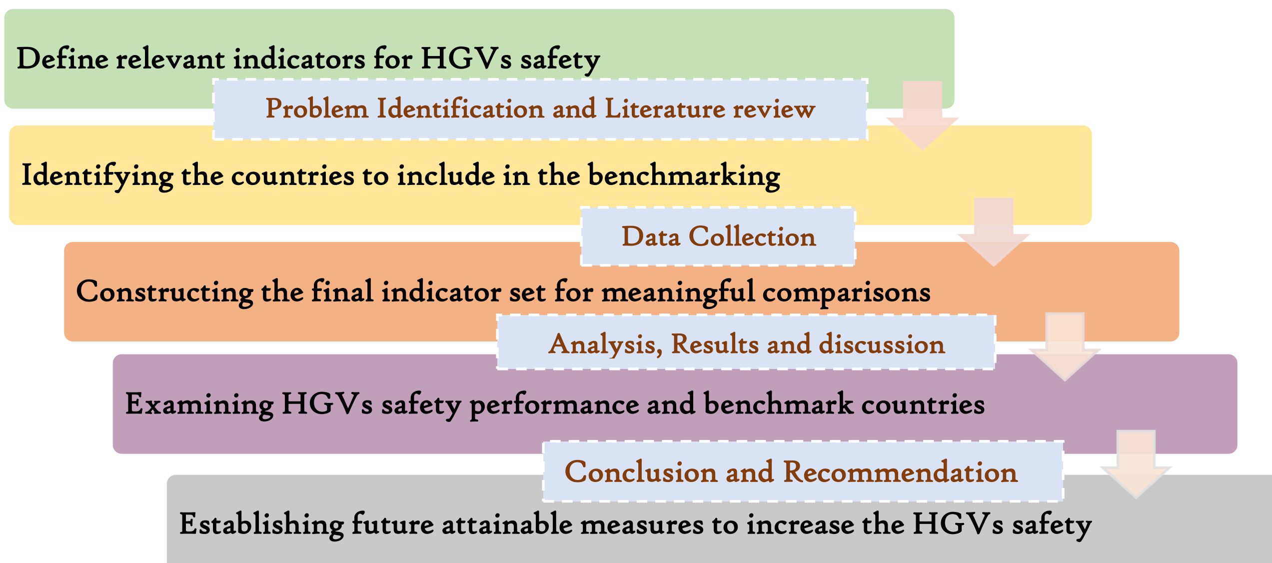

Figure 1: The Conceptual Framework of the study

CHAPTER TWO

2. LITERATURE REVIEW

The purpose of this chapter is to give a general theoretical framework about the topic of benchmarking in road safety; it also aims to present general facts of previous findings, methodology development and trends about related concepts that have been researched. Different scholars, international institutions and countries have attempted to come up with benchmarking. In order to provide a clear and simple understanding of the relevance of the findings of this study, it will highlight the research gaps and the data from the literature. The review will establish whether or not the study's findings agree with the currently available literature.

2.1 Benchmarking Process

In general, according to Wegman and colleagues (2008), benchmarking is built on learning from others, rather than developing new and improved approaches. In the context of road safety a benchmarking process developed by Shen et al. (2015), consists of the following essential activities (Figure 2):

Determining the key components for road safety benchmarking: compare the road safety performance between countries and determine what to benchmark in the first place. For a comprehensive benchmarking framework, four aspects of the road safety management and improvement process (organization, strategy, program and product) have been identified. Shen and colleagues (2015) confirmed that organizational and strategic benchmarking use organizational framework, management, national road safety strategies and resources to compare countries. Product benchmarking uses the road safety final outcomes (e.g. fatality numbers) to compare but most of the road safety benchmarking studies have focused on Program benchmarking, which is used to compare activities related to human-vehicle-infrastructure performance, such as drink driving, seat belt compliance, vehicle safety rating and safe road safety infrastructure, and corresponding policy action. Product benchmarking gives more attention to the current road safety status as they are based on collected crash data (on crashes, causalities or injuries), whereas program benchmarking focuses on the process that leads to crashes or injuries and can provide a better understanding. Since each country may use and be effective in different conditions, using a composite road safety indicator (or index) (Wegman et al., 2008) will be appropriate to achieve meaningful benchmarking.

Figure 2: The road safety benchmarking cycle (Source: Shen et al., 2015)

Identifying the benchmarking countries: to achieve adequate and substantive results throughout comparisons, road safety benchmarking studies typically have to be carried out between similar countries or regions as much as possible at an equivalent level of development, motorization and with a similar pattern of the transport system (Shen et al., 2015). European countries were chosen for this thesis study because there are some data sources available to make an effort and to set a basis for future researches. According to the European Transport Safety Council (2020), varying progress is seen in minimizing crashes involving HGV across European countries; as a result, grouping (see Chapter 4) is done based on similarities and performance in terms of heavy vehicle safety.

Develop indicators for meaningful comparisons and data gathering: developing and assembling appropriate indicators for the selected benchmarking component. They can be measured in number of fatalities per population, vehicles or kilometers traveled, as percentage of seat belt compliance, or as qualitative information such as level of national road safety intervention (extremely high, high, low, and extremely low). Indicator values need to be collected for all the countries involved in the benchmarking study. More information on indicator selection and data collection is given in section 2.3 and 2.4.

Examining gaps in performance and their root causes: identify the gaps in road safety performance between the countries under study and understand the root causes for these gaps. This is the most necessary step during the entire benchmarking study, but also the most difficult task to accomplish. Today, various benchmarking tools have been developed which range from relatively simple (e.g., using statistical tables and graphs) to more complex (e.g., index-based approaches). The procedure of these benchmarking tools depend on the details of collected data, the number of indicators involved, and the complexity of techniques used in calculation and analysis (Shen et al., 2015). In this study, the HGV safety index was created using equal weighting with linear, geometric aggregation and using a Poisson regression model. The procedure of HGV index formation and benchmarking process is presented in chapter 4 section 4.4 and discussion of the findings in chapter 5.

Establishing future attainable performance and monitoring progress: this includes target-setting for those underperforming countries in terms of different road safety aspects, and also determines what needs to be done to perform the best practices and to fill the gaps for the process (Shen et al., 2015).

Unfortunately, this master's thesis cannot fully address the final two steps. The current study does not provide the detailed weaknesses and strengths explanations of each country, and additional research is required to draw specific conclusions about where and how to improve and to establishing future attainable performance target.

Each of these five activities has different challenges for the road safety benchmarking process, and all of them are vital elements in a complete road safety benchmarking study. It is advisable and recommended to deal with a benchmark cycle and to carry out benchmarking at regular intervals, to monitor progress made and to evaluate the results of interventions on road safety in each country to achieve continuous improvement over time.

2.2 Conceptual framework of Benchmarking

A number of road safety benchmarking studies have been undertaken in several countries (mainly in Europe). The preliminary basics of the conceptual framework of benchmarking is the SUNflower pyramid in which three types of indicators are distinguished. The most important road safety benchmarking projects are summarized below.

2.2.1 The SUNflower approach

SUNflower is the abbreviation of a series of projects that started by comparing road safety performances, programs and policies in Sweden, the United Kingdom and the Netherlands (Koornstra et al., 2002). The core aim of the SUNflower approach was to answer the question of what exactly caused road safety to improve in SUN countries and then how these could be used in another SUN country or other countries to further improve their performance. This can be achieved by identifying and assessing the relationship between the developments of traffic risks and road safety policies, programs and measures in these countries. The methodological approach used in the SUNflower project (Koornstra et al., 2002) is based on the road safety target hierarchy as shown in Figure 3.

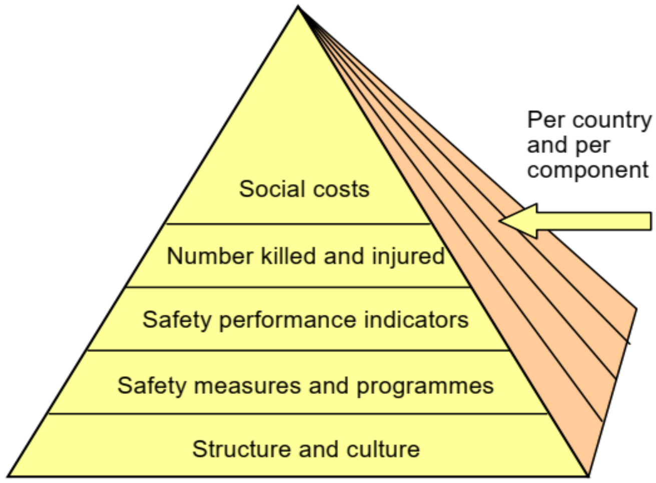

Figure 3: Hierarchy for road safety at a disaggregate level (Source: Koornstra et al., 2002)

The pyramid consisting of five horizontal layers stacked simply but logically implies the causal relationship between indicators at the different layers of the pyramid for a better understanding of the development at the top by explaining the change at the bottom (Shen et al., 2015). From bottom to top they are: The structure and culture layer describes country-specific background conditions and characteristics relevant for road safety. It is related to the policy context/policy input and the societal perception of road safety problems with the respective responsibilities. The next layer concerns safety measures and programs or road safety policy performance/policy output. Followed by the layer of safety performance indicators also known as intermediate outcomes. On the verge of the top of the hierarchy is the layer of numbers of fatalities and injuries as final outcomes, with the very top layer of social costs due to the fatalities and injuries (Shen et al., 2015).

The pyramid hierarchy (Figure 2) also provides a framework for creating road safety systems and highlights the relevance of research at many levels and from distinct viewpoints (Koornstra et al., 2002). For instance, compare percentage distributions across variables like fatality and injury rates, broken down into smaller groupings such as age groups, type of vehicles, area and carriageway type.

2.2.2 SUNflower+6 Project

The SUNflower approach has inspired researchers in many countries throughout Europe and later became a new project - SUNflower+6. The new project included six additional European countries and extended the scope of the original work in more detailed analyses. These countries included the original SUN countries (Sweden, United Kingdom and the Netherlands), 3 countries from Central Europe (the Czech Republic, Hungary and Slovenia) and 3 Southern countries (Greece, Portugal and Spain, and the autonomous Spanish region of Catalonia) (Wegman et al., 2005). A similar method was applied in SUNflower+6 to analyze the road safety performance.

- Compare road safety practices and developments in three groups of countries (SUN countries, Central and Southern countries) identifying the strengths and weaknesses of each country through comparative benchmarking,
- Develop a framework based on knowledge for benchmarking a country's road safety level,
- Present recommendations to improve road safety by non-SUNflower+6 countries and the European Commission.

2.2.3 SUNflowerNext

The third and most recent study is the SUNflowerNext study, developed with the aim of expanding the knowledge-based framework for comprehensive benchmarking of road safety performances of a country or sub-national jurisdictions; it made the first attempts to capture this process in a safety performance index (Wegman et al., 2008). According to Wegman and colleagues (2008), in the SUNflowerNext project it has been decided that it is better not to make comparisons between all 27 European countries as one group, but to try forming a number of country groups that are comparable and to then compare the countries within that specific group. Then the SUNflowerNext study had the objective to

- Identify the best performing countries,
- Understand why they were performing better than other countries, and
- Analyze how outstanding practices from the countries which perform “best-in-class” could be adapted to other countries

Other than the grouping, in SUNflowerNext, an essential and complete set of indicators (three types of indicators) had been developed (Wegman et al., 2008) to measure the road safety performance of a country while including all information from the SUNflower pyramid:

- **Road safety performance indicators:** (outcome indicators or product indicators) capture a country's road safety quality. Final outcomes such as numbers of killed and injured persons, as well as intermediate outcomes such as the safety performance indicators, and social costs.
- **Implementation performance indicators:** (process indicators) specify the quality of the implementation of road safety policies. This indicator follows a vertical line in the pyramid linking safety measures and programs, safety performance indicators, and the numbers of killed and injured people.
- **Policy performance indicators:** deals with the quality of policy to improve road safety. The quality of policy can be seen in two components: the quality of conditions such as strategies, programs, resources, coordination, institutional settings and the quality of intervention, action taken and individual countermeasures in the perspective of the road safety targets.

2.2.4 Road safety Index

For the sake of simplification, quantification and communication, a composite road safety index combining these indicators in 1 index (value) was found to be important for the

SUNflowerNext study. After exploring several ways of creating a composite index it was decided to also explore the opportunities for a composite index for road safety performance. Two weight-based procedures (principal component analysis and common factor analysis) were used, to form a composite index based on the data collected for 27 European countries. The composite index gives a more enriched picture of road safety by ranking and grouping the countries according to their safety performance. Finally, it was concluded that the formation of the composite road safety performance index (the SUNflower index) by collecting relevant information from the different components of the road safety pyramid and weighting, is realistic and meaningful (Wegman et al., 2008).

Another study on benchmarking road safety performance (Hermans et al., 2009), explained that the combination process in the formation of a composite indicator or index consists of two phases. First, the individual indicators per risk domain (alcohol and drugs, speed, protective systems, vehicles, roads, and trauma management) should be combined into one indicator per domain. Then, the domain indicators are combined in one road safety index. According to Hermans and colleagues (2009), the weighting procedure is the most important aspect in combining indicators to form a composite index. From major weighting procedures (factor analysis, budget allocation, analytic hierarchy process, data envelopment analysis, and equal weighting), Hermans and colleagues (2009) recommended that the data envelopment analysis road safety model should be used in the future and more aspects should be investigated.

2.2.5 DaCoTA project: Road Safety Data, Collection, Transfer and Analysis

A last study that aimed to build a composed road safety index is the DaCoTA project. It was a continuation of the SafetyNet and the SUNflower projects, which had developed the hierarchy of the pyramid structure and the concept of road safety performance indicators, and made the first calculations. The main procedures used in the DaCoTA project were first investigating whether indicators for road safety management can be used in the Road Safety Index, then extend the work on indicators for structural and cultural differences among countries, thirdly aggregate the indicators into one single score per layer and finally investigate whether further integrating the top four layers into one single score for the composite index as a whole would provide any added value (Bax et al., 2012). The Social Costs layer is not used in the Index because all available social cost indicators are directly based on the outcome layer.

The International Transport Forum (ITF) completed a project similar to the DaCoTa project to develop a methodology for assessing road safety performance in ten Latin American countries and benchmarking it against a set of indicators (OECD/ITF, 2017). The ten countries were divided into groups in the study, with some unifying similarities among the countries using structural and cultural differences. In addition, this project examines a set of indicators from the pyramid's other layers, as well as the relationships between them. This includes both final and intermediate outcome indicators, also identifying key road safety management practices in key road safety areas as a foundation for benchmarking safety interventions.

2.3 Road Safety Indicators for HGV

As previously mentioned, Wegman et al. (2008) established a critical and comprehensive collection of indicators (outcome or product, process and policy indicators) to quantify the performance of a country's road safety while taking into account all data from the pyramid. At the top level of the pyramid, the social costs of road crashes and injuries can be used to assess road safety. SUNflower employs the term social costs, as well as road crash costs and socio-economic costs. All three terms cover five major categories: medical costs, production loss, quality of life loss, material costs, and settlement costs (Wegman et al., 2005). The next level counts injuries or crashes, is frequently a direct indicator of road safety. Crash and injury incidents are frequently only the tip of the iceberg because they occur as the "worst case" of the road traffic system's unsafe operational conditions (Hakkert et al., 2007). As a result, in order to provide a way to monitor the success of the safety measures that are taken, additional safety performance indicators are needed (in addition to crash and injury statistics) (Wegman et al., 2005). Safety performance indicators can be thought of as measurements that are causally connected to crashes or injuries and are used in addition to statistics about crashes or injuries to show safety performance or comprehend the processes that cause crashes (Wegman et al., 2005;Hermans et al., 2008).

The third-level problems are less visible, and they are related to the underlying processes or conditions of the traffic situation, specifically the organization and management of road safety work, such as central or distributed responsibilities, or the citizens' values and knowledge of road safety measures. These issues are related to the SUNflower project's safety measures and program level (Koornstra et al., 2002; Shen et al., 2015;Wegman et al., 2005). The structure and culture is the lowest layer/level of the pyramid in the SUNflower approach; it was created for two reasons (Shen et al., 2015;Wegman et al., 2005), (1) It provides a necessary context for all observations and indicators at a higher level of the pyramid. Because of not knowing or ignoring these backgrounds, progress in road safety may not be fully understood or even misinterpreted. (2) It is difficult to transfer benchmarking findings and learn from experiences and results in other countries without a clear picture of the context in which these results were achieved or changes were measured.

According to the European Road Safety Observatory (2017), no two EU countries use the same set of indicators same technique, or even same definition when collecting data. In order to meet the current study's objective of combining the main layers of the road safety pyramid into a composite HGV index for benchmarking purposes, problem identification and a literature review of the available indicators were conducted before choosing which layers to take into consideration. According to Hermans et al. (2009), the road safety performance indicators that should be chosen from the range of possible indicators should be those that reflect a compromise between the available and essential road safety performance indicators.

Therefore, in addition to the crash/injury statistics and country background data currently available, safety performance indicators were sought after as a way to monitor the success of safety measures put in place. From a narrow set of safety performance indicators related to HGVs, potential indicators are suggested for each of these areas using a limited set of safety performance indicators connected to HGVs with an aim towards future collaborative analysis, target setting, and benchmarking at the European level. Thus, eight risk domains (problem areas) were explored for the development of HGVs safety performance indicators. which are:

- Seatbelts
- Speed
- Alcohol and drugs
- Driver Distraction
- Driver Fatigue
- Vehicle related indicators
- Permissible maximum weights
- Post-Impact Care

The following sections attempt to explain these key risks, their relevance in terms of HGV road safety, possible programs/measures, and a list of possible HGV indicators.

2.3.1 Seatbelts

The most reliable safety measure in vehicles continues to be the seatbelt. A seatbelt is a strap that fastens a person to the seat to prevent them from being thrown out of the vehicle or from an impact to the interior of the vehicle. The seatbelt has been tested and developed to prevent an injury and the result of that is the feature that is now used in all modern vehicles (Shaikh et al., 2013). Despite the fact that reinforced HGV cabs only protect their occupants if they are securely secured, HGV drivers typically exhibit lower seat belt usage rates than automobile drivers (European Transport Safety Council, 2020). According to a survey by Volvo trucks, 50% of the non-belted HGV occupants killed in crashes would have lived if they had correctly buckled their seatbelts (Kockum et al., 2017). The European Transport Safety Council (2020), presented valuable results provided by the Road Safety Performance Index (PIN) panelist. According to the results of an in-depth crash investigation conducted in Finland between 2014 and 2018, 68% of all fatal HGV drivers were not wearing seatbelts. If they had been wearing seatbelts, 5 out of 17 HGV drivers would have survived. In Czechia, 27% of all fatal HGV drivers between 2015 and 2019 were not wearing seatbelts. Similarly, in France from 2013 to 2017, 28% of fatal HGV drivers were not wearing seatbelts in incidents where doing so was recommended.

All countries that are currently members of the EU mandate the use of seatbelts on every seat, however usage rates still vary widely. Many EU countries have front seat belt usage rates between 90 and 100%, however even in these nations, disproportionately high percentages of car occupant fatalities occur without seatbelts (European Road Safety Observatory, 2017). Given the reduction potential of these protective measures, the capacity of programs such as campaigns to influence use rates, it is predicted that incentives or enforcement will have a significant impact (European Road Safety Observatory, 2017). The German Road Safety Council and partner organizations began the "Did it click?" campaign in 2002 to inform HGV drivers about the benefits of using seatbelts. The total rate of seatbelt use among HGV drivers of commercial vehicles has significantly grown to 87% in 2018, compared to 45% in 2002 (European Transport Safety Council, 2020).

Even though many countries compile indicators on seatbelt use, the indicators' coverage varies, and little is known about the collection techniques. According to the European Road Safety Observatory (2017), there are several ways to directly measure seatbelt usage rates, including: observational roadside surveys, self-reported rates (from interviews or online surveys), wearing rates of crash victims, and police-reported rates (from roadside checks). But still the collection of HGV seatbelt usage statistics is much less common. It could be advantageous to begin the process segregated by vehicle types and road type (urban, rural, motorway) given the statistical capacity needed to provide overall indicators for a country. The proposed possible indicators of seatbelt for HGVs include:

- Seatbelt wearing rates for HGV (front seats, whole country),
- Seatbelt wearing rate for HGVs (front seats, per road type and time of day).

2.3.2 Speed

Drivers in traffic often require one second to react to an unexpected incident and select a suitable response; this is referred to as the reaction time. The distance covered during this reaction time and before the response is launched increases with driving speed, decreasing the chance to prevent a crash (OECD/International Transport Forum, 2018). There is an increase in crash risk due to slower reaction times and poorer maneuverability as speed increases.

In all EU countries, a significant proportion of drivers violate the posted speed limit. The Europe-wide ROADPOL Control campaign took place to strengthen roadside police checks of HGVs and buses across 28 European countries. The police checked adherence to national speed limits as well as compliance with EU regulations (European Transport Safety Council, 2020). In Bulgaria, 8,660 HGVs were inspected during a two-week operation in February 2020. 12% of all checked HGVs were driving faster than the speed limit, making up 37% of all checked drivers who had violated the law. In Italy during a four-week ROADPOL operation in 2019, 40,500 HGVs were inspected, and 33% received fines for violations. Infractions involving the cargo weight were committed by 22% of fined HGV drivers, 22% of them drove faster than the posted speed limit, and 26% of them violated the EU driving hours and resting period's legislation (European Transport Safety Council, 2020).

In principle, 10 km/h reduction in a speed limit could be expected to produce around a 15-20% reduction in injury crashes, and up to around a 40% reduction in pedestrian fatal and serious injuries (Turner et al., 2021; Mitra et al., 2021; OECD/International Transport Forum, 2018). A speed management program was created in Bogotá, Colombia, to enhance the road environment and ensure the safety of all motorists. The program focused on 5 corridors where fatalities occurred at the greatest rates in 2018, where the speed limit was dropped from 60 km/h to 50 km/h and speed cameras were installed to ensure compliance. 46 lives were saved in 2019 as a result of this program, which is a 21% decrease in road fatalities compared to the average for the three years prior (2015-2018). As a result, the interventions were expanded in 2019 to include 10 arterial corridors (ITF, 2021). Individual risk perception may be low, but social risk is often considerable and little understood.

Many countries have adopted the practice of regularly gathering speed data for purposes other than road safety. This strategy, however, frequently only applies to highways with heavy traffic volumes and does not represent the entire road network and vehicle type. The approaches used to collect this data might not yet be sufficient to meet representativeness and comparability. According to the European Road Safety Observatory (2017), any indicator of speed is only useful if it is gathered for a given category (or, to be more precise, length) of vehicle. Differentiating between vehicles (light vehicles), PTWs, small trucks, and HGVs is advised. It is therefore advisable to collect data on the:

- Average (free flow) speed of HGVs per times of day,
- Share of observed speeds of HGVs higher than the speed limit/Mean Speed/Speed deviation/V_{85} Speed on,
  - Motorways with dual carriageway and median separation,
  - Single carriageway rural roads,
  - Single carriageway urban distributor roads (or 30km/h zones).

2.3.3 Alcohol and Drugs

One of the main contributing factors to collisions and injuries has been recognized as Driving under the influence (DUI) of alcohol. It is estimated that alcohol is responsible for 5% to 35% of all road deaths (World Health Organization, 2018). It has been established in numerous scientific literature how the risk of being injured, and even more the risk of dying in a crash, increases exponentially as the blood alcohol concentration (BAC) level rises in particular from a BAC level of 0.5 g/dl onwards (Compton & Berning, 2015; Hels et al., 2011). According to Compton & Berning (2015), the relative crash risk adjusted for age and gender for drivers with a BAC of 0.5 g/l is approximately two times higher and at 0.8 g/l BAC four times higher than for drivers at zero BAC.

Though more difficult to quantify than alcohol, the use of illegal drugs and certain prescription medications is increasingly linked to traffic injuries and deaths, though there are many complexities surrounding testing and establishing the causality of various drugs (World Health Organization, 2018). The most commonly used drugs vary over time and across countries, such as legal medical drugs in prescribed doses, illicit drugs, medical drugs in abuse doses, and combinations of drugs and alcohol (Hakkert et al., 2007). The scope of the drug-driving problem is not well understood in many countries. According to World Health Organization (2018), only 75 countries reported doing some drug testing of the fatally injured drivers (for all drivers). On a European level, alcohol was found in 3.48% of daily traffic drivers, illicit drugs in 1.90%, medicinal drugs in 1.36%, drug-drug combinations in 0.39%, and alcohol-drug combinations in 0.37% of drivers (European Road Safety Observatory, 2017).

According to Fell & Voas (2006), alcohol-related road traffic fatalities may be reduced by 6-8% by lowering blood alcohol concentration (BAC) from 0.1 g/dl to 0.05 g/dl. When alcohol-related legislation like those limiting BAC while driving is introduced, research on their effectiveness has demonstrated that these restrictions reduce the number of crashes involving alcohol on the roads. The study conducted in the US stated from 2000 to 2015, approximately 37% of all motor vehicle crash fatalities died in alcohol-involved crashes, of which 15% of alcohol-involved fatalities or 6% of all fatalities had a blood alcohol concentration <0.08%. The study analyzed the relationship between more restrictive state alcohol policy environments and the odds of alcohol involvement in traffic fatalities and found a result of 10% increase in Alcohol Policy Scale score, was associated with reduced odds of fatalities involving alcohol <0.08% vs 0.00%. Similar results were found for odds of alcohol involvement <0.05% vs 0.00%, and ≥0.05% (Lira et al., 2020). According to Lira and colleagues (2020), states with more restrictive alcohol policies tend to have reduced odds of lower blood alcohol concentration motor vehicle crashes than states with weaker policies.

It is generally accepted that reducing the legal BAC driving limit is an effective drink-driving deterrent and there is a clear trend, especially in Europe, towards introducing a 0.05 limit. Other interventions that are being introduced to support this policy include lower BAC limits for young, learner, probationary and professional drivers such as HGV drivers (sometimes called 'zero tolerance'), and a range of enforcement measures, particularly random breath testing but also alcohol ignition interlock devices and more consistent and intensive enforcement in general (Killoran et al., 2010). In terms of drugs, almost no EU country (with notable exceptions: Denmark, Germany, and Luxembourg) has established substance-specific blood concentrations as offence impairment levels; most countries either treat driver impairment or any detection of a drug in a driver's blood as an offense (European Road Safety Observatory, 2017).

According to the European Road Safety Observatory (2017), the CARE database has data on alcohol testing following fatal traffic crashes for 23 EU countries, however the percentage of crashes that can be attributed to alcohol (out of all crashes) varies greatly. In terms of indicators related to number or proportion of HGV fatalities that can be attributed to alcohol, it will therefore be advised to pursue a step-by-step methodology to develop data that is comparable not just across countries but also across Europe, including:

- Share of drunk HGV drivers among those tested (above the legal limit),
- Share of drugged HGV drivers among those tested (national offence impairment level),

2.3.4 Driver Distraction

Driver distraction is the diversion of attention away from activities vital for safe driving toward a competing activity, which may result in inadequate or no attention to activities critical for safe driving (European Road Safety Observatory, 2018). According to the European Road Safety Observatory (2018), the negative impacts of driver distraction include a reduction in driving task performance, slower speed, closer following distance, longer reaction times, more difficulties maintaining course, more errors, and narrower visual focus, even if the causes of driver distraction may differ. The study of Talbot et al. (2013) indicated that 32 % of crashes recorded events of Germany, Italy, The Netherlands, Finland, Sweden, and United Kingdom involved at least one distracted driver, rider, or pedestrian. The European Road Safety Observatory, in 2018, revealed that up to 25-30% of crashes are attributed to distracted driver.

According to the European Road Safety Observatory (2018), while there are many different types of distraction, they are typically broken down into four main categories: visual (such as looking away from the road), auditory (such as answering a ringing phone), physical (such as manually adjusting the radio volume), and cognitive (such as getting lost in thought).
The use of mobile devices, eating, and other activities are just a few of the many distractions that make it difficult for drivers to focus on the task of driving. According to research, using a phone while driving may be the biggest cause of in-vehicle distraction for drivers (Yannis, 2013). Cell phone use while driving is one of many factors that cause driver distraction, which increases the risk of crashes and injury to those both inside and outside the vehicle. Mobile phone use while driving involves the combination of visual, physical, cognitive, and auditory secondary tasks (European Road Safety Observatory, 2015).

In-vehicle distraction has been shown to be a specific risk in professional drivers. According to information provided by the PIN panelist, in a 2018 observation study on the use of mobile phones by drivers done in Ireland, 15% of light goods vehicles (LGV) drivers were observed using their phone behind the wheel and 12% of HGV drivers compared to 6% of car drivers (European Transport Safety Council, 2020). According to a European naturalistic driving study by the European Commission called UDrive, HGV drivers in the Netherlands spend roughly 20% of their driving time distracted, compared to 10% for drivers of cars (European Commission, 2017). The UDrive study's main focus was on how, when, and where drivers engage in side tasks while they are driving.

The extent to which distracted driving by HGV drivers contributes to fatal or major traffic collisions, however, has not been the subject of much contemporary research. One explanation for this might be high-quality data, as most police reports do not have a field for distraction as a contributing cause of crashes. It is challenging for the authorities to determine whether distraction played a part in a crash even if such a field was there (European Transport Safety Council, 2018).

Handheld cell phone use while driving is prohibited in all EU countries. However, the impact of legislation on driving behavior appears to be limited, particularly among young people, who use handheld cell phones at an alarming rate (European Road Safety Observatory, 2018). The Traffic Safety Synthesis on Cell phone use while driving revealed that compliance with legislation appears to increase only when combined with public awareness and education campaigns, enforcement, and appropriate penalties for noncompliance. Furthermore, technological advancements in voice control or text-to-speech technology, as well as technical provisions that make it impossible to use a phone while driving, can all help to reduce handheld cell phone use (European Road Safety Observatory, 2015).

According to the European Road Safety Observatory (2018), roadside observations or observations from moving vehicles by trained observers can be used as a direct indicator of mobile cell phone use by drivers or riders while driving. The usage of mobile cell phones has been demonstrated to significantly increase the risk of vehicle crashes. As a result, in order to produce comparable figures, it is suggested that countries think about routinely gathering data on:

- Share of HGV drivers using a handheld cell phone while driving (per time of day) on urban, rural, motorway roads,
- Share of HGV drivers using a hands-free cell phone while driving (per time of day) on urban, rural, motorway roads.

2.3.5 Driver Fatigue

Some drivers are unaware of the signs of fatigue and may not even be aware that they are fatigued until an incident happens because fatigue is characterized in a variety of ways. However, many definitions share the idea that fatigue is a state caused by prolonged exertion. It is a condition that manifests itself physiologically, cognitively and emotionally (Vitols & Voss, 2021; Williamson & Friswell, 2013; Phillips, 2014). In drivers, it leads to a decrease in mental (NCSDR/NHTSA, 1987) and physical functioning, which in turn leads to poor steering control, decreased reaction time, poor speed tracking and loss of attention and hazard perception. Experiencing fatigue is not a conscious or planned decision; it is rather an autonomic mental and physical process (Vitols & Voss, 2021).

According to a meta-analysis of 11 researches on professional drivers, the risk of driving while highly fatigued during the day is increased by 72% (Zhang & Chan, 2014). According to European Transport Safety Council (2011), fatigued driving contributes significantly to 20% of commercial vehicle collisions on roads. The European Transport Safety Council (2020) presented police reports in the UK that were obtained from the statistics department of Transport. The reports identify contributory factors that led to an injury collision, including distraction. Based on these reports, in 5% of all reported injury collisions involving LGVs (light goods vehicles) and 4% of all reported injury collisions involving HGVs that occurred in the period 2016-2018, driver distraction was identified as a contributory factor. The most common identified category of distraction was driver fatigue and in-vehicle distraction (European Transport Safety Council, 2020).

Fatigue-related crashes are frequently characterized by a severe loss of control, which causes an unexpected trajectory for the vehicle, and no brake reaction (Vitols & Voss, 2021). In a survey by SWOV (2011), a group of mostly international truck drivers claimed they were sleepy at the wheel and that it happened to them more often than it did to car drivers (23% versus 10%). Additionally, they stated that they had started or continued driving in the past year despite feeling too fatigued to do so (37% of HGV drivers compared to 20% of car drivers) (European Transport Safety Council, 2020;Goldenbeld & Nikolaou, 2019). The number of hours that truck drivers put in goes beyond just the distance between their starting point and their final destination. According to Williamson & Friswell (2013), these include operational factors like the need to wait for loading activities and waiting for activities to finish, and organizational factors like incentive payments that encourage longer hours of work by paying drivers by the work output (by kilometer or by trip), as opposed to time-based payment where drivers are paid by the number of hours they work.

Objectively identifying and measuring fatigue is challenging. Therefore, unlike what is usually done with alcohol usage, there is no legal restriction on the amount of fatigue that is acceptable for driving. This means that there are no explicit laws or guidelines against driving when exhausted that apply to all users of the road (European Commission, 2021). Subject to certain exceptions and national derogations, Regulation (EC) No. 561/2006 provides a common set of EU guidelines for maximum daily and fortnightly driving times as well as daily and weekly minimum rest periods for all drivers of road haulage and passenger transport vehicles. The range of activities that are controlled includes both national and international passenger transportation as well as long and short distance road haulage operations, along with drivers who are employees and self-employed (European Parliament and Council, 2006). The law that specifies the truck drivers' driving and rest periods is recognized as the driving personnel regulation. It establishes a 9 hours daily driving limit and mandates a 45-minute break for drivers after four and a half hours on the road. The maximum weekly driving time is 56 hours, with a daily rest period of 11 hours and 45 hours are allotted for rest each week. Both on-road checks of the on-board tachograph and administrative checks of the transport company's operations are used to enforce these laws (European Commission, 2021). Since all countries have different forms of driving time and rest period legislation, level of enforcement, regularly collecting data on driving time and rest periods will be useful to measure road safety performance and share best practice.

A tachograph is a recording device installed on HGVs that records vehicle movements and driver activity. Smart tachographs will aid in the collection of more detailed, reliable, and accurate information on vehicle movements and driver activity (European Transport Safety Council, 2020). This could aid in the enforcement and compliance of rules. According to European Transport Safety Council (2020), in 2017, 242,758 HGVs were stopped for technical inspections during the cross-border control weeks organized by Euro Contrôle Route (ECR). 53,960 (22%) of the vehicles checked were found to have at least one violation. Driving hour violations accounted for 27% of all offenses, with tachograph violations accounting for 10%.

Though there is a rising percentage of traffic crashes caused by driver fatigue, a set of fundamental indications has not yet included fatigue as a road safety indicator pertaining to all drivers. A study by Davidović et al. (2020), defined road safety performance indicators related to the fatigue of professional drivers and their significance is revealed. The indicators may be analyzed on a nationwide scale if a database was created with information from all transportation companies. The indicators related to fatigue were categorized into four groups; indicators related to the quantity and quality of sleep (Sleep-related indicators), indicators related to working hours and time of the day (Operation-related indicators), indicators related to rest periods and breaks (Rest-related indicators), indicators related to the measures for eliminating fatigue and education of drivers (Indicators of undertaken activities). Some of the identified key performance indicators which affect HGVs driver fatigue are:

- % of driving hours (daytime and night-time driving hours),
- daily rest of the driver,
- daily driving time, weekly driving time, fortnightly driving time of the driver,
- % of drivers using appropriate measures for fatigue prevention (by age groups),
- % of HGVs crashes with tachograph violations.

Some of the measures taken by drivers to combat fatigue include opening windows or improving the climate, stopping the car and getting out to take a walk, exposing themselves to bright light, listening to the radio, interacting with other passengers, drinking caffeinated beverages, and napping (Davidović et al., 2020). According to Davidović et al. (2020), indicators related to fatigue should be included in the collection of fundamental road safety performance indicators at the municipal/town and county level. We can isolate a collection of signs that apply to drivers and that can be precisely, reliably, and easily monitored such as:

- Number of rest stops with facilities for HGV drivers (average frequency per km).

2.3.6 Vehicle-related indicators

Like any disaster management, vehicle crash protection aims at first avoiding a disaster from happening and if that is not sufficient the next strategy is minimizing the effect of the incident. A vehicle crash is always on the card, so the vehicle and the driver should always be active on the lookout for danger. To assist this, active safety systems have been developed and are becoming effective in reducing vehicle crashes. As to all systems, active safety systems are not 100% effective and human error is always a factor, so a secondary system which is called a passive safety system is required (Liikanen, 2002).

The proportion of drivers who are killed or seriously injured is lower in newer vehicles, i.e., vehicles that were registered more recently. On the SUNflower project, it is shown that the overall effect of vehicle safety improvements has produced a 15-20% reduction in occupant fatalities. The result of saving in fatalities between 1980-2000 attributed to Sweden, UK and Netherlands showed that the vehicle safety, seat belt use with drink driving enforcement has estimated 48%, 54% and 46% lives saved respectively (Koornstra et al., 2002).

The vehicle's age serves as a proxy for advancements in automobile engineering made to withstand the effects of collisions, suggesting that vehicle damage will rise with age (Hakkert et al., 2007). According to Hakkert et al. (2007), there are two key reasons for the enhanced protection provided by newer vehicles:

- Modern safety technology is far more likely to be installed in newer vehicles and they are also more likely to have been structurally designed to be more crashworthy in the case of an crash. This suggests that current vehicles' components manage crash energy more effectively, lowering the possibility of energy transfer and, thus, the occupant's risk of injury.
- Older automobiles are more likely to rust, which makes them typically less effective in the event of a collision because the crash-energy is managed by the vehicle considerably less effectively and with a higher chance of injury.

The current EuroNCAP safety rating includes Adult Occupant Protection, Child Occupant Protection, Pedestrian Protection, and Safety Assist tests. The latter is devoted to advanced driver assistance systems (ADAS) and has features like automatic emergency braking, lane support, and speed assistance (Hakkert et al., 2007). Euro NCAP published its first protocol for assessing "heavy vehicles" in 2011. As a result, the 2011 protocol highlighted the ways in which heavy vehicle testing should differ from the established protocols used for other vehicles (EuroNCAP, 2015). To alleviate concerns about increased aggressivity, the frontal impact test speed was reduced to 56km/h, and other protocols were modified to make them more appropriate. The modified protocols, as well as this update, were only intended for use with vehicles weighing up to 3500kg. Therefore, for HGVs above 3500Kg cases the protocol suggests manufacturer should consult with the program manager to determine whether the use of this protocol is appropriate (EuroNCAP, 2015).

Pedestrians and cyclists are frequently hidden in an HGV driver's blind spot - right in front of or directly to the side of an HGV, particularly the passenger side. Because of the size of HGV front and side windows, there are large blind spots in the driver's field of vision (European Transport Safety Council, 2020). In 2018, the Vias Institute in Belgium examined 29 collisions in Antwerp that occurred in an HGV's blind spot and resulted in the injury of a pedestrian or cyclist. The highest risk for VRUs in those collisions was when they were in the blind spot to the right of the passenger side of the cab, as well as the blind spot directly in front of the cab (Ceunynck et al., 2018). As a result of the updated General Safety Regulation (GSR), sensors capable of detecting a pedestrian or a cyclist located in the blind spots near the front or side of the cab will be required beginning in 2022 for new models and 2024 for current models (European Transport Safety Council, 2020).

Most vehicles and trailers are required by EU law to be inspected on a regular basis. It serves as a foundation for ensuring that vehicles throughout the EU are roadworthy and meet the same safety standards as when they were first registered (European Commission, 2020). According to European Commission (2020), unannounced roadside inspections of commercial vehicles are permitted under EU law in any EU country, regardless of whether the vehicle is registered there. These inspections cover the brakes, steering, visibility, lighting equipment, electric system, speed limitation devices, nuisance and emissions, and overall condition of the vehicle. Drivers may also be asked to show recent inspection reports or proof that the vehicle has passed the mandatory roadworthiness test. Vehicle registration and crash information are also maintained by each Member State (European Road Safety Observatory, 2017). Even if their assessments differ, developing a common technique across countries is required. Based on (European Road Safety Observatory ,2017; Hermans et al., 2008; Hakkert et al., 2007) the following indicators (modified for HGV-related indicators) may be critical in future safety monitoring programs:

- % of HGVs failing the official vehicle inspection,
- % of HGVs ≤5 years; 6- 10 years, 11-15 years and >15 years in the total registered HGVs,
- % of HGV with ADAS in the total registered HGVs,
- % of HGVs equipped with blind spots detectors in the total registered HGVs.

2.3.7 Permissible maximum weights of Lorries

HGVs are designed by truck manufacturers to be able to carry particular loads. Most of the time, the truck's structural integrity is designed to withstand at least the heaviest load permitted by the maximum loaded axle weights for the roads being used (Oversize.io, n.d.). According to Oversize.io (n.d.), the truth is that many vehicles are capable of transporting weights that are much heavier than those that are permitted by law. Though, according to a

UK Department for Transport (2003) leaflet, overloading can result in at least three negative impact.

- **Traffic safety**: Overloaded lorries can have a negative impact on the steering and their ability to stop quickly in an emergency.
- **Road pavement deterioration and wear**: Overloading of good vehicles is estimated to cost the community more than £50 million a year in increased damage to roads and bridges. Overloading drive axles (legal limit 11.5 tons) is the leading individual contributor to excessive wear and tear on roadways. Heavy axles produce proportionately significantly greater wear and tear.
- **Competitiveness:** Gross overloading is unjust to most law-abiding motorists who accept the limitations of the maximum weight limits established by the law. Operators that regularly overload lorries can make additional revenues of thousands of pounds every year.

High speed and maneuverability are the common serious problems i.e., a large vehicle traveling down an incline with improper loads or ones that are heavier than they should be will perform dramatically worse (Lyon, 2019). There are effects on steering, maneuverability, stopping, and acceleration. Simply said, a truck that is overloaded needs more distance to stop. All of these scenarios have the potential to immediately create hazardous conditions for the vehicle, the driver, and other road users (Lyon, 2019). In that situation, it is the driver's responsibility to obey established legal or maximum permissible able gross vehicle or axle group weights for the routes on which the vehicle is to be driven, and to be aware of both highway and non-highway limitations for the route of travel (Oversize.io, n.d.).

HGVs operating on European highways must abide by the weight and dimension requirements outlined in Directive 96/53/EC (Znidaric, 2015). The current weight restrictions on individual vehicles and vehicle combinations are imposed by safety regulations as well as a desire to lessen the wear that HGVs place on bridges, substructures, and road surfaces. According to Znidaric (2015), the maximum vehicle mass allowed under the current directive is 40 tones, with the exception of intermodal transfers using 40-foot containers, which are permitted a maximum weight of 44 tones. Maximum axle loads range from 10 tons single to 11.5 tons for driven axles, 11.5 to 19 tons for tandem axles, and 11 to 24 tons for tridem axles. It should be noted that each EU member country's permissible maximum of haulage varies.

Overloading is identified at a wide range of levels across Europe because of the diverse conditions there. It is usually low in countries with tight enforcement regulations, and causing more serious problem in countries where overload enforcement is rare. Not to mention that axle overloads are far lower than they were prior to the implementation of weight enforcement (Znidaric, 2015). In order to understand the implications of vehicle overloading on safety, it is necessary to do roadside checks by police and gather information on:

- Number of HGVs exceed the maximum allowable lorry weights per country (urban, rural, motorway),

2.3.8 Post-Impact Care

Road traffic conditions that are dangerous may be pre-crash related (requiring crash prevention measures), crash related (requiring injury prevention in the event of a crash), or post-crash related (a need in post-crash injury treatment) (Hakkert et al., 2007). The discipline of post-crash (trauma) care, or trauma management, encompasses a number of components of a complicated system that is in charge of treating injuries brought on by vehicle crashes. It is also sometimes referred to as the area of life-sustaining or tertiary safety, and it includes tasks like managing emergency calls, treating patients on the site, transporting them to hospitals and trauma centers, and treating them further at such institutions (European Road Safety Observatory, 2017). According to research conducted by medical professionals in high-income European countries, 50% of fatalities resulting from traffic accidents happen within minutes, either at the scene or while the victim is being transported to the hospital. When victims were admitted to hospitals, about 15% of fatalities happened within 1-4 hours of the collision, whereas about 35% happened after four hours (SafetyNet, 2009).

Various components of trauma management, as well as their development, can help reduce the effects of crashes, including quicker EMS (Emergency Medical Services) response times, highly-trained EMS personnel, well-equipped EMS vehicles, and proper hospital care (Bax et al., 2012). According to the European Road Safety Observatory (2017), there are no trauma management-related indicators being utilized in the EU, especially not for measuring the quality of medical care. However, the majority of the necessary data on the accessibility of trauma treatment services are often accessible from annual publications of national statistics offices that deal with public health. The norms and practices that constitute an effective trauma care system vary greatly among countries. The potential to prevent harm related to effective trauma care is significant, hence it seems well justified to construct performance indicators in this area. It's very hard to identify post impact care indicators specific to HGV crash. Based on (Berghe et al., 2021; European Road Safety Observatory ,2017; Hermans et al., 2008; Hakkert et al., 2007): the contextual information is useful to provide for a proper understanding of response times, for benchmarking with other countries, and for the selection of suitable countermeasures including:

- Number of EMS stations per 10,000 citizens,
- Number of EMS stations per 100 km length of rural public roads,
- Number of EMS vehicles per 100 km road length of total public road,
- Number of EMS transportation units per 10,000 citizens,
- Percentage of all emergency calls that were related to traffic crashes,
- Average arrival time of emergency medical services at the crash scene,
- Percentage of EMS responses which meet the demand for response time,

- Number of EMS medical staff per 10,000 citizens,
- Number of hospital beds per 10,000 citizens,
- Percentage of trauma beds and trauma departments of hospitals out of the total,
- Share of Expenditure on health per GDP share.

The aforementioned indicators are proxy indicators that are general (not HGV-specific). The following indicators specific to HGVs can be used if systematic data collection is used to determine whether a victim was involved in an HGV crash or not:

- Average length of stay of HGV crash victims in the hospital,
- Share of HGV crash victims who are treated in intensive care units,
- Share of HGV crash victims who died during hospitalization.

2.4 Conclusion of selected indicators for HGV

The goal of this study is to create a composite HGV index for benchmarking purposes by combining the main layers of the road safety pyramid. The literature review reveals that there are many lessons to be gained from the previous studies and analysis. Benchmarking practice could be carried out to evaluate the results of interventions and to monitor progress on road safety in each country to achieve continuous improvement over time. However, there is a bias toward overall road safety indicators, and when dealing with specific indicators such as HGV safety, there is a bias toward final outcome indicators. Therefore, it would be advantageous to investigate specific HGV road safety indicators and attention should be given to safety performance indicators in order to evaluate and monitor progress on HGV safety from country to country.

In this study, the layers considered were the final outcome indicators (numbers of fatalities/injuries), intermediate outcomes (as safety performance indicators), and road safety policy performance indicators (safety measures and programs). These layers are defined by A, B and C groups of indicators. As a first attempt to identify components of the lowest level of the pyramid (structure and culture), a fourth group of indicators (D) was added to present some background variables for each country. The final selection of these basic indicators, on the other hand, was constrained by the limited availability of disaggregated data focusing on HGV for European countries from international databases.

The A-group of indicators is concerned with the system's final outcomes, such as the number of road crash fatalities, which should be presented in a format that allows for comparisons. These indicators focused on a variety of issues, including personal risk, traffic risk, and the proportion of the problem linked to road users, traffic, and road categories. One or more indicators were defined for each issue. They are as follows:

- Fatalities in HGV crashes per million inhabitants (2018) (A1)
- Fatalities in HGV crashes per 10,000 HGV registered vehicles (2018) (A2)

- Share of fatalities in HGV crashes out of the total fatalities (2018) (A3)
- Share of VRU fatality in HGV crashes (2016-2018) (A4)
- Share of fatalities in HGV crashes on urban road (2016-2018) (A5)
- Share of fatalities in HGV crashes on Motorway (2016-2018) (A6)

The intermediate outcomes are collected by the B-group of indicators, which includes the safety performance indicators that characterize the safety quality of the HGV safety system. In this thesis, following a review of the literature and identification of the key risk domains for road safety involving HGV, the process of choosing pertinent safety performance indicators began. Sadly, there aren't any well-established or easily accessible road safety performance indicators for HGV in many European countries. Following a thorough search, the most readily available intermediate outcome indicators found include:

- Share of observed speeds of HGVs higher than the speed limit on 50 km/h urban roads (2018) (B1)
- Share of observed speeds of HGVs higher than the speed limit on rural non-motorway roads (2018) (B2)
- Average frequency of rest stops with facilities for truck drivers (No. per 100 km) (B3)
- Share of HGs under 5 years out of total HGV vehicle fleet, in (2018) (B4)

Due to a lack of data for all selected countries, it was decided not to limit the current project to only those indicators where estimates for a large number of European countries are available. As a result, for some relevant indicators (B1 and B2), a separate analysis was performed that includes these indicators while considering a smaller set of countries (see chapter 4) for which data was available.

In terms of road safety policy performance indicators, the indicators chosen were such that they can be used to track/measure the compliance intensity of the risk domains mentioned in the literature review. Similar to B-group indicators, there are currently not many indicators available for measuring the effectiveness of policies relating to the safety of HGVs. They were investigated with the intention of being useful for comparing country performance and to monitor the impact of various countermeasures taken in relation specifically to HGVs safety. Based on these principles, a number of characteristics were proposed for the C-group of indicators to reflect the quality of national road safety programs. The three indicators introduced for the C-group are related to the maximum alcohol limit for professional drivers (C1), the permissible maximum lorry weights (C2), and the maximum urban speed limit for HGV (C3). The categories of values for each indicator were defined as shown in Table 1:

Table 1: Basic indicators for the C-group

Indicators	Possible categories
Maximum blood alcohol limit for professional drivers, 2015 (C1)	a. ≤ 0.02g/dl (2)
	b. >0.02g/dl (1)
Permissible maximum weights of lorries (C2)	a. 40-44 tons (2)
	b. > 44 tones (1)
Maximum urban speed limit for HGV (2015) (C3)*	a. ≤ 50 km/h (2)
	b. > 50 km/h (1)

(*) After collecting the data, it was discovered that the majority of countries fall into Category one, therefore, this indicator did not make it into the final analysis.

Finally, five background indicators (the D-group) were added to characterize the country's HGV motorization level, road network density, and the truck industry. All indicators are used as context variables to reflect the development and structural differences between the countries.

- Share of HGV (over 3.5 tons) out of total vehicle fleet, (2018) (D1)
- Road Network density (km per 100 sq. km) (2018) (D2)
- Goods transport by road (2018) (per billion tkm) (D3)
- Trucks per unit of GDP (2017) (D4)
- Share of employment of road freight transport out of total population (2018) (D5)

Figure 2 depicts the data set for the core set of indicators used in this study.

In a nutshell, to some extent, this study takes into account some of the risk factors from the literature review and tried to provide insights into how some risk factors affect HGV performance. This section is concluded by stating that the progress of HGV safety cannot be entirely captured by these indicators and risk domains. It is important to remember that several other factors influence the frequency and severity of HGV crashes. If the level of HGV safety is studied over time or compared across countries, the risk factors mentioned in the literature review should be considered to better explain the HGV safety performance.

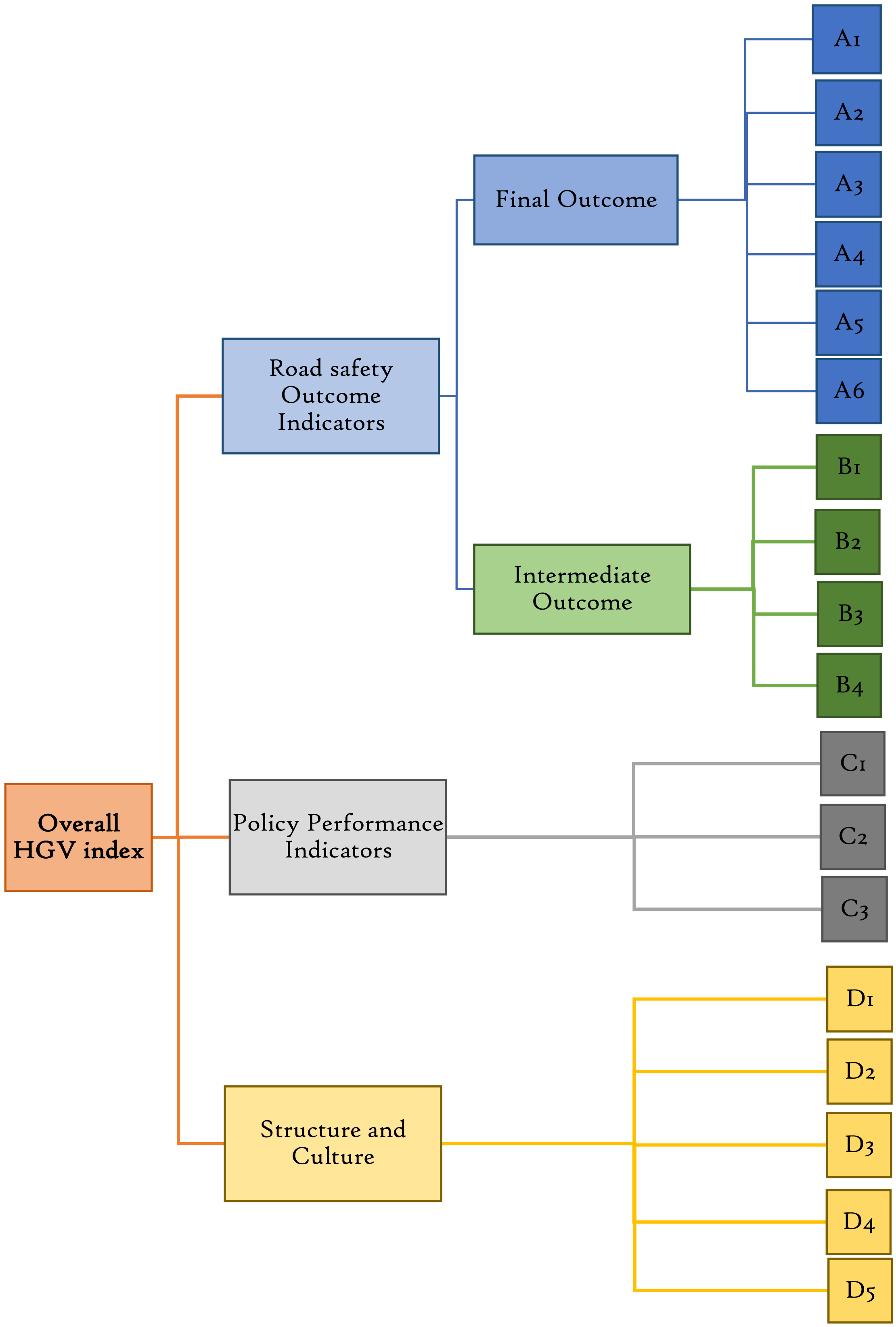

Figure 4: The core set of Indicators used in this study

CHAPTER THREE

3. RESEARCH METHODOLOGY

This chapter will cover different aspects of the methodology used during the research to attain the objectives stated in chapter one. It will present and gives reasons why a particular method was selected at different stages of the project. The data collection and analysis methods selected on the course of the research will also be discussed here.

3.1 Study area

Based on the availability of data over a period of time, this study uses a selection of European countries for which a complete data set for the most recent year was obtained. The study focuses on 28 European countries (25 EU Member States plus Norway, Switzerland, and the United Kingdom), specifically including Austria (AT), Belgium (BE), Croatia (HR), Cyprus (CY), Czech Republic (CZ), Denmark (DK), Estonia (EE), Finland (FI), France (FR), Germany (DE), Greece (EL), Hungary (HU), Ireland (IE), Italy (IT), Latvia (LV), Lithuania (LT), Luxembourg (LU),), the Netherlands (NL), Norway (NO), Poland (PL), Portugal (PT), Romania (RO), Slovakia (SK), Slovenia (SI), Spain (ES), Sweden (SE), Switzerland (CH), and the United Kingdom (UK).

Table 2: Selected European countries and regions (ISO code based on Eurostat)

Region	Northern Europe	Region	Eastern Europe
ISO Code	**Country Name**	**ISO Code**	**Country Name**
DK	Denmark	CZ	Czech Republic
EE	Estonia	HU	Hungary
FI	Finland	PL	Poland
IE	Ireland	RO	Romania
LV	Latvia	SK	Slovakia
LT	Lithuania		
NO	Norway		
SE	Sweden		
UK	United Kingdom		
Region	**Western Europe**	**Region**	**Southern Europe**
ISO Code	**Country Name**	**ISO Code**	**Country Name**
AT	Austria	HR	Croatia
BE	Belgium	CY	Cyprus
FR	France	EL	Greece
DE	Germany	IT	Italy
LU	Luxembourg	PT	Portugal
NL	Netherlands	SI	Slovenia
CH	Switzerland	ES	Spain

3.2 Data Collection

For the sake of analyzing HGV safety problems, benchmarking and suggesting countermeasures, systematic data collection was required on HGV related crashes. After identifying the major risk factors and road safety indicators related to crashes involving HGVs, quantitative secondary data were collected for the selected European countries. The most recent available data relating to HGV indicators' estimates and/or data for their calculation were obtained from European countries databases, international databases and several recent publications of international working groups, including:

Table 3: List of sources used for data collection

Data Item	Year	Source
Total Population (N)	2018	The World Bank
Length of total road network by country, (km) (N)	2018	Eurostat International Road Federation (IRF), national statistics
Density of road, (km per one hundred sq. km)	2009-2018	European Union Road Federation (ERF) The Organization for Economic Co-operation and Development (OECD)
Total Motor Vehicles (N)	2018	The European Automobile Manufacturers' Association (ACEA)
Number of heavy good vehicles (over 3.5 tons) (N)	2018	The European Automobile Manufacturers' Association (ACEA)
Heavy good vehicles (over 3.5 tons), by age (N)	2018	The European Automobile Manufacturers' Association (ACEA)
Goods transport by road (billion tkm) (N)	2018	Eurostat European Union Road Federation (ERF) The organization for Economic Co-operation and Development (OECD)
Trucks per unit of GDP (N)	2017	European Environment Agency Directorate General for Mobility and Transport (DG MOVE) Directorate-General for Economic and Financial Affairs (DG ECFIN)
Employment by mode of transport in EU countries (thousand) (N)	2018	Eurostat European Union Road Federation (ERF)
Number of Rest Stops with facilities for Truck Drivers Average Frequency (No. per 100 km) (N)	2019	Trans-European Road Network, TEN-T (Roads): 2019 Performance Report
Heavy goods vehicles (over 3.5 t) - standard speeds limits in Europe (N)	2015	European Commission

Maximum blood alcohol concentration - Professional drivers (N)	2015	European Commission European Transport Safety Council (ETSC)
Permissible Maximum Weights of Lorries in Europe (in tons) (N)	2019	International Transport Forum (ITF) UNECE Statistical Database
Total road fatalities (N)	2018	The Road Safety Performance Index (PIN) panelists retrieved from Eurostat
Total number of road fatality that occurred in collisions involving an HGV (>3.5t) (N)	2018	The Road Safety Performance Index (PIN) panelists retrieved from European Commission CARE database
Proportion of reported road fatality by road user group in collisions involving HGVs (%)	2016-2018	The Road Safety Performance Index (PIN) panelists retrieved from European Commission CARE database
Proportion of reported road fatality by road type in collisions involving HGVs in the last three years (%)	2016-2018	The Road Safety Performance Index (PIN) panelists retrieved from European Commission CARE database

The indicator values are presented in Appendix 2a-2d.

3.3 Study design

A cross-sectional study design was used to identify the risk factors and road safety indicators of road traffic crashes involving HGVs in selected European countries. Hence, the research design used the following steps to develop the HGVs index score to rank and benchmark countries.

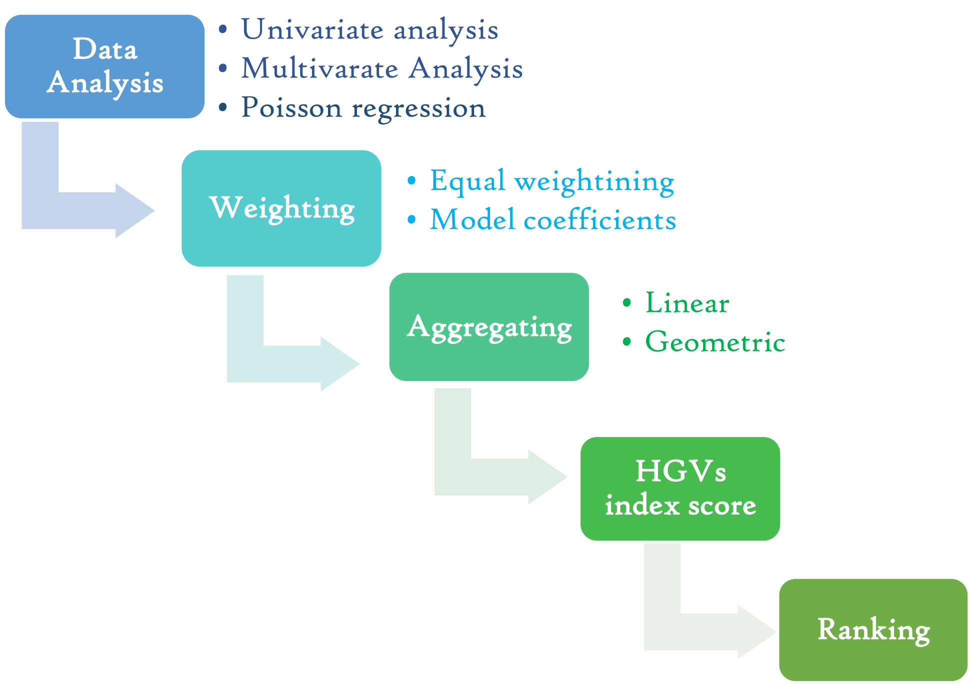

Figure 5: Study design flowchart

3.4 Data Analysis

After collecting the necessary information, data processing and interpretations were done using the Statistical Package for the Social Sciences (IBM SPSS version 28). Initially, the data set was subjected to two major analyses: univariate analyses (to gain insight into each indicator separately) and multivariate analyses (to investigate the structure and interrelationships in the entire data set). The next basic step in calculating the composite HGVs index was to assign weights to each indicator and aggregate them. The following sections discuss the data analysis methods that were used.

3.4.1 Univariate analysis

The univariate part consists of three basic analysis parts (Hermans, Brijs, et al., 2008).

Summary statistics: the first step applies statistical analyses to the collected data to describe and interpret the existing situation (Hermans, Brijs, et al., 2008). As a result, descriptive statistics such as mean, minimum, maximum, standard deviation, and data completeness were computed. Following that, as part of the data processing procedures, potential outliers in the data set were examined to determine whether they represent real values or suspicious individual values that were erroneously entered into the data set.

Missing data Imputation: The second and most crucial step in the data analysis process is missing data management. To account for as much of the available indicator information as possible, there is always a risk of missing values because no data collection system provides perfect data sets. In this regard, several methods such as mean imputation, regression imputation, expected maximization imputation, nearest neighbor imputation, and multiple imputation can be considered (Nardo et al., 2005). In this study, Expectation Maximization (EM) imputation was used to impute missing values, ensuring that countries with missing values were not excluded from the statistical analysis.

Expectation maximization was able to overcome some of the limitations of other techniques by resolving biased estimates and, in particular, underestimating standard errors (Moss, 2016). Expectation Maximization (EM) imputation can be used for a broad range of problems, e.g. variance component estimation or factor analysis (Nardo et al., 2005). The interdependence between model parameters and missing values is the focus of this model. Estimates are obtained through an iterative process used to replace missing values (Nardo et al., 2005; Nelwamondo et al., 2007). First, the missing values are predicted using initial estimates of the model parameter values. Following that, the predictions are used to update the parameter values, and the process is repeated. The parameter sequence converges to maximum-likelihood estimates, and the time to convergence is determined by the proportion of missing data and the flatness of the likelihood function (Nardo et al., 2005; Nelwamondo et al., 2007; Dinov Ivo D., 2008)

Normalization: the third step was to normalize or standardize all indicators to common units before integrating them to ensure that they are comparable/additive and to prevent some indicators from dominating others. Normalization is the process of converting data to a specific range, such as 0 to 1 or -1 to +1 (Ali & Faraj, 2014). Several normalization techniques can be chosen from the literature (Nardo et al., 2005) and the normalization method should take into account both the data properties and the composite indicator's objectives (Nardo et al., 2005; Vafaei et al., 2018).

In this study, Min-Max normalization technique was used to normalize the indicators. The Min-Max normalization technique is a straightforward linear transformation approach that calculates the distance between the actual value and the maximum/minimum values for each indicator using the following formulae (Nardo et al., 2005; Ali & Faraj, 2014; Vafaei et al., 2018):

$$Normalized\ value = \frac{Actual\ value - Minmum\ value}{Maximum\ value - Minimum\ value} \qquad (1)$$

Alternately, if a lower value indicates better road safety performance, as in the cases of final outcome indicators (A1-A4) and intermediate outcome (B1 & B2), we normalize using the formula:

$$Normalized\ value = \frac{Maximum\ value - Actual\ value}{Maximum\ value - Minimum\ value} \qquad (2)$$

Min-Max normalization technique widens the range of indicators within a small interval, increasing the effect of the indicator on the composite indicator (Nardo et al., 2005;). Min-Max normalized indicators have an identical range (0, 1). The normalized values of each indicator for each country is presented in Appendix 4a-b.

3.4.2 Multivariate analysis

The final data related step involved performing multivariate analyses on the whole indicator data set to gain insight into the degree of correlation between the various indicators. However, according to Nardo et al. (2005), it is critical to avoid performing multivariate analysis if the sample size is small in comparison to the number of indicators, as the results will lack known statistical properties. Therefore, the multivariate analysis consists of the following analysis part (Hermans, Brijs, et al., 2008).

Correlation: to avoid the problem of multicollinearity, the bivariate Pearson correlation analysis is used. The Pearson coefficient of correlation indicating whether or not two variables are correlated was utilized to avoid the problem of multicollinearity. Pearson's correlation is a test used to determine the existence (given by a p-value) and strength (given by the coefficient r between -1 and +1) of a linear relationship between two variables. It indicates the magnitude of the association, or correlation, as well as the direction of the relationship (Samuels & Gilchrist, 2014). Positive values denote positive, negative values denote negative, zero denotes no linear correlation and the closer the value is to 1 or −1, the stronger the linear correlation (Cohen, 1988). Although the threshold and interpretations of relationship strength (also known as effect size) differ across disciplines and researchers, according to Nardo et al. (2005), when two variables are identified to have a high correlation, they are partially displaying the same aspect of the phenomenon under investigation.

Principal components analysis (PCA): when investigating the relationships between the indicators, principal components analysis (PCA) is a useful tool. This type of analysis seeks to reveal how different indicators change in relation to one another and how they are related (Nardo et al., 2005; Hermans et al., 2008). When the goal of the analysis is to present a large dataset with a few variables, PCA produces linear combinations of the original variables to generate a few major components, also known as principal components, that explain a large portion of the variance in the data set (Nardo et al., 2005; Shlens, 2005; Holland, 2019). It should be noted that a significant reduction occurs when the original variables are highly correlated either positively or negatively (Nardo et al., 2005).

According to Nardo et al. (2005), PCA is sensitive to the presence of outliers and small-sample issues, which are especially important when focusing on a small number of countries. Based on the "Rule of Ten", to perform PCA, the ratio should be at least 10:1, which means 10 cases for each variable (Hair et al., 2010).

Cluster analysis: is another technique for breaking down large amounts of data into manageable components (Nardo et al., 2005). It has been applied to a wide range of research problems and fields, including in the development of composite indicators to group information on countries based on their similarity on different individual indicators (Wegman et al., 2008; Hermans et al., 2008; Bax et al., 2012; OECD/ITF, 2017). Cluster analysis techniques can be hierarchical if the classification has an increasing number of nested classes, such as tree clustering, or non-hierarchical if the number of clusters is determined ex ante, such as k-means clustering (Nardo et al., 2005; Hermans et al., 2008).

In this study, the hierarchical clustering analysis using the Ward linkage method with Euclidian distance was used to divide the set of 28 European countries into a number of similarly performing classes. Ward's (Ward, 1963) method of clustering is determined by calculating the variance of elements, which is the sum of the squared deviations from the mean of the cluster (Nardo et al., 2005; Nielsen, 2016). A cluster element is one that produces the smallest possible increase in variance. Euclidian distance is the geometric distance in a multi-dimensional space that can be computed from raw data and is not affected by the addition of new objects such as outliers (Nardo et al., 2005; Shetty & Singh, 2021). The graphical representation of this tree, known as a dendrogram, can be used to obtain information about hierarchical clusters.

Regression analysis: finally, a regression analysis can provide useful information and help with indicator selection (Hermans, Brijs, et al., 2008). Regression analysis builds a model to explain or predict a dependent or response variable (usually denoted Y) using one or more independent or explanatory variables (usually denoted X_1, X_2, etc.) (Lovett & Flowerdew, 1989). According to Lovett & Flowerdew (1989), the standard linear regression analysis assumes that the dependent and independent variables are related linearly. If there is one independent variable X for case i, the predicted value of the dependent variable Y is given by the equation:

$$Y = \beta_0 + \beta_1 X_i \quad (3)$$

Where β_0 is the intercept-the value of Y when X is zero, and β_1 is the slope-the amount by which Y changes as X increases by one unit.

The total number of deaths in collisions involving an HGV is the primary outcome variable in this study. This type of variable is frequently referred to as "count data" because the observations of the outcome variable can only take non-negative integers such as 0, 1, 2... Standard linear regression analysis methods developed for data with normal distributed outcome variables are inappropriate for such data, but if specific conditions are satisfied, a Poisson distribution-based form of regression can be used (Lovett & Flowerdew, 1989; Coxe et al., 2009; Gilbert & Yang, 2015). The Poisson regression also known as a log-linear model, is one method for dealing with count data, which counts the number of times a specific event occurs over a given time period. The Poisson distribution has many real-world applications, such as predicting mutation rates, traffic flow distribution, radioactive decay, and road crash rates (Gilbert & Yang, 2015).

The Poisson regression model assumes that the observed outcome variable has a Poisson distribution and is represented by a mean expected value (μ), which also serves as the variable's variance (Gilbert & Yang, 2015). The Poisson Regression aims to "fit" this parameter, to a linear model of the explanatory variables. Since μ can take on only positive values, log transformation of μ is used using the formula below (Coxe et al., 2009; Gilbert & Yang, 2015):

$$log(\mu) = \beta_0 + \beta_1 X_i \quad (4)$$

The equation above can be expressed in the form

$$\mu = \exp(\beta_0 + \beta_1 X_i) \quad (5)$$

Therefore, in this study, the Poisson regression analysis appears to be more suitable to develop a model to predict the number of deaths that occurred in collisions involving an HGV (2018) (dependent variable) plotted against data for the chosen indicators (independent variables) for the same period.

Model comparison and Goodness of Fit

The difficult task in statistical modeling is to pick a model that accurately describes the underlying data from a candidate collection. A fitted model that achieves such a balance must also be generalizable in order to accurately describe or predict new data arising from the same phenomenon (Cavanaugh & Neath, 2019). This is accomplished by maximizing a likelihood function to make the observed data as probable as possible given the assumed statistical model. The likelihood function (Poisson Distribution) is (Gilbert & Yang, 2015):

$$L = \prod_{i=1}^{n} L_i = \prod_{i=1}^{n} \frac{\mu_i^{y_i}}{y_i!} e^{-\mu_i} \tag{6}$$

The logarithm of the likelihood function is:

$$l = \log(L) = \log\left[\prod_{i=1}^{n} L_i\right] = \log\left[\prod_{i=1}^{n} \frac{\mu_i^{y_i}}{y_i!} e^{-\mu_i}\right] \tag{7}$$

Since the main objective of the study is to develop a prediction model that will realistically estimate the number of deaths that occurred in collisions involving an HGV, the model's goodness of fit and its statistical adequacy has to be checked.

Because observed count data often exhibit over or under dispersion, researchers may choose between the estimation of a Poisson model and a Negative binomial model in order to ensure that the inferences from the use of count data models are appropriate (Souza et al., 2020). According to Souza et al. (2020), the correct choice for prediction from a count data estimation is directly linked to the existence of overdispersion of the dependent variable, conditional to the explanatory variables. Overdispersion is the condition in which the variance exceeds the mean. The Poisson model makes the equidispersion assumption, which states that the conditional mean and variance are equal (Coxe et al., 2009), which could be uncommon in the case of data from traffic crashes. Overdispersion can be identified using the Likelihood-Ratio test (LRT), also known as the likelihood-ratio chi-squared test (Gilbert & Yang, 2015).

$$LRT = 2\,(\log L_{NB} - \log L_P) \tag{8}$$

According to Gilbert & Yang (2015), under the null hypothesis, the score statistic is chi-squared with one degree of freedom, which helps LRT determine which of two models is the best. There is overdispersion if the p value is less than 0.05 (Gilbert & Yang, 2015). To check the suitability of the model, Poisson regression and negative binomial regression are discussed and illustrated in section 4.2.4.

From several likelihood measures that have been proposed in statistical literatures, the Akaike information criterion (AIC) is one of the most frequently employed metrics (Gobar & Bashier, 2014). AIC extends the likelihood function (Equation 6 & 7) to define a criterion that is used to evaluate the quality of an assumed model and provides an information theoretic interpretation of the likelihood function. In this study, the AIC was used to assess the developed model's goodness of fit measure, which is defined by (Bozdogan, 2000; Gobar & Bashier, 2014):

$$AIC = -2\log(L) + 2k \tag{9}$$

Where log(L) denotes the fitted log likelihood and k the number of parameters. A relatively small value of AIC is favorable for the fitted model (Bozdogan, 2000; Osuji et al., 2016;

Cavanaugh & Neath, 2019). In other words, the AIC can rank the set models in terms of one another. The model with the lowest AIC is the preferred one given the available data.

3.4.3 Weighting and Aggregating

In this study, two approaches are used to create a composite overall HGV index for the selected European countries. The indicators are combined by assigning a weight to each indicator and using an aggregation method to create the HGV index. There are several weighting and aggregation methods in the literature (Nardo et al., 2005), none of which is the best technique to use in all circumstances (Hermans et al., 2008).

Method 1: as a first step, all indicators were assumed to have equal weights (EW), and the road safety index was calculated using the linear and geometric aggregation method. Equal weight is a type of proportional measuring method that gives the same importance to each variables (indicators) (Nardo et al., 2005). This could correspond to the case in which all indicators have the same worth in the composite index. Equal weighting is transparent and unquestionably an explicit weighting scheme, especially in light of the difficulties involved with explicit weight determination by a third party (Salzman, 2003). Salzman (2003) asserts that this approach lessens the subjectivity of weights and places more emphasis on the interpretive meaning of variables than focusing on numerical weights. As a result, it is a popular approach for indexes (Hermans et al., 2008; Al-haji, 2007, Hudrliková, 2013).

Next, the linear and geometric aggregation method are used in this study to calculate the final index score. Linear aggregation method is useful when all individual indicators have the same measurement unit, it is subject to certain mathematical properties (Nardo et al., 2005). Using linear aggregations the Composite Index (CI_c) for country *c* was computed by adding each normalized value of indicator (x_i) multiplied by its weight (ω_i), using the formula (Nardo et al., 2005):

$$CI_{c} = \sum_{i=1}^{n} \omega_i x_i \quad (10)$$

If some degree of non-compensability between individual indicators or dimensions is desired, geometric aggregations are better suited (Nardo et al., 2005). Linear aggregations reward base-indicators proportionally to weights, whereas geometric aggregations reward higher-scoring countries (Nardo et al., 2005). In geometric aggregation, the Composite Index (CI_c) for country *c* is calculated by raising each indicator value (x_i) to the power of the corresponding weight (ω_i) and multiplying these products, using the equation (Nardo et al., 2005):

$$CI_{c} = \prod_{i=1}^{n} {x_i}^{\omega_i} \quad (11)$$

Method 2: given that constructing a HGV safety index based on equal weights could be biased/sensitive to extremely high or low values in one or more indicators, an alternative approach involving the regression analysis is used. In addition to many information provided by the regression analysis, the magnitude of the coefficients reveals the significance (importance) of the indicator set (Hermans et al., 2008). Therefore, the regression coefficients (β values) were the assigned weights to each of the indicators involved in the model development. Multiple regression analysis was used in earlier research (Akaateba, 2012) against data for the seven indicators to create a road safety performance index for 20 African and EU countries. Moreover, the Poisson regression model was recently employed by researchers to model crash data (Shaik & Hossain, 2020; Machetele & Yessoufou, 2021). As a result, this study attempted to create the composite HGV index (or overall HGV index) for the dataset using the Poisson regression model.

3.4.4 Index scores and country ranking

Three types of index scores were obtained using the EW (linear and geometric) and regression analysis technique. Using the EW linear aggregation method: HGV index scores are obtained by summing up all normalized values of indicators multiplied by EW ($\omega_i = 1/n$, n is total number of indicators) for each country. Using the EW geometric aggregation method: HGV index scores are obtained by multiplying all normalized values of indicators raised to EW ($\omega_i = 1/n$, n is total number of indicators) for each country. Using the Poisson regression model method: HGV index scores are calculated by multiplying weights (obtained from the model coefficient) with normalized data. In terms of HGV safety performance, a higher index in the linear and geometric aggregation technique indicates better performance, whereas a higher index in the Poisson regression model indicates the worst performance in the country, and vice versa.

The initial analysis of the composite index's construction process was performed using 15 indicators (all except B1 and B2) for the 28 European countries. The second analysis of the composite index's construction process was performed using all 17 indicators for 9 European countries (Austria (AT), Croatia (HR), Cyprus (CY), Finland (FI), France (FR), Ireland (IE), Lithuania (LT), Sweden (SE), and the United Kingdom (UK)).

All the above HGV index scores are obtained based on cross sectional data for 2018 for each country and ranked accordingly. In addition, to ensure that the rankings are not based on only year 2018, which may be an untypical year for some countries, a reference ranking was used with time-series data for eight years using average annual change in deaths involving HGVs 2010-2018 for all countries.

The performance of the selected countries in terms of HGVs safety is monitored and compared using the created road safety indexes and their rankings. Furthermore, a non-parametric test called Spearman rank correlation is used to assess the strength of association between the index rankings. When the variables are measured on a scale that is at least ordinal, the Spearman rank correlation test is the appropriate correlation analysis because it carries no assumptions about the distribution of the data (Sedgwick, 2014). Finally, to rank the countries cluster and benchmark the countries within the cluster, the ranking (from the three index rankings) that has a positive high correlation with the reference ranking is chosen.

CHAPTER FOUR

4. DATA ANALYSIS AND RESULTS

This chapter analyzes and presents the major findings of the data collected using the methods described in the methodology section. In this section, software and document analysis are primarily used, and an attempt is made to provide answers to the research questions. The findings of this study are presented in three parts. The findings of the univariate and multivariate analyses are presented in the first section. The second section explains how the road safety performance index was created. The results of weighting and aggregation methods are discussed in this section. The rankings and comparison of countries based on index scores (based on linear, geometric aggregation and Poisson regression model), and the average annual change in deaths involving HGVs are discussed in the last section.

4.1 Findings of the univariate analyses

4.1.1 Descriptive Analysis

In general, in this study 17 indicators were defined for consideration for the 28 selected European countries. To provide an overview of the collected data, table 4 gives descriptive statistics of the 6 final outcome (blue), 4 intermediate outcome (green), 5 background (structure and culture) (yellow) and the frequency distribution of the 2 policy performance indicators (grey). Out of the total basic indicators, 10 indicators (A1, A2, A3, A5, A6, C1, C2, D1, D2, & D3) have full values for all 28 European countries. A4 has 1 (3.57%) missing value whereas B4, D4, and D5 have 2 (7.14%) missing values. B3 has 9 (32.14%) missing values whereas B1 and B2 with 20 (71.43%) have the largest number of missing values.

The descriptive statistics also provides insight into the indicators (raw data), for example, the share of fatalities in HGV crashes out of total fatalities in the selected countries ranges from 3.91% to 27.62% (M=15.12%, SD=6.15), while fatalities in HGV crashes per million inhabitants range from 1.68 to 20.76 (M=7.31, SD=3.90). The minimum, maximum, and mean values are also used in the subsequent steps of outlier detection and normalization. Similarly, descriptive statistics were conducted on the frequency distribution of the policy indicators. Out of all selected countries, 20 (71.43%) countries have a maximum alcohol limit for professional drivers less than 0.02g/dl, whereas 25 (85.71%) of the countries have permissible maximum weights of lorries between 40 and 44 tons.

Table 4: Results of Descriptive Statistics

Variables		N	Min	Max	Mean	SD	Missing (%)
Fatalities in HGV crashes per million inhabitants	A1	28	1.68	20.76	7.31	3.90	0.00
Fatalities in HGV crashes per 10,000 HGV registered vehicles	A2	28	1.60	14.44	5.51	2.93	0.00
Share of fatalities in HGV crashes out of the total fatalities	A3	28	3.91%	27.62%	15.12%	6.15%	0.00
Share of VRU fatality in HGV crashes	A4	27	15.00%	50.00%	30.30%	7.47%	3.57
Share of fatalities in HGV crashes on urban road	A5	28	7.00%	67.00%	26.07%	13.45%	0.00
Share of fatalities in HGV crashes on Motorway	A6	28	0.00%	52.00%	18.43%	13.66%	0.00
Share of observed speeds of HGVs higher than the speed limit on 50 km/h urban roads	B1	8	17.00%	64.00%	36.63%	18.78%	71.43
Share of observed speeds of HGVs higher than the speed limit on rural non-motorway roads	B2	8	17.00%	78.00%	39.00%	23.08%	71.43
Average Frequency of Rest Stops with facilities for Truck Drivers	B3	19	0.00	15.90	5.54	5.02	32.14
Share of HGV (over 3.5 tons) under 5 years out of HGV vehicle fleet	B4	26	0.80%	60.30%	29.55%	14.87%	7.14
Share of HGV (over 3.5 tons) out of total vehicle fleet	D1	28	1.21%	4.85%	2.52%	1.03%	0.00
Road Network density (km per 100 sq. km)	D2	28	15.62	510.50	140.86	108.36	0.00
Goods transport by road (per billion tkm)	D3	28	0.90	316.80	79.85	92.91	0.00
Trucks per unit of GDP	D4	26	0.76	7.79	3.30	2.00	7.14
Share of employment of road freight transport out of total population	D5	26	0.18%	2.94%	0.87%	0.53%	7.14

Max alcohol limit for professional drivers (C1)	Frequency	Percent		Permissible maximum weights of lorries (C2)	Frequency	Percent
≤ 0.02g/dl (2)	20	71.43%		40-44 tons (2)	25	85.71%
>0.02g/dl (1)	8	28.57%		> 44 tons (1)	3	10.71%
Total	**28**	**100.00%**		**Total**	**28**	**100.00%**

4.1.2 Outlier detection

By creating a box plot for the dataset, potential outliers were investigated to determine whether they represent real values or suspicious individual values that were erroneously entered into the data set. Outliers are identified on the boxplot (see Appendix 3); the circle is an indication that a potential outlier is present in the data and extreme values are marked with a star.

Both outliers are plotted and explored, but for the sake of simplicity the box plots showing only extreme values are shown below. Two extreme outliers related to fatalities in HGV crashes per million inhabitants (A1) and road network density (km per 100 sq. km) (D2) are detected for two different countries. By checking the raw data set in Appendix 2a & 2d, these indicator values are extremely higher than others. Taking the fatalities in HGV crashes per million inhabitants (A1) in Latvia (LV) a relatively high indicator value (20.76) was recorded while the mean value of this indicator by all the other countries was only 7.31.

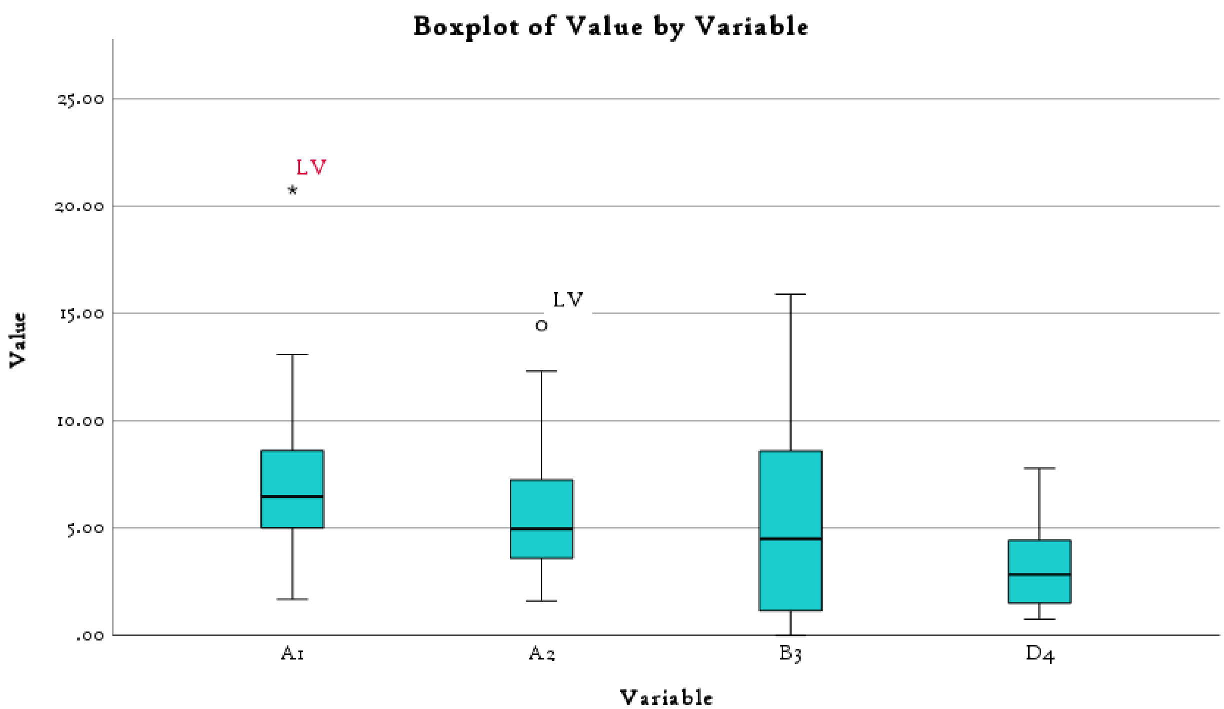

Figure 6: Boxplot of extreme outlier value by variable (A1 in LV)

The same goes to the road network density (D2) in Belgium (BE) (figure 2) a relatively high indicator value (510.5) was recorded while the average value of this indicator by all the other countries was only 140.86.

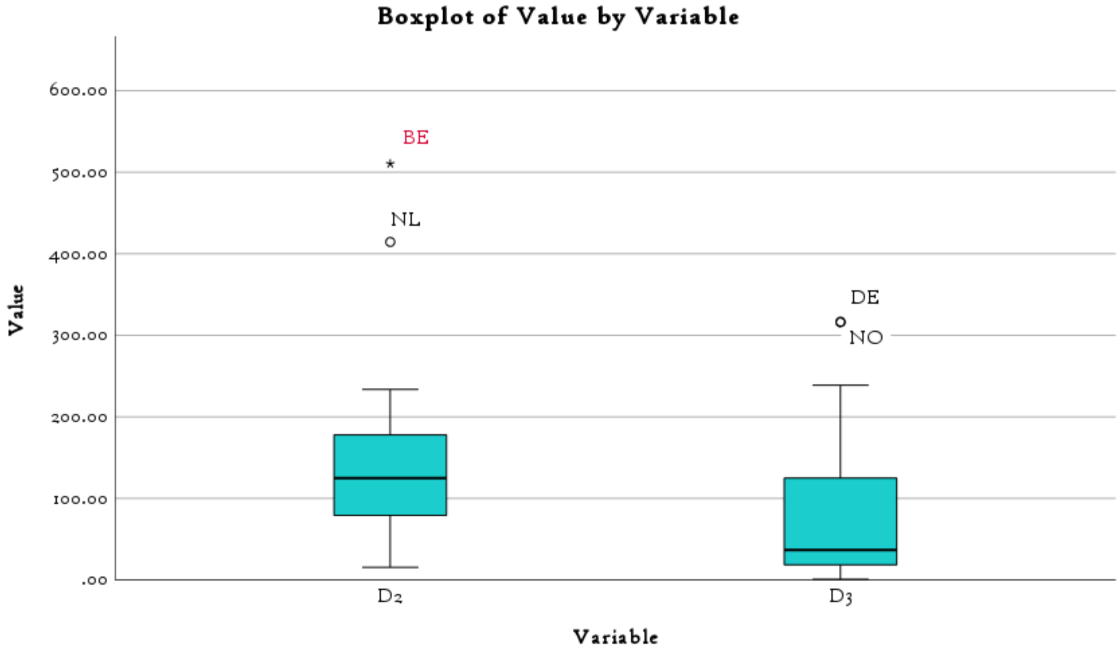

Figure 7: Boxplot of extreme outlier value by variable (D2 in BE)

Given the fact that the data were collected from secondary sources, it could probably happen due to misreading and/or wrong entering into the data set. As a consequence, by checking the raw data in the corresponding data sources as well as by exploring other international data sources, it was believed that they were the true values for these two countries, although they were statistically potential outliers. Therefore, it is reasonable to keep them in the data set.

4.1.3 Missing data Imputation

According to the data collected (see appendix A1a-1d), only three of the 28 selected European countries have values for the entire set of basic indicators A to D. Similarly, as it was revealed by descriptive statistics in table 4 out of the 17 basic indicators, 9 indicators have full values for the whole 28 European countries. Therefore, Expectation Maximization (EM) imputation was used to impute missing values, ensuring that countries with missing values were not excluded from the statistical analysis. Estimates obtained through 25 iterative processes were used to replace missing values. The final dataset of basic indicators with the imputed values (highlighted in red) are presented in the tables below.

Due to the large missing values with (n=20 or 71.43%) with respect to share of observed speeds of HGVs higher than the speed limit on 50 km/h urban roads (B1) and Share of observed speeds of HGVs higher than the speed limit on rural non-motorway roads (B2), imputation was performed using: (1) all indicators except B1 and B2 for the 28 European countries (Table 5), (2) all indicators with B1 and B2 for 9 European countries (Austria (AT), Croatia (HR), Cyprus (CY), Finland (FI), France (FR), Ireland (IE), Lithuania (LT), Sweden (SE), and the United Kingdom (UK)) (Table 6).

Table 5: The imputed data for 28 European countries

ISO	A1	A2	A3	A4	A5	A6	B3	B4	C1	C2	D1	D2	D3	D4	D5
AT	6.33	7.73	13.69%	32.00%	22%	26%	15.90	60.30%	0.00	0.00	1.32%	158.01	25.80	1.29	0.70%
BE	9.71	7.60	18.38%	32.00%	23%	38%	7.40	30.00%	0.00	0.00	2.18%	510.50	32.70	2.02	0.55%
HR	6.12	5.47	7.89%	29.00%	31%	20%	4.60	17.46%	0.00	0.00	2.47%	47.16	12.60	3.43	0.56%
CY	1.68	1.60	4.08%	33.00%	67%	33%	6.78	15.47%	0.00	0.00	1.88%	110.00	0.90	5.38	0.18%
CZ	11.76	6.67	19.05%	25.00%	22%	15%	4.55	27.07%	0.00	1.00	2.85%	72.22	41.10	3.62	1.24%
DK	5.70	7.72	19.30%	36.00%	29%	14%	9.80	45.13%	1.00	0.00	1.41%	186.82	15.00	1.50	0.55%
EE	8.32	2.87	16.42%	37.00%	29%	0%	11.50	12.69%	0.00	0.00	4.39%	136.10	5.80	4.83	1.23%
FI	11.97	6.86	27.62%	15.00%	8%	4%	2.00	17.26%	1.00	0.00	3.07%	25.65	28.30	2.68	0.82%
FR	6.62	7.87	13.68%	27.00%	19%	21%	6.13	39.45%	1.00	0.00	1.25%	199.37	173.30	2.94	0.56%
DE	7.26	6.36	18.38%	29.00%	23%	35%	1.00	45.82%	0.00	0.00	1.86%	197.4	316.80	1.00	0.55%
EL	6.71	3.13	10.29%	37.00%	32%	20%	7.36	0.80%	0.00	0.00	3.64%	90.00	29.30	7.46	0.34%
HU	11.97	12.32	18.48%	26.00%	16%	17%	14.00	27.62%	0.00	0.00	2.26%	233.73	37.90	4.32	0.83%
IE	4.73	4.31	16.20%	29.00%	27%	9%	0.00	23.86%	1.00	0.00	2.10%	143.60	11.60	1.18	0.50%
IT	5.76	3.85	10.44%	24.00%	16%	38%	4.00	12.94%	0.00	0.00	2.05%	86.30	124.90	2.45	0.57%
LV	20.76	14.44	27.03%	36.00%	18%	0%	5.60	24.04%	1.00	0.00	3.85%	94.13	15.00	3.22	1.41%
LT	8.57	3.64	13.87%	32.00%	27%	5%	4.50	35.61%	0.00	0.00	4.85%	136.63	43.60	2.73	2.94%
LU	3.29	1.66	5.56%	40.00%	40%	30%	6.70	52.01%	0.00	0.00	2.59%	119.92	6.80	0.76	1.28%
NL	5.11	5.22	14.72%	29.00%	25%	32%	0.00	39.73%	1.00	1.00	1.69%	414.57	68.90	1.39	0.75%
NO	4.89	3.04	24.07%	19.00%	7%	1%	1.30	34.73%	0.00	1.00	2.57%	25.99	315.90	2.3	0.93%
PL	13.09	4.48	17.37%	30.00%	30%	6%	4.50	12.41%	0.00	0.00	4.06%	138.67	33.00	7.79	1.21%
PT	6.22	4.92	9.09%	32.00%	43%	14%	7.51	17.92%	0.00	0.00	2.07%	15.62	58.80	6.82	0.71%
RO	3.75	2.36	3.91%	28.00%	51%	2%	4.93	11.42%	0.00	0.00	4.11%	37.48	35.60	5.19	0.83%
SK	6.61	4.22	13.85%	30.66%	16%	9%	5.97	29.01%	0.00	0.00	3.18%	120.07	22.20	3.73	0.93%
SI	8.68	5.02	19.78%	19.00%	8%	52%	0.00	54.18%	0.00	0.00	2.67%	105.20	239.00	2.40	1.33%
ES	6.05	4.99	15.67%	26.00%	11%	32%	0.00	22.80%	1.00	0.00	1.97%	130	43.50	4.43	0.73%
SE	6.68	8.10	20.99%	24.00%	20%	17%	11.60	42.22%	0.00	0.00	1.52%	52.95	159.10	1.32	0.81%
CH	2.58	3.55	9.44%	50.00%	42%	14%	6.50	33.29%	0.00	0.00	1.21%	181.06	213.40	3.33	0.88%
UK	3.91	4.29	14.14%	42.00%	28%	12%	4.60	40.65%	1.00	0.00	1.51%	174.88	1250	1.94	0.44%

Table 6: The imputed data for 9 European countries

ISO	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	C1	C2	D1	D2	D3	D4	D5
AT	6.33	7.73	13.69%	32%	22%	26%	25%	24%	15.90	60.30%	0.00	0.00	1.32%	158.01	25.8	1.29	0.70%
HR	6.12	5.47	7.89%	29%	31%	20%	64%	22%	1.32	17.46%	0.00	0.00	2.47%	47.16	12.6	3.43	0.56%
CY	1.68	1.60	4.08%	33%	67%	33%	26%	17%	10.76	46.81%	0.00	0.00	1.88%	110	0.9	5.38	0.18%
FI	11.97	6.86	27.62%	15%	8%	4%	55%	53%	2.00	17.26%	1.00	0.00	3.07%	25.65	28.3	2.68	0.82%
FR	6.62	7.87	13.68%	27%	19%	21%	25%	23%	8.79	39.45%	1.00	0.00	1.25%	199.37	173.3	2.94	0.56%
IE	4.73	4.31	16.20%	29%	27%	9%	64%	78%	0.00	23.86%	1.00	0.00	2.10%	143.60	11.6	1.18	0.50%
LT	8.57	3.64	13.87%	32%	27%	5%	26%	65%	4.50	35.61%	0.00	0.00	4.85%	136.63	43.6	2.73	2.94%
SE	6.68	8.10	20.99%	24%	20%	17%	17%	28%	11.60	50.73%	0.00	0.00	1.52%	52.95	159.1	1.32	0.81%
UK	3.91	4.29	14.14%	42%	28%	12%	46%	30%	4.60	40.65%	1.00	0.00	1.51%	174.88	125	1.94	0.44%

4.2 Findings of the multivariate analyses

In this step, multivariate analyses are conducted on the entire indicator dataset (raw data) to understand the level of correlation between the different indicators.

4.2.1 Correlation

A bivariate Pearson correlation analysis was done to check for correlation among all selected indicators. Since most defaults or suggested thresholds still allow for significant collinearity, each researcher must determine the level of collinearity that is acceptable (Hair et al., 2010). In this study, a Pearson coefficient value of 0.70 (highly correlated) was used as a threshold. For indicators that have a value above 0.70 there is high collinearity among the selected variables/indicators. Because of the small sample size, a Pearson correlation was only performed on the first set of data to check the correlation between all indicators variables except B1 and B2 for the 28 European countries. Based on the Pearson correlation results in Table 7, a positive strong correlation was observed between the fatalities in HGV crashes per million inhabitants (A1) and fatalities in HGV crashes per 10,000 HGV registered vehicles (A2) with a Pearson coefficient value of 0.731. A negative strong correlation was also observed between the Share of fatalities in HGV crashes out of the total fatalities (A3) and share of fatalities in HGV crashes on urban road (A5) with a Pearson coefficient value of -0.767.

Table 7: Bivariate Pearson correlation (28 European countries)

		A1	A2	A3	A4	A5	A6	B3	B4	D1	D2	D3	D4
A2	Pearson Corr	.731**											
	Sig. (2-tailed)	0.000											
A3	Pearson Corr	.683**	.619**										
	Sig. (2-tailed)	0.000	0.000										
A4	Pearson Corr	-0.235	-0.162	-.447*									
	Sig. (2-tailed)	0.228	0.411	0.017									
A5	Pearson Corr	-.460*	-.455*	-.767**	.570**								
	Sig. (2-tailed)	0.014	0.015	0.000	0.002								
A6	Pearson Corr	-0.266	-0.069	-0.226	-0.129	-0.048							
	Sig. (2-tailed)	0.172	0.727	0.248	0.514	0.808							
B3	Pearson Corr	0.061	0.310	-0.121	0.331	0.208	-0.154						
	Sig. (2-tailed)	0.756	0.109	0.539	0.085	0.289	0.433						
B4	Pearson Corr	-0.153	0.200	0.190	0.037	-0.269	0.358	0.099					
	Sig. (2-tailed)	0.436	0.307	0.332	0.852	0.167	0.061	0.617					
D1	Pearson Corr	.456*	-0.151	0.074	-0.067	0.021	-.493**	-0.085	-.490**				
	Sig. (2-tailed)	0.015	0.444	0.707	0.734	0.917	0.008	0.667	0.008				
D2	Pearson Corr	0.007	0.212	0.060	0.236	-0.056	.390*	0.048	0.284	-0.289			
	Sig. (2-tailed)	0.972	0.278	0.760	0.226	0.778	0.040	0.807	0.143	0.136			
D3	Pearson Corr	-0.188	-0.056	0.236	-0.210	-0.325	0.233	-0.330	.400*	-0.337	-0.040		
	Sig. (2-tailed)	0.337	0.776	0.227	0.284	0.091	0.233	0.087	0.035	0.079	0.838		
D4	Pearson Corr	0.160	-0.192	-0.281	0.089	0.360	-0.269	0.111	-.758**	.466*	-0.302	-0.310	
	Sig. (2-tailed)	0.415	0.329	0.147	0.652	0.060	0.167	0.575	0.000	0.012	0.118	0.108	
D5	Pearson Corr	.380*	0.013	0.194	-0.017	-0.175	-0.295	-0.059	0.158	.639**	-0.126	-0.051	-0.032
	Sig. (2-tailed)	0.046	0.947	0.322	0.931	0.372	0.127	0.764	0.423	0.000	0.524	0.796	0.872

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Additionally, a negative significant correlation was observed between the share of HGV (over 3.5 tons) under 5 years out of HGV vehicle fleet (B4) and Trucks per unit of GDP (D4) with a Pearson coefficient value of -0.758. Moderately correlated variables are also highlighted in the table. Finally, the result of the Pearson's correlation used to select and take action on the highly correlated variables for the model development (see section 4.2.4).

4.2.2 Principal components analysis (PCA)

In addition to the Bivariate Pearson correlation analysis, Principal components analysis was used to investigate the relationships between the indicators, revealing how different indicators change in relation to one another and how they are related. The indicators are organized into four major components that explain a large portion of the variance in the data as shown in table 9.

There are several assumptions made in the application of PCA which are discussed including enough number of cases (countries) are necessary to do PCA as the rule of 10 implies there should be at least 10 cases for each variable. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) statistic should vary from 0 to 1.0 (Nardo et al., 2005; Hair et al., 2010). The KMO measure of sampling adequacy is a statistic that compares the magnitudes of observed and partial correlation coefficients. According to Nardo et al. (2005), these and other assumptions are stated in most literatures, yet they are often neglected when composite indicators are developed.

As the rule of 10 implies, each variable should have at least 10 cases, and because the second data set contains fewer cases (number of countries=9), PCA did not work for the dataset. Therefore, PCA was performed to the first set of the 28 European countries between all indicators variables except B1 and B2. The sample adequacy of the collected data set is checked using KMO and Bartlett's test, as shown in table 8. Because the sample size (number of countries) of N = 28, the value of the KMO test result is 0.453 which is expected to be less than 0.6. On the other hand, the significance value of Bartlett's test is <0.001 ($p < 0.05$), which indicates that our correlation matrix is not an identity matrix. It can be verified by looking at the off-diagonal values of the correlation matrix. These values should not be equal to zero, indicating that the matrix is not an identity matrix.

Table 8: KMO and Bartlett's Test

KMO Measure of Sampling Adequacy.		0.453
Bartlett's Test of Sphericity	Approx. Chi-Square	243.483
	df	105
	Sig.	<0.001

Since the goal of PCA is to reduce the set of variables, it would be useful to have a criterion for selecting the optimal number of components that are smaller than the total number of items. One criterion is that the associated eigenvalues of the chose components should be greater than 1 (Holland, 2019). This can be confirmed by the Scree Plot which plots the eigenvalue (total variance explained) by the component number.

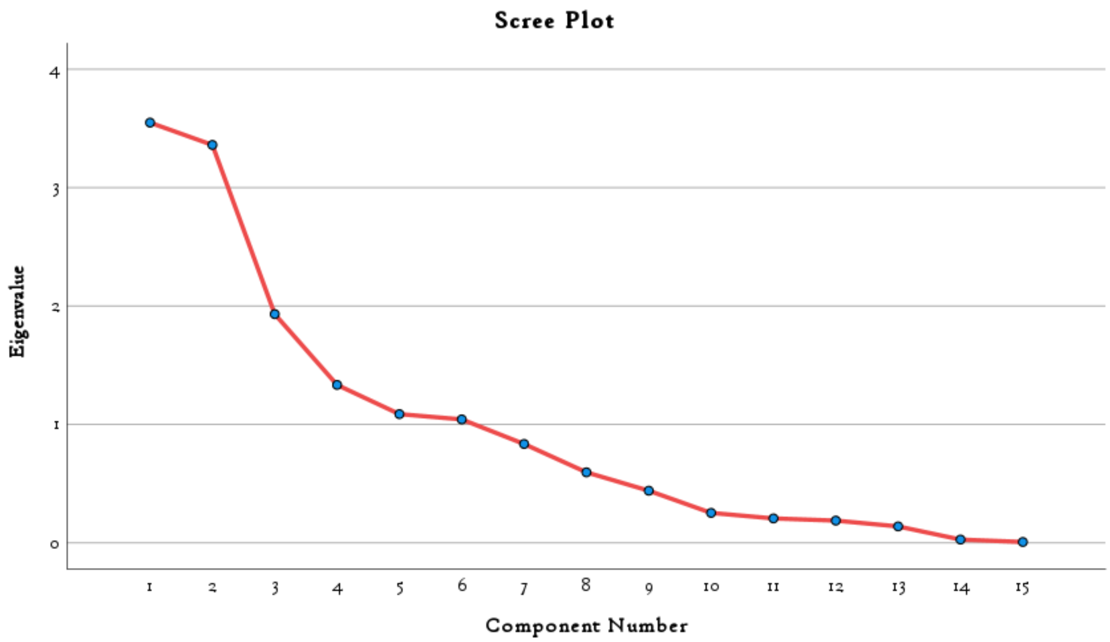

Figure 8: Scree Plot

The scree plot graphically displays the information in the next table (Table 9), the successive eigenvalues of the components' eigenvalues. As it can be seen from figure 8, the line with the first 6 components drops off sharply and have an eigenvalue greater than 1. From the seventh component on, the line tends to level, indicating that each successive component accounts for a smaller and smaller proportion of the total variance. Based on the graph, the first four principal components with eigenvalues greater than one were considered for this study.

The next step was to check the variance explained by each component as well as the cumulative variance explained by all components. Using Varimax and Kaiser Normalization as a rotation method, the Rotated Component Matrix was generated. Varimax Rotation reduces the number of sub indicators that have a high loading on the same factors (Nardo et al., 2005). At this point, the results of the Rotated Component Matrix with the total variance explained in 4 component PCA as shown in Table 11.

Table 9: Total Variance Explained

	Initial Eigenvalues			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.608	24.053	24.053	3.218	21.451	21.451
2	3.119	20.793	44.845	2.887	19.244	40.695
3	1.981	13.206	58.051	2.265	15.099	55.795
4	1.445	9.633	67.684	1.783	11.889	67.684

Extraction Method: Principal Component Analysis.

Based on the Total Variance Explained in table 9, the first principal component explains the maximum variance of 21.451% (eigenvalue of 3.218) in all the sub-indicators. The second principal component explains the next maximum amount of variance of 19.244% (eigenvalue of 2.887). The third and fourth principal components explain the remaining 15.099% and 11.889% (eigenvalue of 2.265 and 1.783) of the variance in the dataset respectively. The result also indicates that, 67.684% of the variance in the data set was explained by the 4 extracted components, which is adequate to continue with the PCA.

The final step was interpreting each variable's loading on each component using the rotated component matrix table (table 10). The table displays the loadings for each variable on each rotated component, again clearly showing which items make up each component. From the output, the 15 indicators are grouped in four components A1, A2, A3 and A5 in component 1; A6, B4, D2 and D4 in component 2; A4, B3, C2 and D3 in component 3; C1, D1 and D5 in component 4. From the output, five variables (A5, D4, and D3) have negative loadings, which means that these variables correlate negatively with the other variables in the given principal component. Loadings with the same sign contribute in the same way within the component, while those with the opposite sign contribute in the opposite way. The 4 extracted factors' values of PCA for all countries are given in Appendix 5.

Table 10: The Rotated Component Matrix

Variables (Indicators)	Component			
	1	2	3	4
Fatalities in HGV crashes/ 10,000 HGVs **(A2)**	0.862	0.164	0.242	-0.145
Share of fatalities in HGV out of the total fatalities **(A3)**	0.861	0.103	-0.341	
Fatalities in HGV crashes /million inhabitants **(A1)**	0.856	-0.277		0.221
Share of fatalities in HGV crashes on urban road **(A5)**	**-0.685**	-0.249	0.488	
Share of HGV under 5 years out of HGV vehicle fleet **(B4)**	0.113	0.911		0.159
Trucks per unit of GDP **(D4)**	-0.188	**-0.803**	0.161	
Share of fatalities in HGV crashes on Motorway **(A6)**	-0.268	0.555		-0.264
Road Network density (km per 100 sq. km) **(D2)**	0.144	0.470	0.257	-0.273
Average Frequency of Rest Stops with facilities/100km **(B3)**			0.788	0.154
Share of VRU fatality in HGV crashes **(A4)**	-0.316		0.692	
Permissible Maximum Weights of Lorries **(C2)**		0.104	0.564	
Goods transport by road (per billion tkm) **(D3)**	-0.102	-0.497	**-0.560**	0.110
Share of HGV out of total vehicle fleet **(D1)**	0.140	0.628		0.630
Share of employment of road freight transport/popn. **(D5)**	0.236			0.852
Maximum blood alcohol concentration in g/l **(C1)**	-0.441		0.125	0.611
Extraction Method: Principal Component Analysis.				
Rotation converged in 6 iterations. Loadings greater than 0.4 are highlighted				

4.2.3 *Clustering analysis*

In this study, the hierarchical clustering analysis (using the Ward linkage method with Euclidian distance) was used to group the 28 countries based on all variables (except B1 and B2) and the 4 extracted factors' values with the PCA analysis. The resulting classification tree is shown in the dendrogram, using a rescaled distance of 15; all 28 the countries are subdivided as follows (see Figures 9, Figure 10 and Table 11).

Table 11: Clustering countries using the hierarchical cluster analysis

Cluster	Based on all variables	Based on PCA factors' values
1	EE,IE,LT,PL,SK,ES,CZ, EL,LV,CY,LU,AT, DK,HU,PT,RO, HR,FI	IE,ES,IT,FR,UK,NL,DE,SI,NO
2	BE,NL	LU,CH,AT,SE,BE,DK,HU
3	NO,SI,DE,IT,SE, FR,CH,UK	HR,PT,EL,RO,CY
4		FI,LV,EE,PL,CZ,SK,LT

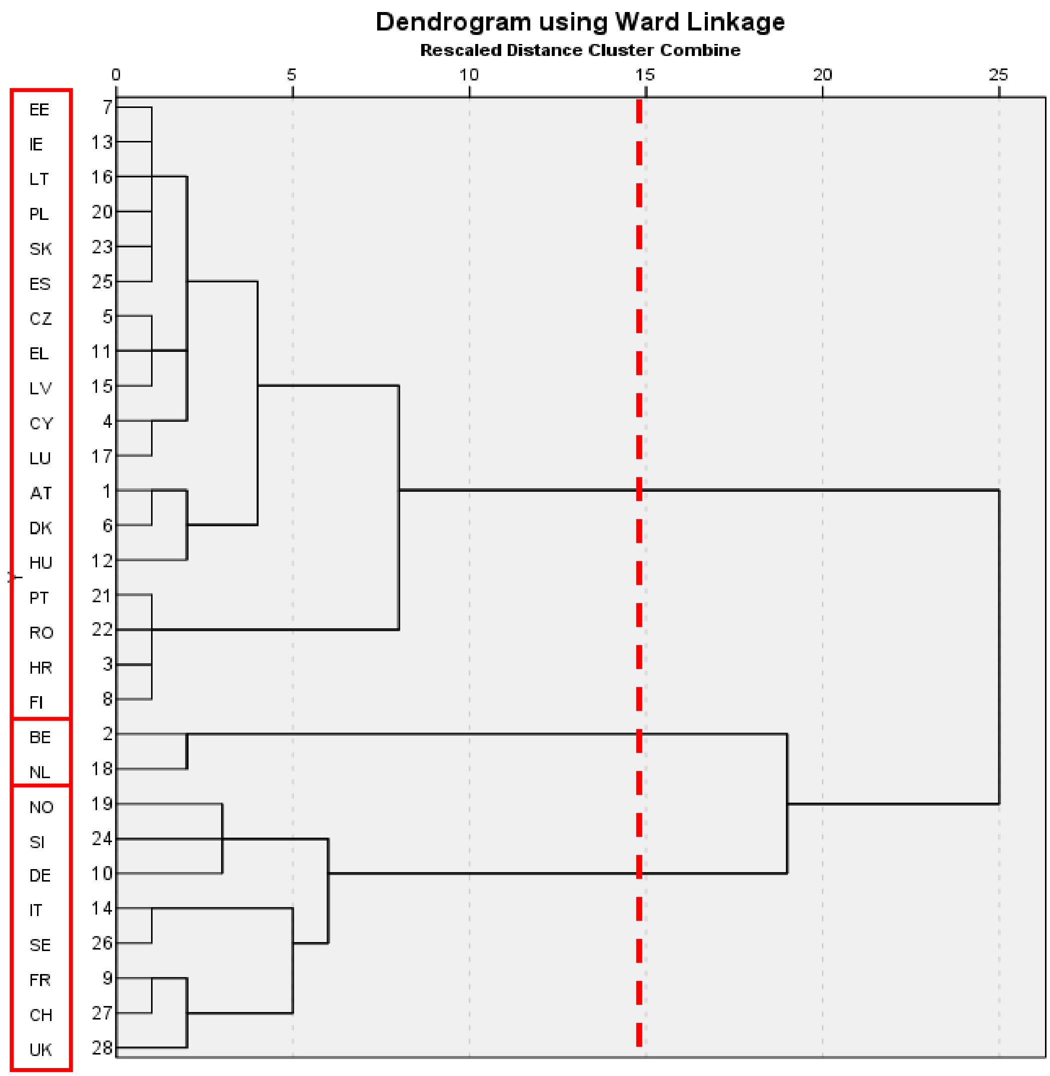

Figure 9: Clustering based on all variables (except B1 and B2)

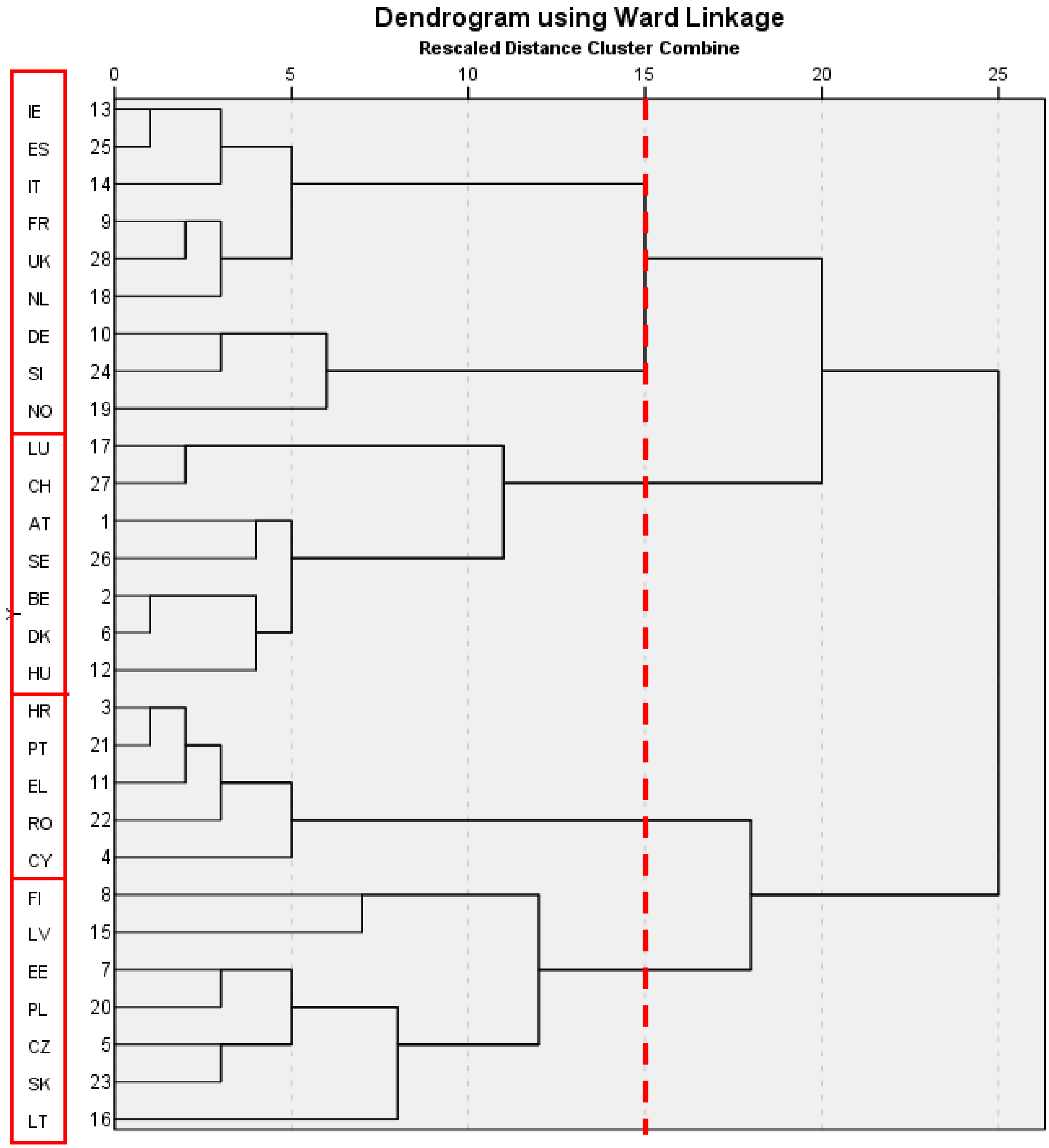

Figure 10: Clustering based on the 4 extracted factors' values with PCA

Similarly, hierarchical clustering analysis (using the Ward linkage method with Euclidian distance) was used to group the second dataset with 9 European countries (Austria (AT), Croatia (HR), Cyprus (CY), Finland (FI), France (FR), Ireland (IE), Lithuania (LT), Sweden (SE), and the United Kingdom (UK)) based on all selected indicators, including B1 and B2. As shown in the dendrogram (figure 11; using a rescaled distance of 10), the 9 European countries are grouped into 3 groups. The first group contains 4 countries (i.e., IE, LT, AT, CY), the second group contains 2 countries (i.e., HR, FI), and the other contains the remaining 3 countries (i.e., FR, UK, SE).

In the following chapter, between and within groups will be discussed in detail to draw important conclusions on their HGV safety performance and provide recommendations for underperforming countries to improve their performance. In addition, comparison of clusters based on their rank will be discussed in section 4.5.

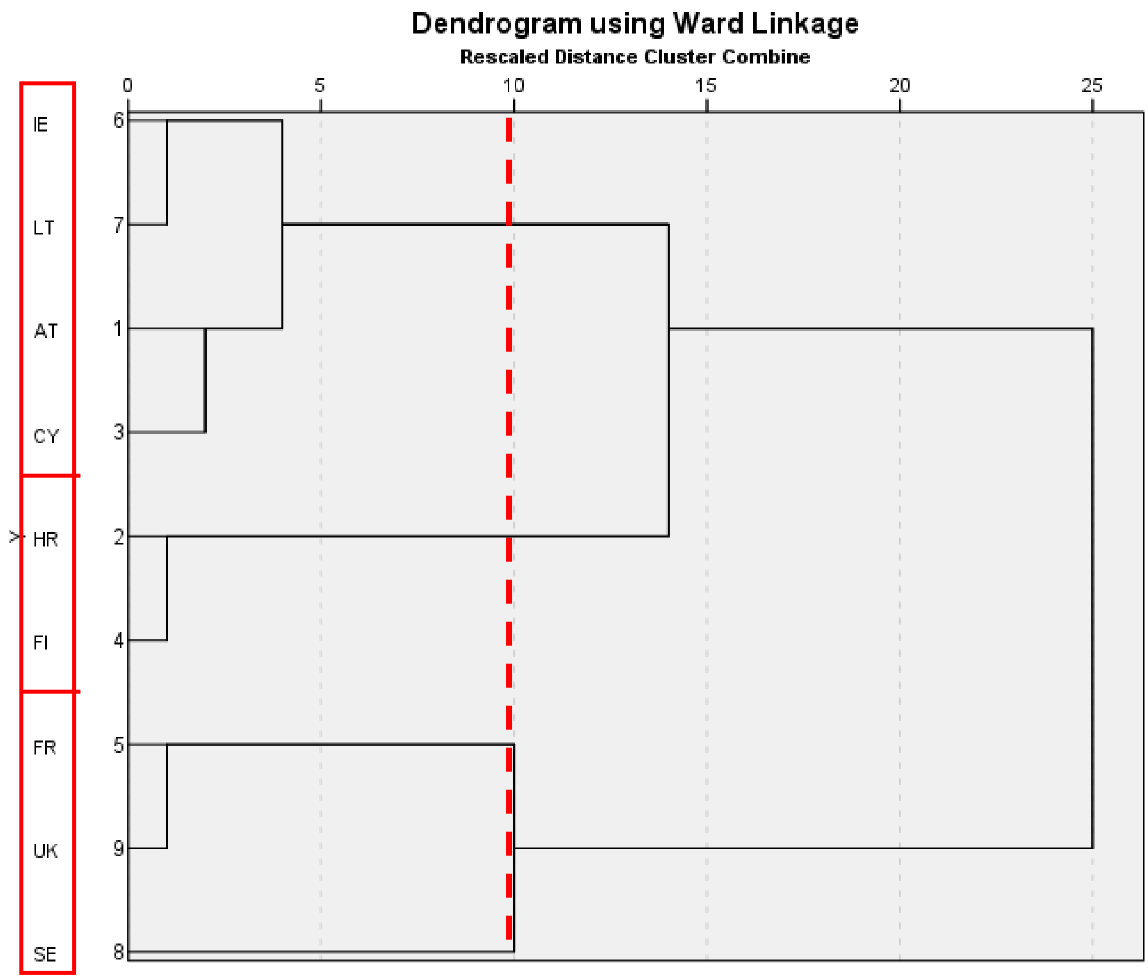

Figure 11: Clustering of 9 countries based on all variables

4.2.4 *Poisson regression model*

In this section, the results from the Poisson regression model are discussed. As explained in the methodology, the response variable (outcome variable) is the total number of fatalities that occurred in collisions involving an HGV, which is a "count data", meaning that the appropriate link function to specify in model fitting is the Poisson regression model.

Because of the small sample size, only using the first dataset with 28 European countries both Poisson and Negative binomial regression analysis was used to develop a model for the total number of fatalities per population that occurred in collisions involving an HGV against 17 selected indicators (all except B1 and B2).

Prior to all these analyses, multicollinearity among predicting variables is first tested using bivariate Pearson Correlation analysis (see section 4.2.1 on table 7). Because some indicators are inter-related/correlated, the multicollinearity problem was dealt with the stepwise selection technique. Stepwise estimation involves sequentially adding or removing independent variables into the discriminant function based on their discriminant power (Hair et al., 2010).

The first attempt of fitting the model results showed statistically insignificant results with the AIC value=237.978; the SPSS model output results are summarized in Appendix 6a. Successively, using the stepwise selection techniques, collinear variables were removed one by one from the model, the model is rerun, and the AIC values, and p values calculated. This stepwise selection was repeated until the model is made up of only parameters/variables with Sig<0.05 and AIC is smaller than all combinations, see table 12. At the end, the final Poisson regression model was reconstructed using only models with non-collinear variables except for A2 and A3, which are useful in determining (highly correlated) with the response variable. The AIC values for this model is: AIC=230.20. The SPSS final Poisson model output is summarized in Appendix 6b.

Table 12: The AIC values for the trial models

Model No.	Parameters fitting	AIC	Value/df	Significant Parameters
1	All	237.978	3.178	A2, A3, D1, D4
2	Excluding A4	237.413	3.057	A2, A3, D1, D4
3	Excluding A5	236.047	2.957	A2, A3, D1, D4
4	Excluding A6	237.485	3.033	A2, A3, C1, D2, D4
5	Excluding B4	236.235	2.971	A2, A3, D1, D4
6	Excluding D1	240.611	3.223	A2, A3, C1,D2, D4, D5
7	Excluding D4	259.646	4.645	A2, A3, B4, D1, D5
8	Excluding D4	237.571	3.064	A2, A3, D1, D4
Testing Combination effect				
9	Excluding A5, A6, B4, D5	234.929	2.702	A2, A3, A4, C1, D1, D2, D4
10	Excluding A4, A6, B4, D5	234.165	2.662	A2, A3, A5, C1, D1, D4
11	Excluding A4, A6, B4, C2, D5	232.170	2.517	A2, A3, A5, C1, D1, D4
12	**Excluding A4, A6, B4, C2, D3, D5**	**230.220**	**2.386**	**A2, A3, A5, B3, C1, D1, D2, D4**

The adequacy of the final model was also tested based on the existence of overdispersion of the dependent variable, conditional to the explanatory variables. The following comparison and discussion between a Poisson regression and a negative binomial regression examine the model's suitability.

Table 13: Measures of model adequacy (Goodness of Fit)

Model	Log likelihood	LRT*	P value	AIC
Poisson	-106.110			230.220
Negative binomial	-142.072	-71.924	0.5	302.145

$$LRT^* = 2\,(\log L_{NB} - \log L_P) \tag{12}$$

From the SPSS output the Log likelihood values are produced as shown in the table. Therefore, using the LRT equation, we can proceed with the Poisson regression model since LRT=-71.924 with a P value > 0.05 indicates that there is no evidence of overdispersion. Moreover, the AIC of the preferred model is the lowest. The SPSS negative binomial regression output is presented in Appendix 6c.

Below, table 14 represents the results of the parameter estimation of the independent variables (selected indicators) and dependent variable (number of Fatalities in HGV crashes per population) of the Poisson regression model.

Table 14: Parameter estimation of the Poisson regression model

Parameter	β	Std. Error	95% Wald Confidence Interval		Exp(β)	df	Sig.
			Lower	Upper			
(Intercept)	-13.097	0.1167	-13.326	-12.868	2.05E-06	1	0.000
[C1=1]	-0.227	0.0446	-0.315	-0.14	0.797	1	0.000
A2	0.089	0.013	0.064	0.115	1.094	1	0.000
A3	0.026	0.0062	0.013	0.038	1.026	1	0.000
A5	-0.008	0.0026	-0.013	-0.003	0.992	1	0.002
B3	-0.015	0.0069	-0.028	-0.001	0.985	1	0.030
D1	0.144	0.0371	0.072	0.217	1.155	1	0.000
D2	0.00043	0.0002	2.42E-05	0.001	1.000	1	0.038
D4	0.077	0.0136	0.05	0.104	1.080	1	0.000

Dependent Variable: Fatalities in HGV crashes per population
Model: (Intercept), A2, A3, A5, B3, C1, D1, D2, D4 a. Set to zero because this parameter is redundant.

From the result, A2, A3, A5, B3, C1, D1, D2, and D4 are significantly related to the number of Fatalities in HGV crashes per population, with the significance value less than 0.05. Table 14 provides the coefficient estimates (β values) of the Poisson regression and the exponentiated values of the coefficients (exp (β)), used to interpret the results. It is important to remember that a negative (or positive) value of the corresponding variable's coefficient β_i indicates that an increase of the corresponding variable xi contributes to a decrease (or increase) in the rate of fatalities in HGV crashes per population. For example, average frequency of rest stopes with facilities for track drivers (B3) is negative meaning every 1-unit increase in B3, the rate of fatalities in HGV crashes per population will decrease. Similarly, the direction of all variables found to be logical except the share of fatalities in HGV crashes on urban road (A5) and the maximum alcohol limit for professional drivers (C1 >0.02g/dl (1)). Although the coefficient signs of the two independent variables differ from what would be predicted by theory, both are statistically significant. However, they weren't left out when the model was created, because the development of a composite index is more concerned with the overall effects of all indicators than the causal effects of each individual indicator in each country. Moreover, by comparing the estimated coefficients of the variables, we can rank the impact of the variables on the rate of fatalities in HGV crashes per population. That is, the maximum alcohol limit for professional drivers (C1 >0.02g/dl (1)) has the greatest negative impact (β = -0.227) whereas share of HGV out of total vehicle fleet (D1) has the greatest positive impact (β = 0.144) on the rate of fatalities in HGV crashes.

As shown in table 14, the maximum alcohol limit for professional drivers greater than 0.02g/dl C1 (1) has an exp (β) value=0.797 times higher effect on the rate of fatalities in HGV crashes than maximum alcohol limit for professional drivers less than 0.02g/dl C1(2). Similarly, another way of interpreting the exp (β) result is for every unit increase of B3 (average frequency of rest stops with facilities for truck drivers) and D1 (share of HGV out of total vehicle fleet) there is a 1.5% (0.985 - 1) decrease and 15.5% (1.155- 1) increase in the rate of fatalities in HGV crashes per population respectively.

Therefore, from the analysis of the Poisson regression model, the estimated number of fatalities in HGV crashes per population was plotted as the dependent variable against data for the remaining 8 indicators (independent variables) (p value < 0.05) is:

$$\mu = \exp(-13.097 + 0.089A2 + 0.026A3 - 0.008A5 - 0.015B3 - 0.227C1 + 0.144D1 + 0.00043D2 + 0.077D4) \quad (13)$$

Where: A2 = Fatalities in HGV crashes per 10,000 HGV registered vehicles
A3 = Share of fatalities in HGV crashes out of the total fatalities
A5 = Share of fatalities in HGV crashes on urban road
B3 = Average frequency of rest stops with facilities for truck drivers
C1 = Maximum blood alcohol limit for professional drivers
D1 = Share of HGV out of total vehicle fleet
D2 = Road Network density
D4 = Trucks per unit of GDP

4.3 Developing the HGV Safety Index

In this study, two methods were used to develop the overall HGV index (Composite Index for HGV) for the selected European countries.

4.3.1 Method 1

This approach involved assigning equal weights to all indicators and constructing the Composite Index for HGVs (CI_{HGVc}) for the selected European countries the linear and geometric aggregation method. First each indicator is assigned by $\omega_i = 1/n$, where ω_i is the weight of the i^{th} indicator and n is the number of indicators in the analysis. Therefore, all of the major categories are given equal weighting at the beginning, as well as all of the indicators within each category (see table 15).

Next, using linear aggregation the CI_{HGVc} for country *c* was computed by adding each normalized value of indicator (x_i) multiplied by its weight (ω_i), using equation 10. Where the normalized values of the indicators were prepared previously using the formulas (1 and 2), see Appendix 4a-b. In geometric aggregation, the CI_{HGVc} is calculated by raising each indicator value (x_i) to the power of the corresponding weight (ω_i) and multiplying these products, using equation 11. The geometric aggregation method may appear impossible with one or more of the data values is zero (0). An often-used solution is to add a very small value close to zero, thus ($x_i + 10^{-10}$) was added for calculation purposes. Therefore initially, the CI_{HGVc} for the first dataset with 28 European countries was constructed using linear aggregation. For example, the CI_{HGVs} for Austria (AT)≈0.69 as shown in table 16 was derived from:

$$\omega_i = 1/n = 1/15 = 0.0667$$
$$CI_{HGVs(AT)} = (0.76+0.52+0.59+0.51+0.75+0.50+1.0+1.0+2.0+2.0+0.03+0.29+0.08+0.08+0.19)*1/15$$
$$\mathbf{CI_{HGVs(AT)} \approx 0.69}$$

In the same way, the CI_{HGV} for all countries are summarized in table 16, indicating the higher index the better HGV safety performance. Following, using geometric aggregation for the same set of countries and indicators, the CI_{HGVc} was constructed (see table 16). The CI_{HGV} for Austria (AT)≈0.41 was derived from:

$$\omega_i = 1/n = 1/15 = 0.0667$$
$$\mathbf{CI_{HGVs(AT)}} = (0.76^{0.0667})*(0.52^{0.0667})*(0.59^{0.0667})*(0.51^{0.0667})*(0.75^{0.0667})*(0.50^{0.0667})*(1.0^{0.0667})*(1.0^{0.0667})*(2.0^{0.0667})*(2.0^{0.0667})*(0.03^{0.0667})*(0.29^{0.0667})*(0.08^{0.0667})*(0.08^{0.0667})*(0.19^{0.0667})$$
$$\mathbf{CI_{HGVs(AT)} \approx 0.41}$$

In a same manner, the CI_{HGVs} for the second dataset with 9 European countries ((Austria (AT), Croatia (HR), Cyprus (CY), Finland (FI), France (FR), Ireland (IE), Lithuania (LT), Sweden (SE), and the United Kingdom (UK)) was constructed by assigning equal weights (see table 15) to all indicators and using linear and geometric aggregation. The CI_{HGV} for the second dataset are summarized in table 17.

4.3.2 Method 2

This method involved developing CI_{HGVc} based on the Poisson regression analysis. From the developed Poisson regression model in part 4.2.4 (Equation 13), the total estimate of fatalities in HGV crashes per population in the case study countries (dependent variable) was plotted as the dependent variable against data for the chosen indicators (independent variables). Recall that the regression coefficients (β values) were the assigned weights to each of the indicators involved in the model development (see table 15).

Therefore, the overall HGV index (Composite Index for HGV) for the first dataset with 28 European countries was constructed. As the Poisson model consider 1 and 0 for categorical variables the maximum alcohol limit for professional drivers greater than 0.02g/dl C1=1 and the maximum alcohol limit for professional drivers less than 0.02g/dl C1=0 is considered. The final result is presented after being multiplied by 10^5 for calculation purposes. The CI_{HGV} for Austria (AT)≈0.22 was derived from:

$$\mu = \exp(-13.097 + 0.089A2 + 0.026A3 - 0.008A5 - 0.015B3 - 0.227C1 + 0.144D1 + 0.00043D2 + 0.077D4)$$

$$\mu = \exp(-13.097 + 0.089(0.52) + 0.026(0.59) - 0.008(0.75) - 0.015(1.0) - 0.227(0) + 0.144(0.03) + 0.00043(0.29) + 0.077(0.08))$$

$$\mu * 10^5 = \mathbf{CI_{HGVs(AT)}} \approx \mathbf{0.22}$$

In the same way, the CI_{HGVs} for all countries are summarized in table 16.

Table 15: Assigned weights and coefficients of the indicators based on different methods

Indicators		Weighting Method 1 (Dataset 1)	Weighting Method 1 (Dataset 2)	Coefficients Method 2 (Dataset 1)
Fatalities in HGV crashes/million inhabitants	A1	1/15	1/17	-
Fatalities in HGV crashes/10,000 HGVs	A2	1/15	1/17	0.089
Share of fatalities in HGV crashes/ total fatalities	A3	1/15	1/17	0.026
Share of VRU fatality in HGV crashes	A4	1/15	1/17	-
Share of fatalities in HGV crashes on urban road	A5	1/15	1/17	-0.008
Share of fatalities in HGV crashes on Motorway	A6	1/15	1/17	-
Share of observed speeds of HGVs higher than the speed limit on 50 km/h urban roads	B1	-	1/17	-
Share of observed speeds of HGVs higher than the speed limit rural non-motorway roads	B2	-	1/17	-
Average Frequency of Rest Stops with facilities	B3	1/15	1/17	-0.015
Share of HGV under 5 years/HGV vehicle fleet	B4	1/15	1/17	-
Maximum blood alcohol concentration	C1	1/15	1/17	-0.227
Permissible Maximum Weights	C2	1/15	1/17	-
Share of HGV out of total vehicle fleet	D1	1/15	1/17	0.144
Road Network density (km per 100 sq. km)	D2	1/15	1/17	0.00043
Goods transport by road (per billion tkm)	D3	1/15	1/17	-
Trucks per unit of GDP	D4	1/15	1/17	0.077
Share of employment of road freight transport/popn	D5	1/15	1/17	-

4.4 HGV index scores and country ranking

Using two types of the datasets - one is composed of 28 European countries and 15 selected indicators, and the other consists of 9 European countries and 17 selected indicators – linear, geometric aggregations and Poisson regression analysis are applied respectively to obtain the overall HGV index scores for each country. Countries were then ranked based on these index scores. The countries are ranked in accordance with a higher index in the Poisson regression model indicating the worst performance, whereas a higher index in the linear and geometric aggregation technique indicates better performance, and vice versa. The results are presented in Table 16.

Table 16: Country ranking by different weighting and aggregation methods (28 countries)

ISO Code	EW linear aggregation		EW geometric aggregation		Poisson regression model	
	CI_{HGV} score	Rank	CI_{HGV} score	Rank	CI_{HGV} score	Rank
LT	0.78	1	0.61	1	0.26	24
EE	0.74	2	0.50	5	0.26	25
RO	0.73	3	0.48	6	0.27	28
SK	0.71	4	0.54	2	0.25	22
PL	0.71	5	0.53	3	0.27	27
SI	0.70	6	0.03	26	0.24	16
EL	0.69	7	0.11	19	0.26	26
CH	0.69	8	0.03	25	0.23	14
AT	0.69	9	0.41	14	0.22	9
LU	0.69	10	0.11	20	0.24	20
NO	0.68	11	0.44	11	0.24	17
PT	0.68	12	0.12	18	0.24	21
HU	0.68	13	0.50	4	0.22	11
SE	0.67	14	0.44	10	0.22	10
DE	0.66	15	0.41	15	0.22	12
IT	0.65	16	0.45	8	0.23	15
BE	0.64	17	0.45	9	0.23	13
HR	0.64	18	0.41	16	0.24	19
CY	0.64	19	0.01	28	0.25	23
FR	0.62	20	0.43	12	0.18	2
UK	0.59	21	0.43	13	0.18	4
CZ	0.59	22	0.46	7	0.24	18
ES	0.58	23	0.11	21	0.19	8
FI	0.57	24	0.09	24	0.19	7
DK	0.57	25	0.37	17	0.17	1
IE	0.55	26	0.09	23	0.18	5
NL	0.52	27	0.10	22	0.18	3
LV	0.51	28	0.02	27	0.18	6

Note: Due to the score values' approximation to two decimals, two or more score values appear to be identical, even though they are not.

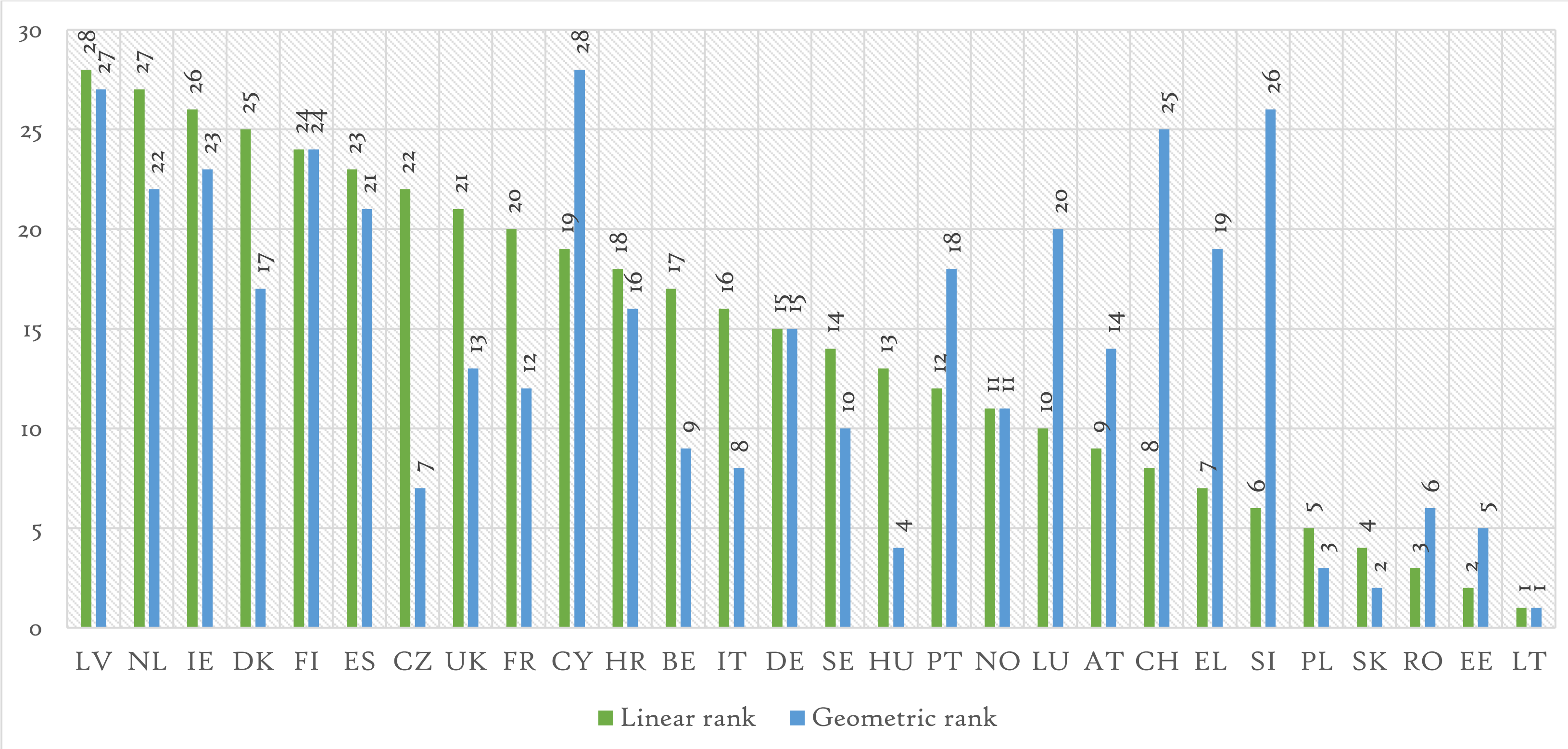

Figure 12: Country ranking by EW linear and geometric aggregation (28 countries)

A quick glance at the results reveals a notable distinction between the chosen European countries. From the generated results shown in figure 12, it can be seen that Lithuania ranked 1st in both linear and geometric ranking while Estonia ranked 2nd with linear and 5th with geometric ranking; this shows that these two countries have the best performance overall. On the other end of the ranking Latvia ranked 28th with linear and 27th with geometric ranking, preceded by Netherlands 27th in linear ranking and 22nd in geometric ranking. In addition, it can be seen that four countries (FI, DE, NO, LT) have the same ranking in both aggregation while most countries show minor decrease or increase in ranking. In case of countries such as (SI, CH, CZ, EL, LU) the change from linear to geometric aggregation ranking is high. The difference in the results is mainly due to the effect of indicator values close to zero. For example, in case of SI there are 2 close to zero indicator values (A6, B3) that affect the geometric value reducing the ranking from 6 to 26, also the impact of numbers close to zero can be seen in CY (the data contain

3 close to zero indicator values) where it end up 28th in the geometric aggregation ranking. Also the effect of having numbers that are not close to zero can be seen in CZ where the ranking has increased from 22nd in linear to 7th in geometric aggregation ranking.

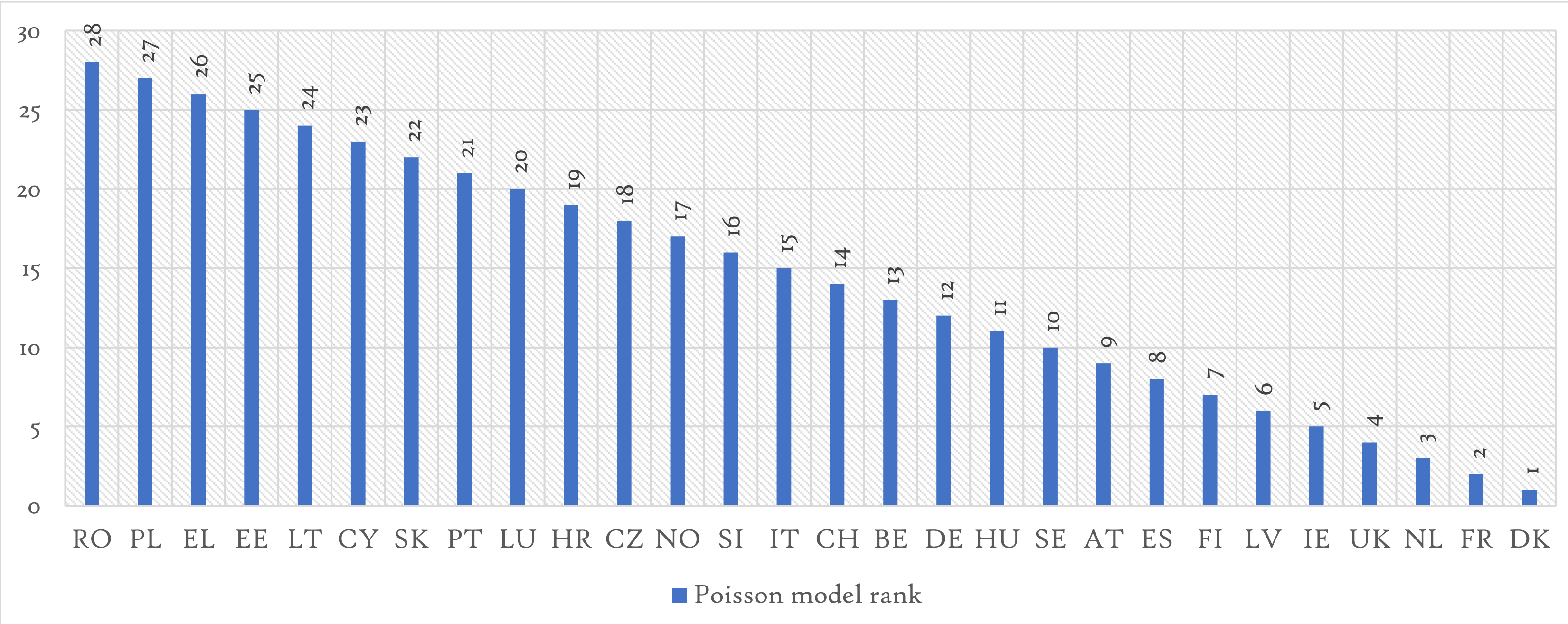

Figure 13: Country rankings by Poisson regression analysis (28 countries)

The poison regression model shows a wide difference with the two extremes of the countries. Romania preceded by Poland are the worst performers in the Poisson regression, they were ranked 3rd and 5th in linear ranking respectively. While Denmark followed by France are found to be best performers with a lower death rate, they were ranked 25th and 20th in linear ranking respectively. The rankings by Poisson regression result are very dissimilar from the others. Even though creating an index based on Poisson regression is useful for combining a number of pertinent indicators into a single model, the final model (table 14 and equation 13) does not consider the entire set of indicators. The model estimated the number of fatalities in HGV crashes per population and was plotted as the dependent variable against 8 indicators (independent variables). Furthermore, as seen in table 15, all the coefficients (weights) obtained were also not between 0 and 1. These reasons add up and can help to explain the ranking differences.

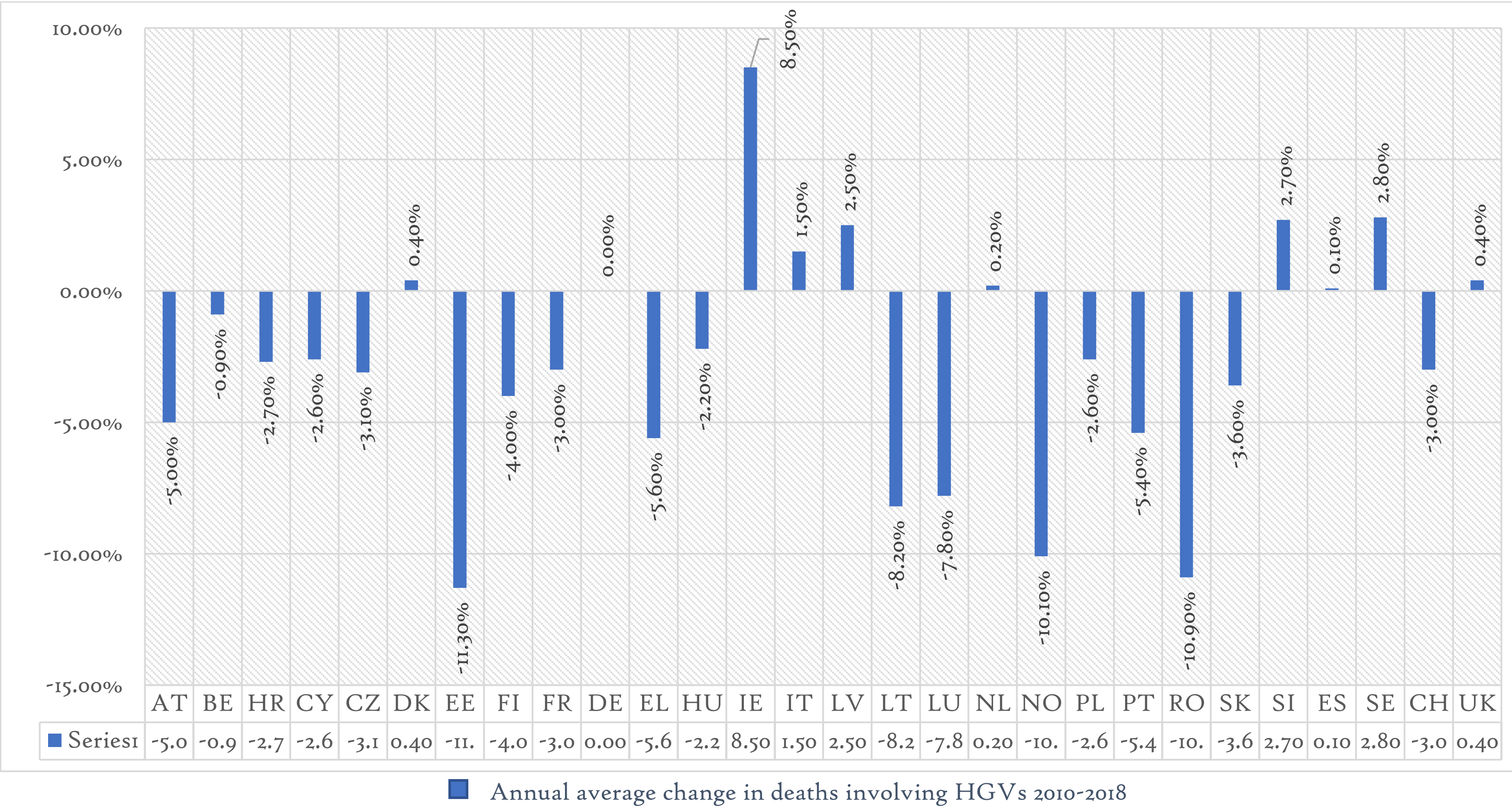

Figure 14: Countries annual average change in deaths involving HGVs 2010-2018 (28 countries)

Most European countries showed a considerable reduction in road fatalities involving HGVs; of these countries Estonia has shown the biggest improvement with 11.3% followed by Romania and Norway with 10.9% and 10.1%. On the other hand some countries showed an increase; of these countries Ireland has shown the largest increase 8.5% followed by Sweden with 2.8%.

In a same manner, after obtaining the CI_{HGV} for the second dataset with 9 European countries ((Austria (AT), Croatia (HR), Cyprus (CY), Finland (FI), France (FR), Ireland (IE), Lithuania (LT), Sweden (SE), and the United Kingdom (UK)) using linear and geometric aggregation, countries were then ranked based on these index scores. The countries are ranked as follows; a higher index in the linear and geometric aggregation technique indicates better performance, and vice versa. The results are presented in Table 17.

Table 17: Country ranking by different aggregation methods (9 countries)

ISO Code	EW linear aggregation		EW geometric aggregation	
	CI_{HGV} score	Rank	CI_{HGV} score	Rank
LT	0.75	1	0.58	1
CY	0.71	2	0.01	8
SE	0.71	3	0.49	2
AT	0.71	4	0.45	4
FR	0.66	5	0.48	3
HR	0.61	6	0.11	6
UK	0.59	7	0.44	5
FI	0.54	8	0.10	7
IE	0.49	9	0.01	9

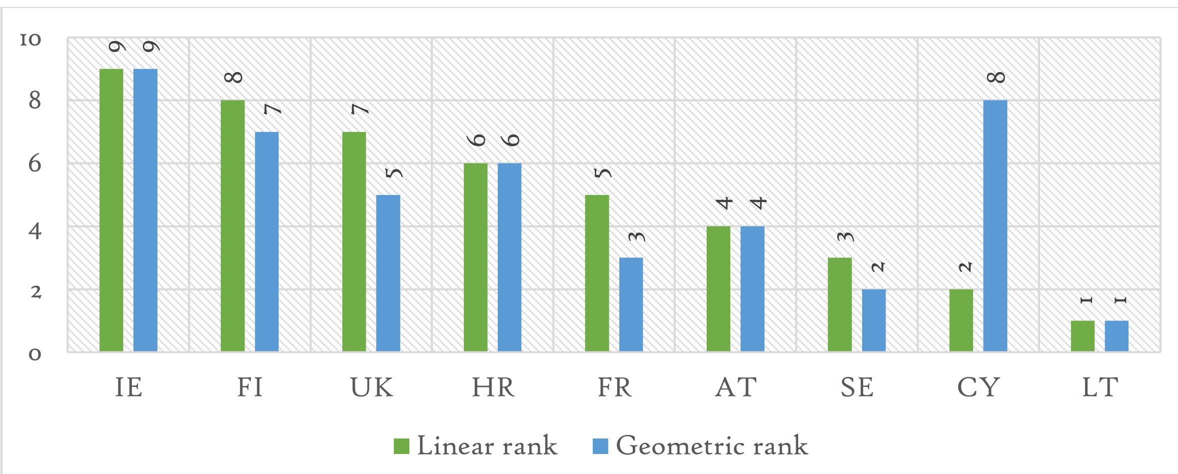

Figure 15: Country ranking by EW linear and geometric aggregation (9 countries)

The above graph generated shows that Lithuania ranked 1st in both linear ranking and Geometric Ranking, suggesting that this country has the best HGV performance; on the other hand Ireland is positioned 9th in both rankings. While Cyprus is ranked 2nd in linear but 8th in geometric aggregation, the result shows extreme result in the two aggregation. The indicator values for Cyprus and Ireland contains 3 close to zero data which has greatly affected the geometric aggregation.

From the data collected between 2010 to 2018 out of the 9 European countries in the graph below, 6 of them showed reduction in deaths involving HGVs. Among these countries Lithuania made the most improvement with a reduction of 8.2 %. On the other hand, Ireland showed an increase in deaths involving HGVs with 8.5%.

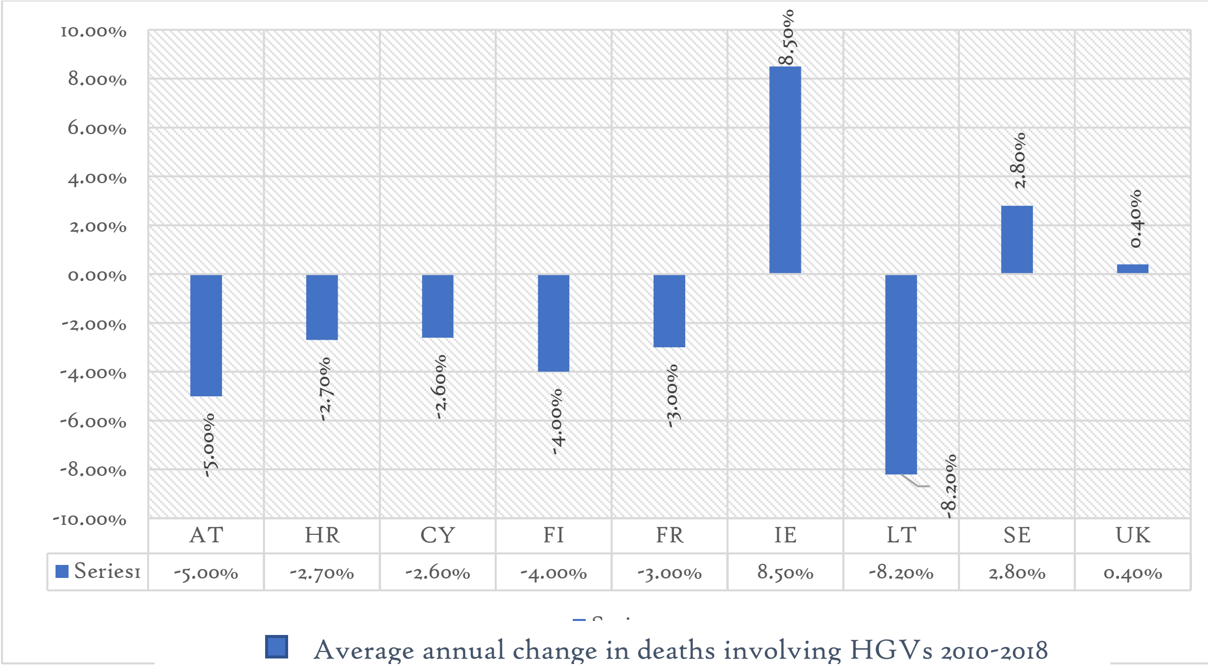

Figure 16: Countries annual average change in deaths involving HGVs 2010-2018 (9 countries)

4.5 Identification of the best-in-class

As presented above, the performance of the selected countries in terms of HGVs safety was ranked and compared using the created three road safety indexes. In addition, to ensure that the rankings are not only based on the year 2018, which may be an untypical year for some countries, the final ranking was used with time-series data for eight years using average annual change in deaths involving HGVs for the period 2010-2018 for all European countries. Therefore, to determine whether the index scores and ranks developed by the three aggregation methods were accurate estimates of each country's progress in deaths involving HGVs for the period 2010-2018, a Spearman's correlation analysis on each ranking and the average annual change in deaths involving HGVs for the period 2010-2018 and other rankings ranking is performed.

Table 18: Spearman's correlation between rankings

			Linear Rank	Geometric Rank	Poisson regression model Rank
Spearman's rho	Geometric Rank	Correl. Coeff.	**0.511****	--	
		Sig. (2-tailed)	0.005		
	Poisson regression model Rank	Correl. Coeff.	**-0.776****	**-0.376***	--
		Sig. (2-tailed)	0.000	0.049	
	Average annual change in deaths involving HGVs 2010-2018 rank	Correl. Coeff.	**0.601****	0.344	**-0.625****
		Sig. (2-tailed)	0.001	0.073	0.000

**. Correlation is significant at the 0.01 level (2-tailed) *. Correlation is significant at the 0.05 level (2-tailed).

The result (table 18) shows that the geometric and linear aggregation rankings are strongly correlated with a coefficient value of 0.511. A negative significant correlation was also observed between the Poisson regression model and the other rankings. Additionally, a positive significant correlation was observed between linear aggregation rankings and average annual change in deaths involving HGVs for the period 2010-2018 ranking with a coefficient value of 0.601, whereas the geometric aggregation resulted in a non-significant correlation coefficient of 0.344. As a result, it was revealed that the linear aggregation ranking provided a more appropriate description of a country's HGV safety performance and can be used to rank per cluster and benchmark countries within the cluster.

In this study, the hierarchical clustering analysis was used to group the 28 countries based on the 4 extracted factors' values with the PCA analysis (see section 4.2.3). As shown in Table 19, the four classes are grouped from the best performers to the least performers by means of the linear aggregation ranking.

Table 19: Classes of countries derived from PCA factors and their ranking (28 countries)

Class per PCA factors	ISO Code	Ranks		
		CI_{HGVs} score	Linear overall Rank	Linear rank per cluster
1	**RO**	**0.73**	**3**	1
	EL	0.69	7	2
	PT	0.68	12	3
	HR	0.64	18	4
	CY	0.64	19	5
2	**CH**	**0.69**	**8**	1
	AT	0.69	9	2
	LU	0.69	10	3
	HU	0.68	13	4
	SE	0.67	14	5
	BE	0.64	17	6
	DK	0.57	25	7
3	**LT**	**0.78**	1	1
	EE	0.74	2	2
	SK	0.71	4	3
	PL	0.71	5	4
	CZ	0.59	22	5
	FI	0.57	24	6
	LV	0.51	28	7
4	**SI**	**0.70**	**6**	1
	NO	0.68	11	2
	DE	0.66	15	3
	IT	0.65	16	4
	FR	0.62	20	5
	UK	0.59	21	6
	ES	0.58	23	7
	IE	0.55	26	8
	NL	0.52	27	9

Linear overall rank	Performance	
1-7	Excellent	
8-14	Good	
15-21	Poor	
21-28	Inadequate	
Best in class		

Table 20: Class of the countries with the respective best-in-class (28 countries)

Class	HGVs safety level	Countries	Best-in-class
1	Excellent	HR, PT, EL, RO, CY	RO
2	Good	LU, CH, AT, SE, BE, DK, HU	CH
3	Poor	FI, LV, EE, PL, CZ, SK, LT	LT
4	Inadequate	IE, ES, IT, FR, UK, NL, DE, SI, NO	SI

It can be seen in Table 19 that the grouping of the countries, obtained from the PCA factors are ranked per cluster and within the cluster using the CI_{HGVs} scores derived from the linear aggregation technique. The best performing cluster is highlighted in green whereas the least performing cluster is highlighted in red. An overall ranking is made in the middle column and each country within the cluster is ranked in the right column, which enables to identify the best-in-class within each class. The final results are further shown in Table 20. In Figure 17 a colored map that visualizes the geographical position distribution of the final classifications of the countries related to HGV safety level, is shown.

As shown in Table 20 and Figure 17, it can be noted that Romania (RO) from class 1, Switzerland (CH) from class 2, Lithuania (LT) from class 3 and Slovenia (SI) from class 4 are identified as the best-in-class in terms of the best performance of HGV safety. In terms of poor performance of HGV safety, Cyprus (CY) from class 1, Denmark (DK) from class 2, Latvia (LV) from class 3, and the Netherlands (NL) from class 4 are found to be the worst performers.

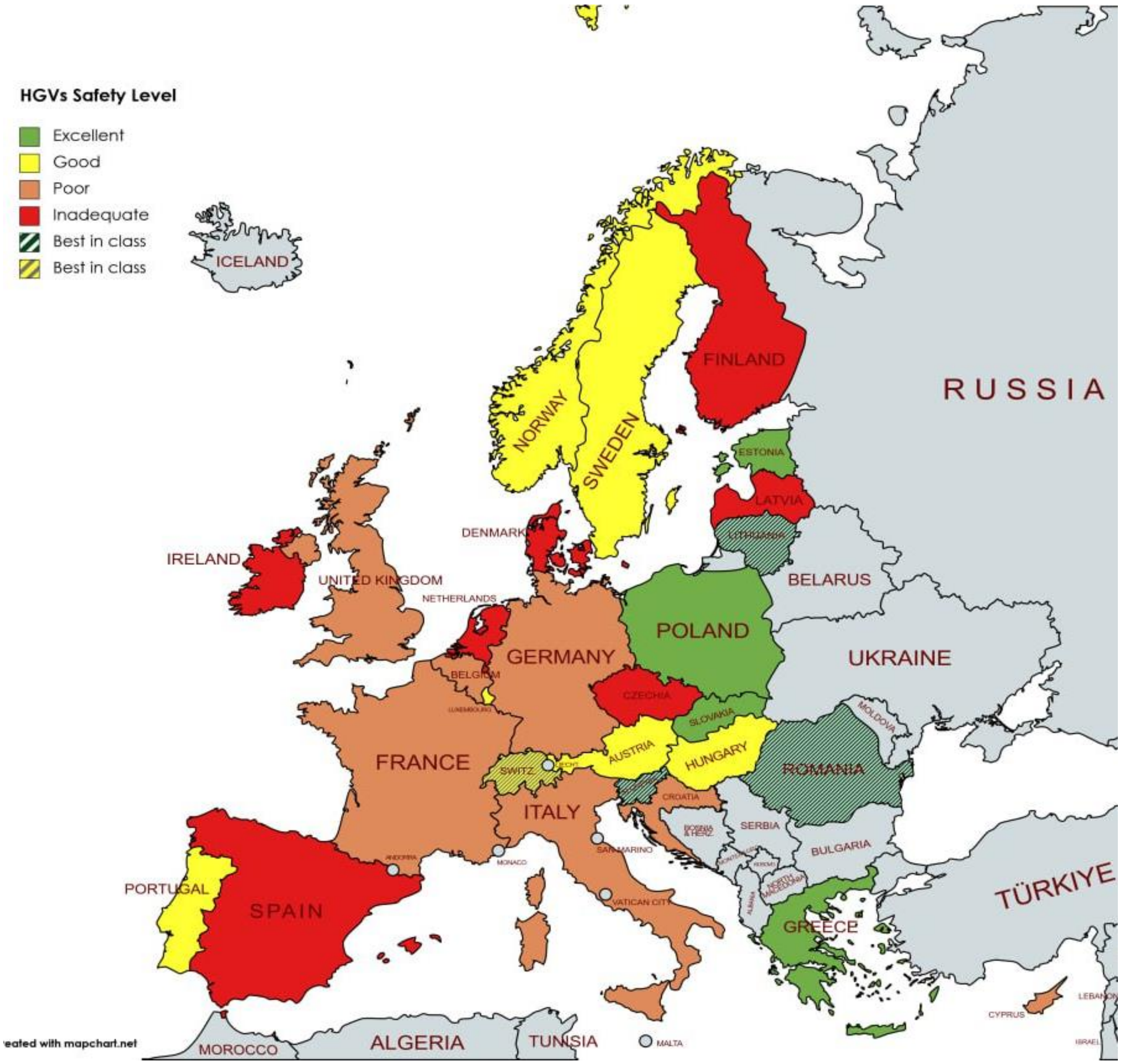

Figure 17: Colored map for the final classification of the countries based on HGVs safety level (28 countries)

In a same manner, the second dataset with 9 European countries, used the linear aggregation score to rank the countries and benchmark within the cluster. Based on the hierarchical clustering analysis used to group the 9 countries based on all selected indicators (see section 4.2.3), two classes were formed and we investigated their performance by means of the average ranking as shown in Table 21.

Table 21: Classes of countries and their ranking (9 countries)

Class	ISO Code	Linear CI_{HGVs} score	Linear Rank	Linear rank per cluster
1	**LT**	**0.75**	1	1
	CY	0.71	2	2
	AT	0.71	4	3
	IE	0.49	9	4
2	**SE**	**0.71**	3	1
	FR	0.66	5	2
	UK	0.59	7	3
3	**HR**	**0.61**	6	1
	FI	0.54	8	2

Linear overall rank	Performance	
1-3	Good	(green)
4-6	Average	(yellow)
7-9	Poor	(red)
Best in class		(hatched)

Table 22: Class of the countries with the respective best-in-class (9 countries)

Class	HGVs safety level	Countries	Best-in-class
1	Good	IE, LT, AT, CY	LT
2	Average	FR, UK, SE	SE
3	Poor	HR, FI	HR

Using the linear aggregation, the countries are ranked per cluster and within the cluster in table 22. The cluster that performed the best is highlighted in green, and the cluster that performed the worst is highlighted in red. To determine the best-in-class within each class, an average ranking is made in the middle column, and each country within the cluster is ranked in the right column. The final results are further shown in Table 22 and Figure 18, make clear that and Lithuania (LT) from class 1, Sweden (SE) from class 2, and Croatia (HR) from class 3 are considered to be the best-in-class. Ireland (IE) from class 1, the United Kingdom (UK) from class 2, and from Finland (FI) from class 3 are found to be the worst performers in terms of HGV safety.

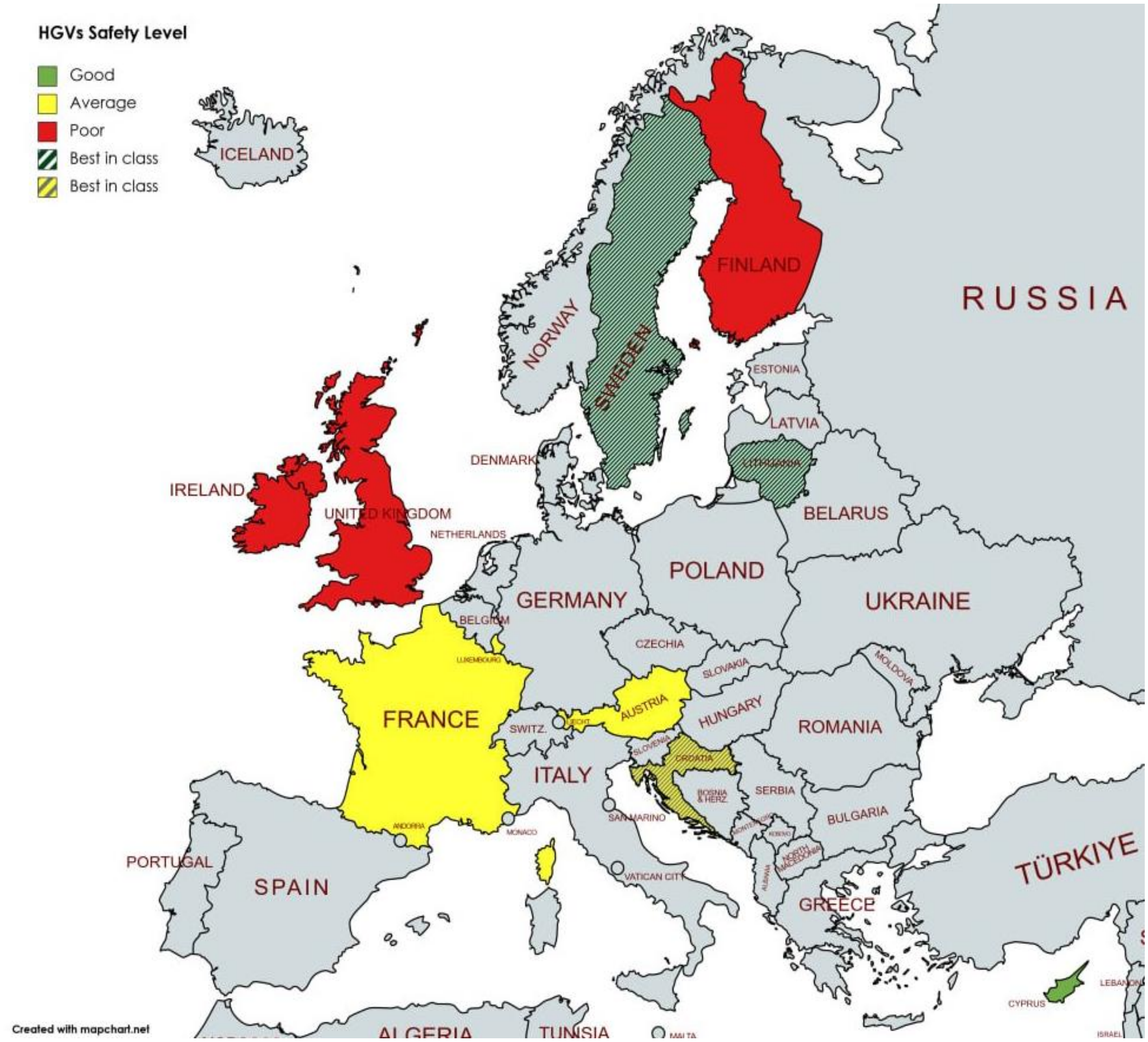

Figure 18: Colored map for the final classification of the countries based on HGVs safety level (9 countries)

CHAPTER FIVE

5. DISCUSSION

5.1 General discussion

This research aims to examine data on HGVs traffic safety performance in selected European countries to assess how well those countries perform relatively in terms of HGV safety using a set of available indicators. The trend of traffic crashes and casualties involving HGVs, the major contributing factors, and the progress of HGV safety in a country were assessed in selected European countries based on data collected from several sources.

Based on the pyramid hierarchy employed in the SUNflower project (Koornstra et al., 2002), this study attempted to develop a composite HGVs index for benchmarking purposes, which combines the four layers of the road safety pyramid (final outcome, safety performance indicators, road safety policy performance, and structure and culture indicators). Similar layers were considered in (Wegman et al., 2008), in the DaCoTA project (Bax et al., 2012), and in the ITF project in Latin American countries (OECD/ITF, 2017).

The current study obtained three types of index scores using EW (linear and geometric) and Poison regression analysis techniques. Similar to other studies (Hermans et al., 2008, Al-haji, 2007, Akaateba, 2012, Hudrliková, 2013), variations were seen in the rankings of the countries obtained using different methods. The result reveals that using geometric aggregation resulted in lower index scores for countries with indicators values close to zero compared to linear aggregation. This finding supports the argument made by Nardo et al. (2005) that countries with poor performance on some sub-indicators would favor a linear rather than a geometric aggregation in a benchmarking exercise.

Additionally, the rankings based on the Poisson regression results differed significantly from the others. This is primarily because, as the correlation analysis revealed, some indicators are interrelated or correlated. The multicollinearity problem was solved using the stepwise selection technique (collinear variables were removed one by one from the model). As a result, when constructing an index based on the final Poisson regression model, not all indicators were taken into account. This supports the argument made by Hermans et al. (2008) that, when selecting a small number of indicators from a larger set of qualified candidates, the indicator that is significant in relation to the dependent variable and has a low correlation coefficient with the other indicators should be preferred. In contrast, a study by Akaateba (2012) used a multiple regression analysis to create a road safety performance index while ignoring multi-collinearity among the various indicators in the development of the model. This was done because the development of the composite index was more interested in the combined effects of all indicators than the individual indicator causal effects in each country.

5.1.1 Progress of countries in reducing death related to HGVs crashes

Based on cross-sectional data for 2018, the aforementioned HGV index scores for each country were determined and ranked. Additionally, a reference ranking was used with time-series data for eight years using the average annual change in deaths involving HGVs for all countries from 2010 to 2018 to ensure that the rankings are not solely based on 2018, which may be an outlier year for some countries.

The current study observed that, deaths in collisions involving HGVs were reduced in 18 countries out of 28 European countries between 2010 and 2018 (Figure 14). The average annual reduction in the number of fatalities involving HGVs was highest (-11%) in Estonia and Romania. This is not the case when comparing reductions in traffic fatalities not involving goods vehicles over 2010–2018 (European Transport Safety Council, 2020), in which Estonia decreased by -3.8% and Romania by -1.7%, respectively. Germany (0.0%), Spain (-0.1%), the UK (-0.4%), and Denmark (-0.4%) made nearly zero progress in lowering the number of fatalities involving HGVs, but these countries saw a slight decreases in their average annual change in fatalities not involving HGVs of -1.9, -3.6, -0.8, and -4.8, respectively. The number of deaths involving HGVs and deaths not involving HGVs stagnated in the Netherlands. On the other hand, the average annual increase in fatalities from collisions involving HGVs was +9.0% in Ireland, +3.0% in Sweden, Slovenia, and Latvia, and +2% in Italy. This finding is also interesting because it differs from the average annual change in deaths not involving goods vehicles (European Transport Safety Council, 2020), which showed significant declines in Ireland, Slovenia, and Latvia (-5.1%, -6.0%, and -5.9%, respectively).

5.1.2 Comparisons of countries' rankings

Spearman's correlation analysis between the rankings and the reference ranking revealed that the linear aggregation ranking provided a more appropriate description of a country's HGV safety performance.

Part one of the HGVs index scores obtained from the linear aggregation was used to rank the grouping of 28 European countries (first dataset) obtained from the PCA factors and countries within the cluster (see table 19). Romania topped class 1 according to the results, with Cyprus placing last. A deep look into the two countries it can be seen that Cyprus has the highest (33%) share of VRU fatalities in HGV crashes (Mean=30.30%) vs Romania's (28%), the share of fatalities in HGV crashes in the urban road is 67% (Mean=26.07%) vs Romania's (51%), and share of fatalities in HGV crashes on motorway is 33% (Mean=18.43%) vs Romania's (2%). A look into the intermediate outcomes, Cyprus has slightly better values than Romania. Along with background characteristics, Cyprus has the lowest value of goods transport by road (per billion tkm) of all countries (which has greatly impact the overall score).

From class 2, Switzerland and Denmark are the best and worst performers. Looking into the raw data, we can observe that Denmark has the worst HGV crashes per million inhabitants at 5.7 (Mean=7.31) to 2.58 of Switzerland, with fatalities in HGV crashes per 10,000 HGV registered vehicles at 7.72 (Mean=5.51) to 3.55 of Switzerland. The share of fatalities in HGV crashes out of the total fatalities is 19.3% (Mean=15.12%) to 9.44% in Switzerland. Switzerland has the worst share of VRU fatality in HGV crashes (50%) of any country in the study, while Denmark has a share of 36%. Denmark performs better than Switzerland in the intermediate outcomes, with a share of HGVs under 5 years which is 45.13% compared to Switzerland's 3.29%. Denmark also exhibits weakness in the policy indicator, with a weak policy of max alcohol limit for professional drivers greater than 0.02g/dl.

Class 3 of table 19 gives us Lithuania and Latvia as the class best and least, and the two countries are the two most extreme in overall performance. Lithuania ranks 1st, while Latvia ranks 28th. Latvia performed weak in the final outcome, with the most notable fatalities in HGV crashes per million inhabitants (20.76) and fatalities in HGV crashes per 10,000 HGV registered vehicles (14.44%), which are two of the maximum data against any country in the study. Similar to Denmark, Latvia also has a weak policy of max alcohol limit for professional drivers, which is greater than 0.02g/dl. On top of this, Lithuania outperforms all other countries in the study in the background characteristics, with the highest percentage of heavy goods vehicles (HGV) in the total fleet (4.85%) and the second-highest percentage of people employed in road freight transport (2.94%).

Finally, Slovenia and the Netherlands are placed in the two extremes of class 4, with Slovenia toping the class. The major difference between the two in the final outcome is share of VRU fatality in HGV crashes (29% in the case of the Netherlands to 19% in Slovenia). Furthermore, the Netherlands does not typically have as many rests stops with facilities for truck drivers. With the maximum alcohol limit for professional drivers being greater than 0.02g/dl and the permitted maximum weights of lorries being greater than 44 tons, the Netherlands has received a lower score in terms of both policy indicators, which lower the overall calculation.

Part two of the composite index's construction process was performed with the additional intermediate outcome indicators of the share of observed HGV speeds higher than the speed limit on urban roads (B1) and motorways (B2). The results of this dataset are very helpful in highlighting the effects of B1 and B2 and showing the safety level of HGVs across the nine European countries (second dataset). Using the linear aggregation index scores, the countries are ranked per cluster (Table 21). Among the nine countries, Ireland has the highest proportion of HGV drivers driving excessively in urban roads (64%) and on motorways (78%). On the other hand, Lithuania has excessive driving of 26% in urban and 65% on the motorway, which is one of the reasons Lithuania is ranked first and Ireland is last from class 1. Additionally, the average frequency of truck driver rest stops in Ireland is zero and 4.5 per 100 km in Lithuania.

When class 2 was investigated, it was discovered that the UK performed poorly in both B1 (46%) and B2 (30%). On the contrary, Sweden has shown a decent figure with the best B1 (17%) of all countries and B2 (28%). Besides that, there are 4.6 truck driver rest stops on average per 100 kilometers in the UK and 11.6 in Sweden, which together with other data contributed to placing the UK last. The last class contains only two countries, with Croatia outperforming Finland in the ranking. The two countries show somehow a balanced performance where Finland out-perform Croatia in B1 with 55% to 64% while Croatia has B2 better with 22% to 53%. The most important finding was that all low-performing countries (Finland, Ireland, and the United Kingdom) have weak policies regarding the maximum alcohol limit for professional drivers, which is greater than 0.02g/dl.

The above findings support the idea that having rest areas with facilities for truck drivers improves how well countries oversee the wellbeing of HGV drivers. This is due to research analysis showing that fatigued driving contributes to 20% of commercial vehicle collisions on roads (European Transport Safety Council, 2011) and that professional drivers are at an increased risk of driving while extremely fatigued during the day (72%) (Zhang & Chan, 2014). The result that countries with a higher share of HGVs under 5 years perform well aligns with the argument made by Hakkert et al. (2007) that newer vehicles are more likely to have modern safety technology installed and are also more likely to have been structurally designed to be more crashworthy in the event of a crash.

The result can as well add to Lira and colleagues (2020) countries with more restrictive alcohol policies tend to have reduced odds of lower BAC crashes than countries with weaker policies. There are a variety of conditions that contribute to overloading in EU countries (Znidaric, 2015). One of which could be the fact that different countries have different permitted maximum weights for lorries. According to Znidaric (2015), overloading is usually low in countries with tight enforcement regulations, causing more serious problems in countries where overload enforcement is rare. Finally, the results of the second dataset showed that a lot of observed HGV speeds above the speed limit on highways and urban roads contributed to the poor performance of countries. According to the European Transport Safety Council (2020), a high percentage of drivers in all EU nations exceed the posted speed limit.

Based on the aforementioned findings, it is clear that this study successfully examined the already available data and provided insightful information about each country's HGV safety situation and comparison. Similar to previous research findings (e.g., Wegman et al., 2008; Hermans et al., 2008; Al-haji, 2007; Akaateba, 2012), the results reveal that the rankings of countries based on composite indicators are not always the same as the traditional rankings based solely on death or fatality rates. Furthermore, by including data on intermediate outcome and policy performance indicators, the ranking and grouping process enhances the results and makes them more understandable and meaningful.

5.2 Limitations and future research

For the sake of making the study manageable, this study has been limited in scope, time, and coverage areas. Hence, the study focused on 28 European countries (25 EU Member States plus Norway, Switzerland, and the United Kingdom). Besides a spatial boundary, the data set used in this study is limited in time. The composite HGV index was only computed for one year because there isn't data available for all indicators over time.

This study found a major problem with data accessibility, or more specifically, a dearth of comparable road safety indicators for HGV data. The challenge of gathering all necessary data from a single source or database was a major data source limitation. The studies mentioned in the previous section of this study are the main source of HGV indicators estimates and/or data were collected from databases of European countries, international databases, and several recent publications of international working groups (such as OECD/ITF, EC, IRF, ERF, PIN, and ETSC). These sources are not consistent, despite the fact that they do share some information. For example, data for a specific year may be available in one database or publication but not in another. Generally speaking, care must be taken when combining information from different sources because they might each use a different definition for the same indicator.

Missing data was another challenge that appeared while conducting this study. There has been an ongoing need for high-quality, comparable data for the involved countries throughout the study period. However, some countries lack some essential data, particularly in terms of intermediate outcomes (see section 4.1). The missing values were imputed using SPSS software. This might skew the results and the country's performance.

The small sample size for the second dataset having 17 indicators and 9 European countries, prevented some statistical analysis of interesting variables (Poisson regression analysis). Even if these steps were missing, this dataset still added value by demonstrating the level of HGV safety across the nine countries and emphasizing the impact of two additional intermediate outcome indicators, the share of observed speeds of HGVs exceeding the speed limit on urban roads (B1) and motorways (B2).

However, every effort was made to get past the aforementioned challenges and successfully finish the intended work. The time frame for this study and a number of methodological decisions (relating to indicator selection, weighting method, aggregation operator, etc.) that could affect the final rankings of the countries are additional limitations. Therefore, it is highly recommended that future research broaden the types of data it collects and considers various methodologies at each stage. Additionally, conducting uncertainty and sensitivity analyses is an essential step in the index process because it demonstrates the indicator's reliability.

5.3 Recommendation and Practical implications

Despite the lack of comparable data on road safety indicators for HGVs in selected countries, this study tried to present a complete picture of the safety situation for HGVs in Europe. This study examined the available data on road traffic crashes involving HGVs in selected European countries to assess the HGVs safety performance in selected countries based on a set of indicators and to benchmark their performance and identify the best performers.

According to Al-haji (2007), as data availability increases, data quality will also increase. In other words, reliable indicators are generated when data are accessible. The most recent data on HGV indicators estimates and/or data were collected from databases of European countries, international databases, and several recent publications of international working groups (such as OECD/ITF, EC, IRF, ERF, PIN, and ETSC). This study amply demonstrated the relevance of HGV indicators and need for improved data collection and analysis in order to create a strong foundation for road safety policymaking. This should be done uniformly, and it is advised that publications of international working groups play a crucial role, as not all countries and international databases are accessible to everyone. The trend of traffic crashes and casualties involving HGVs, the major contributing factors, and the progress of HGV safety in a country or region should be published annually or on a regular basis. Therefore, it is necessary to develop a common data collection methodology across countries, and the data collection portals should be updated and accessible year after year. According to the literature review of the contributing factors and risk domains, the HGV-related indicators crucial in future safety monitoring programs are proposed in Appendix 7.

General Recommendations for improvement of HGVs safety performance

As stated at the start of this study, every flourishing and expanding economy needs an integrated, multimodal freight transportation system, which must be supported to offer sustainable and safe freight transportation. There are several policy recommendations that have been proposed to improve the safety of HGVs. On the basis of the findings of the study and literature review, the following general recommendations are drawn that will greatly increase HGV safety in Europe:

- Encourage safer driving among HGV drivers by putting rewards for safe driving and penalties for unsafe driving into place. Some safe driving behaviors that should be encouraged among HGV drivers include:
    - Following the posted speed limits and traffic laws,
    - Maintaining a safe following distance from other vehicles,
    - Avoiding distractions, such as using a cell phone or eating while driving,
    - Driving while not impaired by alcohol or drugs,
    - Properly maintaining the vehicle, including brakes, tires, and lights check,
    - Taking regular breaks to avoid fatigue,
    - Planning the route and schedule to avoid rush hours and heavy traffic,

  - Respect the permissible weight and adequately secure the load.
- Provide driver-friendly rest stops for HGV drivers,
- Improving HGV vehicle safety requirements, such as:
  - Require a high level of performance of Intelligent Speed Assistance (ISA) systems to be fitted in all new HGVs,
  - Mandate Autonomous Emergency Braking (AEB) systems with a pedestrian, and cyclist detection for all new HGVs,
  - Making Anti-lock Braking Systems (ABS) and Electronic Stability Control (ESC) mandatory,
  - Mandate alcohol interlocks for vehicles driven by professional drivers,
  - Insist on the highest achievable vehicle regulation standards with regard to blind spot detection systems and direct vision,
  - Implementing collision warning and lane departure warning systems to alert HGV drivers to potential hazards.
- Encourage employers through financial incentives (such as tax breaks) to fit and purchase HGVs with in-vehicle technologies that have a high life-saving potential,
- Promote the uptake of speed management technology amongst goods vehicle fleets,
- Strict enforcement of traffic laws and regulations on the compliance of speed limits, seatbelt usage, BAC, loading weight and resting time.
- Providing more comprehensive and mandatory training for HGV drivers to develop the skills and knowledge needed to operate these vehicles safely,

Recommendations to Cities

- Consider imposing access restrictions for HGVs to protect VRUs (e.g., HGVs ban at the beginning and end of school day),
- Implement logistics strategies for urban areas that restrict loading and unloading to times when there are many VRUs on the road,
- Provide sufficient parking spaces for loading and unloading.

Lastly, researching relevant risk domains, indicators related to HGVs, weighting, aggregation, ranking, and benchmarking has to gain attention. This will be helpful with the challenge of comparing HGVs safety performance across international borders, and enable a sufficient understanding of the processes that cause HGVs involved road crashes. Additional research may be necessary to reach precise conclusions about how to proceed and the areas that probably require more investigation. An in-depth analysis of the weaknesses and strengths of each country and the identifying regions will also serve as a resource for knowledge- and data-driven policymaking, guiding decision-makers in developing appropriate policies and strategies based on the problems with HGV safety. This study is crucial and could be a starting point for developing the HGV safety index for researchers, transport experts, and transportation policymakers.

CHAPTER SIX

6. CONCLUSION

In this study, Vehicles with a maximum permitted gross weight of over 3,5 tons are referred to as heavy goods vehicles (HGVs). This study examined the available data on road traffic crashes involving HGVs in selected European countries to assess the HGVs safety performance in selected countries based on a set of indicators and to benchmark their performance and identify the best performers.

This study discovered that, between 2010 and 2018, the number of fatalities in collisions involving HGVs decreased in 18 of the 28 European countries. Estonia and Romania had experienced the biggest average annual declines, while Germany, Spain, the UK, Denmark, and the Netherlands had stagnated or made hardly any progress. The average annual increase in fatalities from HGVs, however, was highest in Ireland, followed by Sweden. When comparing decreases in traffic fatalities not involving goods vehicles over the period 2010-2018, the study further confirmed that these trends are different. It is also worth mentioning that when an HGV is involved in a crash, the consequences can be severe due to the weight and size of these vehicles.

HGVs can be involved in crashes for a variety of reasons, including driver error, mechanical failures, and poor road conditions. In this study, eight risk domains (problem areas) were explored for the development of HGVs safety performance indicators. These are seatbelts, speed, alcohol and drugs, driver distraction, driver fatigue, vehicle-related indicators, permissible maximum weights, and post-impact care. Potential indicators are suggested for each of these areas using a limited set of safety performance indicators connected to HGVs with an aim toward future collaborative analysis, target setting, and benchmarking.

This study obtained three types of index scores using EW (linear and geometric) and Poison regression analysis techniques. Using two datasets and the linear aggregation ranking, the "best-in-class" was determined using groups of countries with comparable levels of HGV safety performance. The study's results showed that the investigated countries' HGVs performed differently regarding safety. As a result of the first dataset, Slovenia (SI), Lithuania (LT), Switzerland (CH), and Romania (RO) were recognized as the top performers in terms of HGV safety. Lithuania (LT), Sweden (SE), and Croatia (HR) were regarded as the top performers from the second dataset. The study's conclusions confirmed differences in how well HGVs perform in terms of safety between the countries under investigation and made an effort to pinpoint why. In light of this, benchmarking HGV safety performance results in recommendations that support best practices, encourage the adoption of effective HGV safety strategies and measures, and, more importantly, inspire researchers, transportation experts, and transportation policymakers with regard to the idea of developing the HGV safety index.

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APPENDICES

Appendix 1: The selected European countries and their ISO codes (Eurostat, 2022b)

ISO Code	Country
AT	Austria
BE	Belgium
HR	Croatia
CY	Cyprus
CZ	Czech Republic
DK	Denmark
EE	Estonia
FI	Finland
FR	France
DE	Germany
EL	Greece
HU	Hungary
IE	Ireland
IT	Italy
LV	Latvia
LT	Lithuania
LU	Luxembourg
NL	Netherlands
NO	Norway
PL	Poland
PT	Portugal
RO	Romania
SK	Slovakia
SI	Slovenia
ES	Spain
SE	Sweden
CH	Switzerland
UK	United Kingdom

Appendix 2a: The values of the Final Outcome indicators (See sources in section 3.2)

ISO Code	Final Outcomes					
	Fatalities in HGV crashes per million inhabitants (2018)	Fatalities in HGV crashes per 10,000 HGV registered vehicles (2018)	Share of fatalities in HGV crashes out of the total fatalities (2018)	Share of VRU fatality in HGV crashes (2016-2018)	Share of fatalities in HGV crashes on urban road (2016-2018)	Share of fatalities in HGV crashes on Motorway (2016-2018)
	A1	A2	A3	A4	A5	A6
AT	6.33	7.73	13.69%	32%	22%	26%
BE	9.71	7.60	18.38%	32%	23%	38%
HR	6.12	5.47	7.89%	29%	31%	20%
CY	1.68	1.60	4.08%	33%	67%	33%
CZ	11.76	6.67	19.05%	25%	22%	15%
DK	5.70	7.72	19.30%	36%	29%	14%
EE	8.32	2.87	16.42%	37%	29%	0%
FI	11.97	6.86	27.62%	15%	8%	4%
FR	6.62	7.87	13.68%	27%	19%	21%
DE	7.26	6.36	18.38%	29%	23%	35%
EL	6.71	3.13	10.29%	37%	32%	20%
HU	11.97	12.32	18.48%	26%	16%	17%
IE	4.73	4.31	16.20%	29%	27%	9%
IT	5.76	3.85	10.44%	24%	16%	38%
LV	20.76	14.44	27.03%	36%	18%	0%
LT	8.57	3.64	13.87%	32%	27%	5%
LU	3.29	1.66	5.56%	40%	40%	30%
NL	5.11	5.22	14.72%	29%	25%	32%
NO	4.89	3.04	24.07%	19%	7%	1%
PL	13.09	4.48	17.37%	30%	30%	6%
PT	6.22	4.92	9.09%	32%	43%	14%
RO	3.75	2.36	3.91%	28%	51%	2%
SK	6.61	4.22	13.85%	n/a	16%	9%
SI	8.68	5.02	19.78%	19%	8%	52%
ES	6.05	4.99	15.67%	26%	11%	32%
SE	6.68	8.10	20.99%	24%	20%	17%
CH	2.58	3.55	9.44%	50%	42%	14%
UK	3.91	4.29	14.14%	42%	28%	12%

Appendix 2b: The values of the Intermediate Outcome indicators (See sources in section 3.2)

ISO Code	Intermediate Outcomes			
	Share of observed speeds of HGVs higher than the speed limit on 50 km/h urban roads (2018)	Share of observed speeds of HGVs higher than the speed limit rural non-motorway roads (2018)	Average Frequency of Rest Stops with facilities for Truck Drivers (No. per 100 km)	Share of HGV under 5 years out of HGV vehicle fleet, in (2018)
	B1	B2	B3	B4
AT	25%	24%	15.90	60.30%
BE	n/a	n/a	7.40	30.00%
HR	64%	22%	n/a	17.46%
CY	26%	17%	n/a	n/a
CZ	n/a	n/a	n/a	27.07%
DK	n/a	n/a	9.80	45.13%
EE	n/a	n/a	11.50	12.69%
FI	n/a	53%	2.00	17.26%
FR	25%	23%	n/a	39.45%
DE	n/a	n/a	1.00	45.82%
EL	n/a	n/a	n/a	0.80%
HU	n/a	n/a	14.00	27.62%
IE	64%	78%	0.00	23.86%
IT	n/a	n/a	4.00	12.94%
LV	n/a	n/a	n/a	24.04%
LT	26%	65%	4.50	35.61%
LU	n/a	n/a	6.70	52.01%
NL	n/a	n/a	0.00	39.73%
NO	n/a	n/a	1.30	34.73%
PL	n/a	n/a	4.50	12.41%
PT	n/a	n/a	n/a	17.92%
RO	n/a	n/a	n/a	11.42%
SK	n/a	n/a	n/a	29.01%
SI	n/a	n/a	0.00	54.18%
ES	n/a	n/a	0.00	22.80%
SE	17%	n/a	11.60	n/a
CH	n/a	n/a	6.50	33.29%
UK	46%	30%	4.60	40.65%

Appendix 2c: The values of the Policy Performance indicators (See sources in section 3.2)

ISO Code	Policy performance indicator		
	Maximum blood alcohol concentration - Professional drivers, in g/l (2015)	Permissible Maximum Weights of Lorries in Europe (in tonnes)	Heavy goods vehicles standard speeds limits in urban roads (2015)
	C1	C2	C3
AT	0.1 ‰	40	50 km/h
BE	0.2 ‰	44	50 km/h , 20 km/h in residential areas. 30 km/h near schools and in streets with cycle paths
HR	0 ‰	40	50 km/h
CY	0.2 ‰	40	50 km/h
CZ	0 ‰	48	50 km/h
DK	0.5 ‰	44	50 km/h
EE	0.2 ‰	40	50 km/h
FI	0.5 ‰	44	50 km/h
FR	0,5 ‰ (For bus and coach drivers the limit is 0.2 ‰)	40 (44)	50 km/h
DE	0,0 ‰ offenders can be sacked	40	50 km/h
EL	0.2 ‰	40 (42)	50 km/h
HU	0 ‰	40 (42)	50 km/h
IE	0.5 ‰	44	50 km/h
IT	0 ‰	44	50 km/h
LV	0.5 ‰	40	50 km/h
LT	0,0 ‰ vehicles weighing more than 3.5 tons	40	50 km/h
LU	0.2 ‰	44	50 km/h
NL	0.5 ‰	50	50 km/h
NO	0.2 ‰	46-50	50 km/h
PL	<0.2 ‰	40	50 km/h (5 a.m. – 11 p.m.) 60 km/h (11 p.m. – 5 a.m.)
PT	0.2 ‰	44	50 km/h
RO	0 ‰	40 (42)	50 km/h
SK	0 ‰	40	50 km/h
SI	0 ‰	40 (44)	50 km/h, 30 km/h – in speed limit zones, 10 km/h – in pedestrian zones where traffic is allowed
ES	0.3 ‰	42 (44)	50 km/h
SE	0,2 ‰	44	50 km/h
CH	0,1 ‰	40	50 km/h
UK	0,8 ‰, 0,5 ‰ in Scotland	40 (44)	48 km/h

Appendix 2d: The values of the Background Characteristics indicators (See sources in section 3.2)

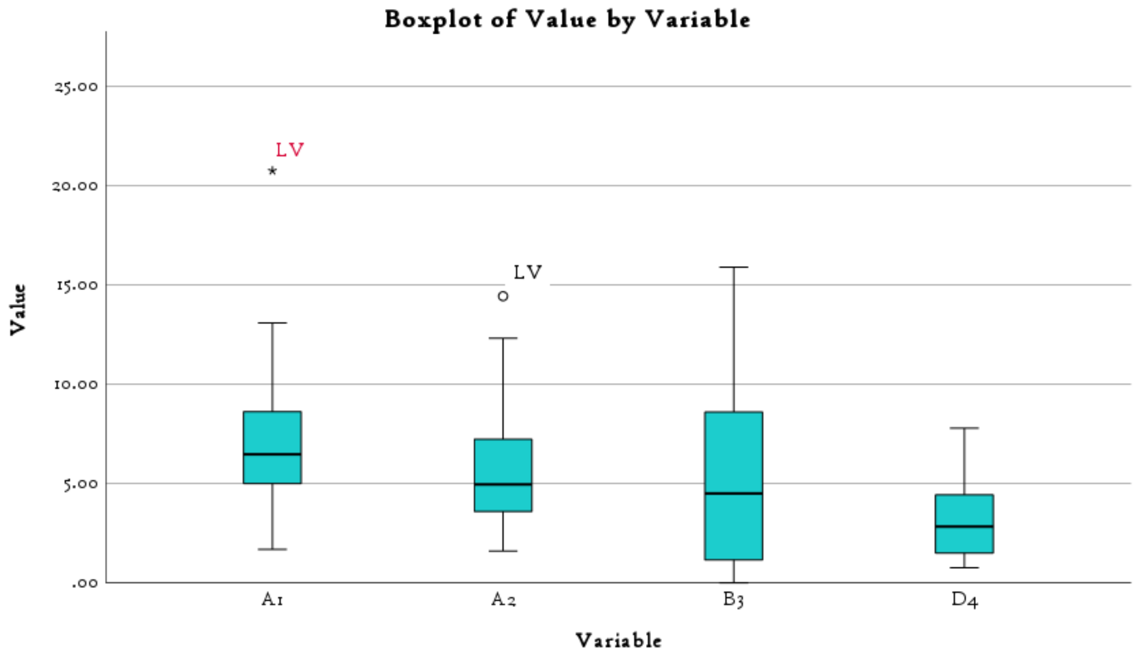
ISO Code	Background Characteristics				
	Share of HGV (over 3.5 tons) out of total vehicle fleet, (2018)	Road Network density (km per 100 sq. km)(2018)	Goods transport by road (per billion tkm) (2018)	Trucks per unit of GDP 2017	Share of employment of road freight transport out of total population, 2018
	D1	D2	D3	D4	D5
AT	1.32%	158.01	25.8	1.29	0.70%
BE	2.18%	510.5 [1]	32.7	2.02	0.55%
HR	2.47%	47.16	12.6	3.43	0.56%
CY	1.88%	110	0.9	5.38	0.18%
CZ	2.85%	72.22	41.1	3.62	1.24%
DK	1.41%	186.82	15	1.50	0.55%
EE	4.39%	136.10	5.8	4.83	1.23%
FI	3.07%	25.65	28.3	2.68	0.82%
FR	1.25%	199.37	173.3	2.94	0.56%
DE	1.86%	197.4 [2]	316.8	1	0.55%
EL	3.64%	90	29.3	7.46	0.34%
HU	2.26%	233.73	37.9	4.32	0.83%
IE	2.10%	143.60	11.6	1.18	0.50%
IT	2.05%	86.3 [3]	124.9	2.45	0.57%
LV	3.85%	94.13	15	3.22	1.41%
LT	4.85%	136.63	43.6	2.73	2.94%
LU	2.59%	119.92	6.8	0.76	1.28%
NL	1.69%	414.57	68.9	1.39	0.75%
NO	2.57%	25.99	315.9	n/a	n/a
PL	4.06%	138.67	33	7.79	1.21%
PT	2.07%	15.62	58.8	6.82	0.71%
RO	4.11%	37.48	35.6	5.19	0.83%
SK	3.18%	120.07	22.2	3.73	0.93%
SI	2.67%	105.20	239	2.40	1.33%
ES	1.97%	130	43.5	4.43	0.73%
SE	1.52%	52.95	159.1	1.32	0.81%
CH	1.21%	181.06	213.4	n/a	n/a
UK	1.51%	174.88	125	1.94	0.44%

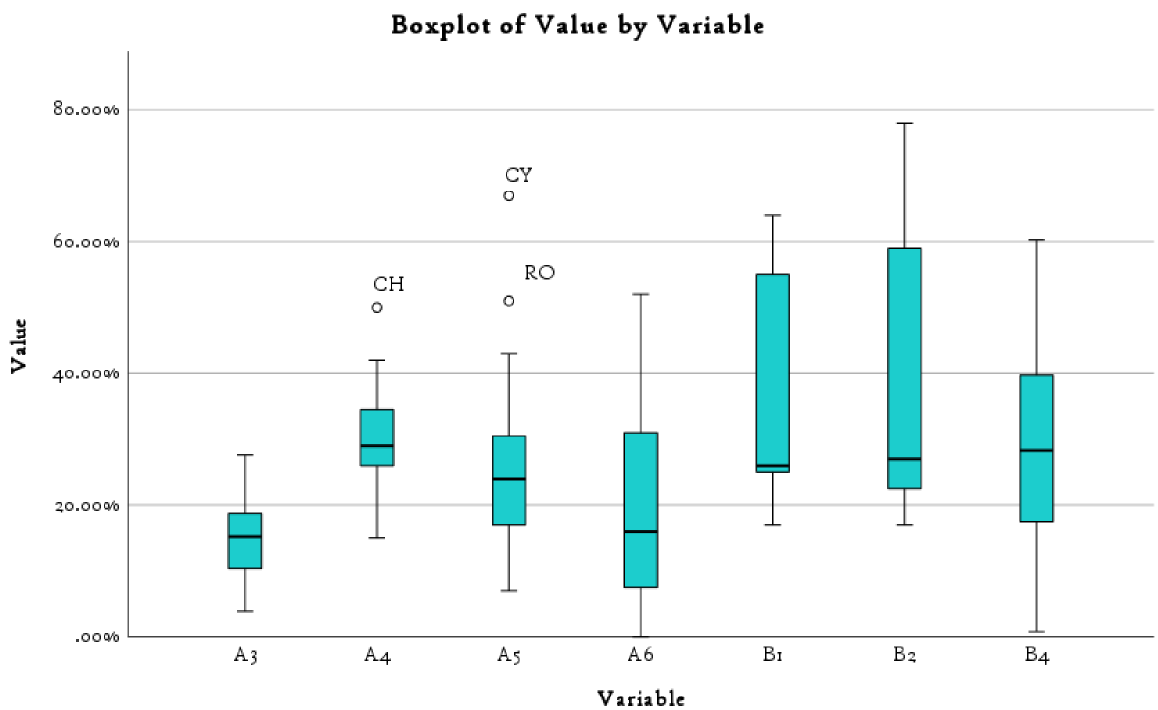
(1) BE end of 2015

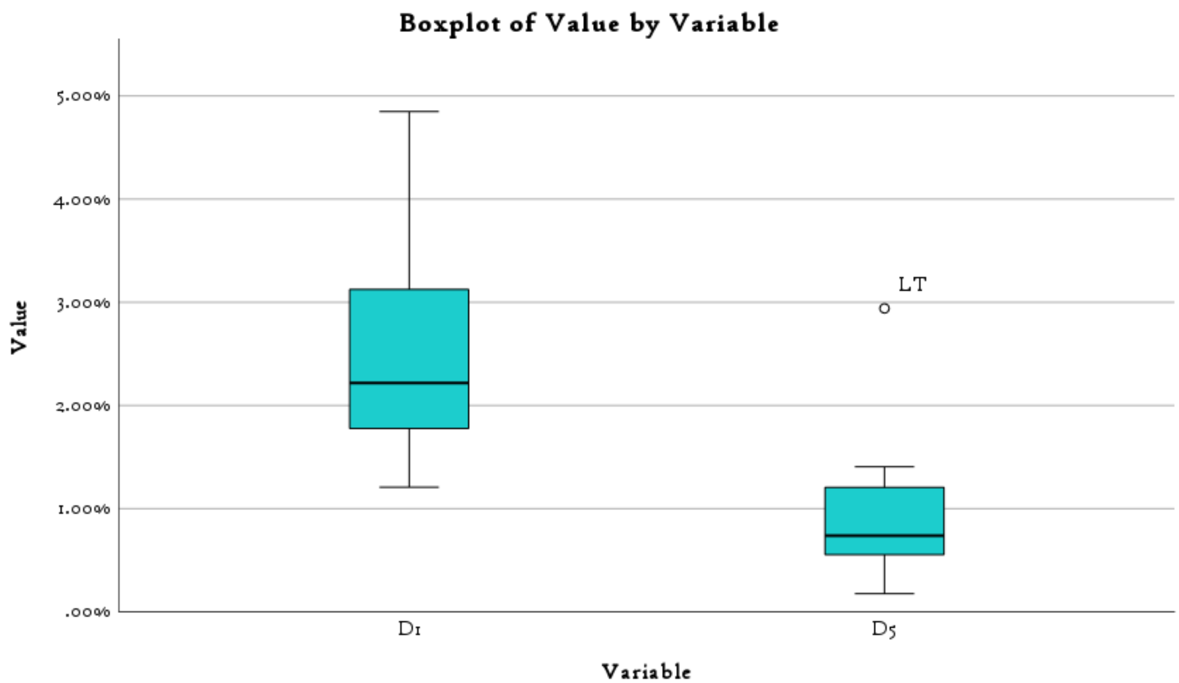
(2) DE end of 2009

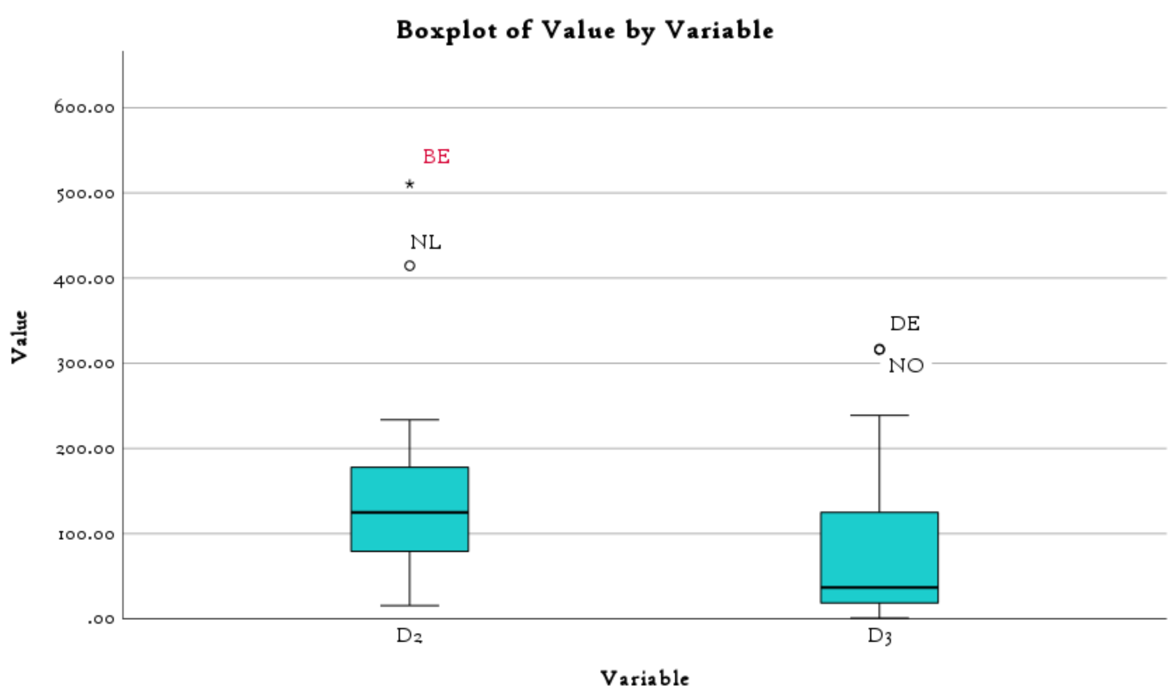
(3) IT end of 2017

Appendix 3: The boxplot of outlier values by variable






Boxplot of Value by Variable
5.00%
4.00%
3.00%
2.00%
1.00%
.00%
Value
LT
D1
D5
Variable


Boxplot of Value by Variable
600.00
500.00
400.00
300.00
200.00
100.00
.00
Value
BE
NL
DE
NO
D2
D3
Variable

Appendix 4a: The normalized indicators (28 European countries)

ISO Code	A1	A2	A3	A4	A5	A6	B3	B4	C1*	C2*	D1	D2	D3	D4	D5
AT	0.76	0.52	0.59	0.51	0.75	0.50	1.00	1.00	2.00	2.00	0.03	0.29	0.08	0.08	0.19
BE	0.58	0.53	0.39	0.51	0.73	0.27	0.47	0.49	2.00	2.00	0.27	1.00	0.10	0.18	0.13
HR	0.77	0.70	0.83	0.60	0.60	0.62	0.29	0.28	2.00	2.00	0.35	0.06	0.04	0.38	0.14
CY	1.00	1.00	0.99	0.49	0.00	0.37	0.43	0.25	2.00	2.00	0.18	0.19	0.00	0.66	0.00
CZ	0.47	0.61	0.36	0.71	0.75	0.71	0.29	0.44	2.00	1.00	0.45	0.11	0.13	0.41	0.38
DK	0.79	0.52	0.35	0.40	0.63	0.73	0.62	0.75	1.00	2.00	0.05	0.35	0.04	0.11	0.14
EE	0.65	0.90	0.47	0.37	0.63	1.00	0.72	0.20	2.00	2.00	0.87	0.24	0.02	0.58	0.38
FI	0.46	0.59	0.00	1.00	0.98	0.92	0.13	0.28	1.00	2.00	0.51	0.02	0.09	0.27	0.23
FR	0.74	0.51	0.59	0.66	0.80	0.60	0.39	0.65	1.00	2.00	0.01	0.37	0.55	0.31	0.14
DE	0.71	0.63	0.39	0.60	0.73	0.33	0.06	0.76	2.00	2.00	0.18	0.37	1.00	0.03	0.13
EL	0.74	0.88	0.73	0.37	0.58	0.62	0.46	0.00	2.00	2.00	0.67	0.15	0.09	0.95	0.06
HU	0.46	0.16	0.39	0.69	0.85	0.67	0.88	0.45	2.00	2.00	0.29	0.44	0.12	0.51	0.24
IE	0.84	0.79	0.48	0.60	0.67	0.83	0.00	0.39	1.00	2.00	0.24	0.26	0.03	0.06	0.12
IT	0.79	0.82	0.72	0.74	0.85	0.27	0.25	0.20	2.00	2.00	0.23	0.14	0.39	0.24	0.14
LV	0.00	0.00	0.02	0.40	0.82	1.00	0.35	0.39	1.00	2.00	0.73	0.16	0.04	0.35	0.44
LT	0.64	0.84	0.58	0.51	0.67	0.90	0.28	0.59	2.00	2.00	1.00	0.24	0.14	0.28	1.00
LU	0.92	1.00	0.93	0.29	0.45	0.42	0.42	0.86	2.00	2.00	0.38	0.21	0.02	0.00	0.40
NL	0.82	0.72	0.54	0.60	0.70	0.38	0.00	0.65	1.00	1.00	0.13	0.81	0.22	0.09	0.21
NO	0.83	0.89	0.15	0.89	1.00	0.98	0.08	0.57	2.00	1.00	0.37	0.02	1.00	0.22	0.27
PL	0.40	0.78	0.43	0.57	0.62	0.88	0.28	0.20	2.00	2.00	0.78	0.25	0.10	1.00	0.37
PT	0.76	0.74	0.78	0.51	0.40	0.73	0.47	0.29	2.00	2.00	0.24	0.00	0.18	0.86	0.19
RO	0.89	0.94	1.00	0.63	0.27	0.96	0.31	0.18	2.00	2.00	0.80	0.04	0.11	0.63	0.23
SK	0.74	0.80	0.58	0.55	0.85	0.83	0.38	0.47	2.00	2.00	0.54	0.21	0.07	0.42	0.27
SI	0.63	0.73	0.33	0.89	0.98	0.00	0.00	0.90	2.00	2.00	0.40	0.18	0.75	0.23	0.42
ES	0.77	0.74	0.50	0.69	0.93	0.38	0.00	0.37	1.00	2.00	0.21	0.23	0.13	0.52	0.20
SE	0.74	0.49	0.28	0.74	0.78	0.67	0.73	0.70	2.00	2.00	0.08	0.08	0.50	0.08	0.23
CH	0.95	0.85	0.77	0.00	0.42	0.73	0.41	0.55	2.00	2.00	0.00	0.33	0.67	0.37	0.25
UK	0.88	0.79	0.57	0.23	0.65	0.77	0.29	0.67	1.00	2.00	0.08	0.32	0.39	0.17	0.09

(*) C1 and C2 are ordinal variables used to categorize the indicators

Appendix 4b: The normalized indicators (9 European countries)

ISO Code	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	C1*	C2*	D1	D2	D3	D4	D5
AT	0.76	0.52	0.59	0.51	0.75	0.50	0.83	0.89	1.00	1.00	2.00	2.00	0.03	0.29	0.08	0.08	0.19
HR	0.77	0.70	0.83	0.60	0.60	0.62	0.00	0.92	0.08	0.28	2.00	2.00	0.35	0.06	0.04	0.39	0.14
CY	1.00	1.00	0.99	0.49	0.00	0.37	0.81	1.00	0.68	0.77	2.00	2.00	0.18	0.19	0.00	0.67	0.00
FI	0.46	0.59	0.00	1.00	0.98	0.92	0.20	0.41	0.13	0.28	1.00	2.00	0.51	0.02	0.09	0.28	0.23
FR	0.74	0.51	0.59	0.66	0.80	0.60	0.83	0.90	0.55	0.65	1.00	2.00	0.01	0.37	0.55	0.32	0.14
IE	0.84	0.79	0.48	0.60	0.67	0.83	0.00	0.00	0.00	0.39	1.00	2.00	0.24	0.26	0.03	0.06	0.12
LT	0.64	0.84	0.58	0.51	0.67	0.90	0.81	0.21	0.28	0.59	2.00	2.00	1.00	0.24	0.14	0.29	1.00
SE	0.74	0.49	0.28	0.74	0.78	0.67	1.00	0.82	0.73	0.84	2.00	2.00	0.08	0.08	0.50	0.08	0.23
UK	0.88	0.79	0.57	0.23	0.65	0.77	0.38	0.79	0.29	0.67	1.00	2.00	0.08	0.32	0.39	0.17	0.09

(*) C1 and C2 are ordinal variables used to categorize the indicators

Appendix 5: The 4 extracted factors' values of PCA

ISO Code	FAC1_1	FAC2_1	FAC3_1	FAC4_1
AT	0.26819	1.67015	1.53489	0.35548
BE	0.62324	1.01171	1.02587	-0.62484
HR	-0.59635	-0.60154	0.06738	-0.33804
CY	-2.06392	-0.69187	0.70077	-1.0555
CZ	0.53333	-0.38095	-0.97005	0.73883
DK	0.64891	0.7512	1.04847	-1.0109
EE	0.01433	-1.08198	0.92277	1.13883
FI	1.62516	-1.17707	-1.27501	-0.6977
FR	0.40912	0.64979	-0.09558	-1.16305
DE	-0.19832	1.49204	-0.89608	0.05461
EL	-0.77691	-1.65985	0.42583	-0.41921
HU	1.4833	0.13095	1.28992	0.00383
IE	0.01209	-0.34258	-0.53159	-1.34073
IT	-0.65526	-0.01233	-0.81221	-0.4346
LV	2.92389	-0.91139	0.87872	0.22231
LT	0.06354	-0.0471	0.15959	3.1309
LU	-1.33641	1.14128	0.84436	1.07294
NL	-0.02059	0.97743	-0.99313	-1.22121
NO	-0.12971	0.29182	-2.83332	0.92407
PL	0.33558	-1.69566	0.10828	0.67685
PT	-0.81042	-0.99585	0.45064	-0.19032
RO	-1.38017	-1.53378	0.03766	0.40529
SK	-0.06578	-0.33223	0.08288	0.52108
SI	0.04298	1.32246	-1.59157	1.02073
ES	0.1502	-0.43811	-0.90778	-1.34091
SE	0.50646	0.99576	0.14224	0.39911
CH	-1.31853	0.85115	0.86748	0.20457
UK	-0.28796	0.61656	0.31854	-1.03243

Appendix 6a: SPSS Poisson model 1 output results (all parameters included)

Model Information

Dependent Variable	Fatality
Probability Distribution	Poisson
Link Function	Log
Offset Variable	Population

Case Processing Summary

	N	Percent
Included	28	100.0%
Excluded	0	0.0%
Total	28	100.0%

Categorical Variable Information

			N	Percent
Factor	C1	2	20	71.4%
		1	8	28.6%
		Total	28	100.0%
	C2	2	25	89.3%
		1	3	10.7%
		Total	28	100.0%

Omnibus Test[a]

Likelihood Ratio Chi-Square	df	Sig.
460.388	14	.000

Dependent Variable: Fatality
Model: (Intercept), C1, C2, A2, A3, A4, A5, A6, B3, B4, D1, D2, D3, D4, D5, offset = Population
a. Compares the fitted model against the intercept-only model.

Continuous Variable Information

		N	Minimum	Maximum	Mean	Std. Deviation
Dependent Variable	Fatality	28	2	602	126.29	162.416
Covariate	A2	28	1.5988	14.4352	5.5105	2.9301
	A3	28	3.910%	27.615%	15.120%	6.151%
	A4	28	15.000%	50.000%	30.309%	7.328%
	A5	28	7.000%	67.000%	26.071%	13.4465%
	A6	28	0.000%	52.000%	18.429%	13.664%
	B3	28	0.0000	15.9000	5.6685	4.1516
	B4	28	0.804%	60.299%	29.496%	14.764%
	D1	28	1.209%	4.848%	2.520%	1.025%
	D2	28	15.6245	510.5000	140.8585	108.3628
	D3	28	0.9000	316.8000	79.8500	92.9055
	D4	28	0.7600	7.7900	3.2661	1.9306
	D5	28	0.177%	2.941%	0.870%	0.514%
Offset	Population	28	13.3179	18.2332	15.9882	1.2972

Goodness of Fit[a]

	Value	df	Value/df
Deviance	43.229	13	3.325
Scaled Deviance	43.229	13	
Pearson Chi-Square	41.314	13	3.178
Scaled Pearson Chi-Square	41.314	13	
Log Likelihood[b]	-103.989		
Akaike's Information Criterion (AIC)	237.978		
Finite Sample Corrected AIC (AICC)	277.978		
Bayesian Information Criterion (BIC)	257.961		
Consistent AIC (CAIC)	272.961		

Dependent Variable: Fatality

Model: (Intercept), C1, C2, A2, A3, A4, A5, A6, B3, B4, D1, D2, D3, D4, D5, offset = Population

a. Information criteria are in smaller-is-better form.

b. The full log likelihood function is displayed and used in computing information criteria.

Tests of Model Effects

Source	Type III		
	Wald Chi-Square	df	Sig.
(Intercept)	1589.524	1	.000
C1	.896	1	.344
C2	.001	1	.977
A2	22.624	1	<.001
A3	15.388	1	<.001
A4	1.429	1	.232
A5	.069	1	.792
A6	1.505	1	.220
B3	.001	1	.973
B4	.256	1	.613
D1	4.636	1	.031
D2	1.982	1	.159
D3	.335	1	.563
D4	23.114	1	<.001
D5	1.623	1	.203

Dependent Variable: Fatality

Model: (Intercept), C1, C2, A2, A3, A4, A5, A6, B3, B4, D1, D2, D3, D4, D5, offset = Population

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence Interval for Exp(B)	
			Lower	Upper	Wald Chi-Square	df	Sig.		Lower	Upper
(Intercept)	-13.425	0.3977	-14.204	-12.645	1139.412	1	0.000	1.478E-06	6.780E-07	3.223E-06
[C1=1]	-0.103	0.1085	-0.315	0.110	0.896	1	0.344	0.902	0.730	1.116
[C1=2]	0a							1		
[C2=1]	-0.002	0.0855	-0.170	0.165	0.001	1	0.977	0.998	0.844	1.179
[C2=2]	0a							1		
A2	0.075	0.0157	0.044	0.105	22.624	1	0.000	1.078	1.045	1.111
A3	0.035	0.0090	0.018	0.053	15.388	1	0.000	1.036	1.018	1.054
A4	-0.006	0.0048	-0.015	0.004	1.429	1	0.232	0.994	0.985	1.004
A5	-0.001	0.0046	-0.010	0.008	0.069	1	0.792	0.999	0.990	1.008
A6	0.005	0.0043	-0.003	0.014	1.505	1	0.220	1.005	0.997	1.014
B3	0.000	0.0143	-0.028	0.029	0.001	1	0.973	1.000	0.973	1.029
B4	-0.002	0.0036	-0.009	0.005	0.256	1	0.613	0.998	0.991	1.005
D1	0.138	0.0640	0.012	0.263	4.636	1	0.031	1.148	1.012	1.301
D2	0.000	0.0003	0.000	0.001	1.982	1	0.159	1.000	1.000	1.001
D3	0.000	0.0004	-0.001	0.001	0.335	1	0.563	1.000	0.999	1.001
D4	0.075	0.0157	0.045	0.106	23.114	1	0.000	1.078	1.046	1.112
D5	0.130	0.1024	-0.070	0.331	1.623	1	0.203	1.139	0.932	1.393
(Scale)	1b									

Dependent Variable: Fatality

Model: (Intercept), C1, C2, A2, A3, A4, A5, A6, B3, B4, D1, D2, D3, D4, D5, offset = Population

a. Set to zero because this parameter is redundant. b. Fixed at the displayed value.

Appendix 6b: SPSS final Poisson model output results (8 parameters included)

Model Information

Dependent Variable	Fatality
Probability Distribution	Poisson
Link Function	Log
Offset Variable	Population

Case Processing Summary

	N	Percent
Included	28	100.0%
Excluded	0	0.0%
Total	28	100.0%

Categorical Variable Information

		N	Percent
Factor C1	2	20	71.4%
	1	8	28.6%
	Total	28	100.0%

Omnibus Test[a]

Likelihood Ratio Chi-Square	df	Sig.
456.146	8	.000

Dependent Variable: Fatality
Model: (Intercept), C1, A2, A3, A5, B3, D1, D2, D4, offset = Population

a. Compares the fitted model against the intercept-only model.

Continuous Variable Information

		N	Minimum	Maximum	Mean	Std. Deviation
Dependent Variable	Fatality	28	2	602	126.29	162.416
Covariate	A2	28	1.5988	14.4352	5.5105	2.9301
	A3	28	3.910%	27.615%	15.120%	6.151%
	B3	28	7.000%	67.000%	26.071%	13.447%
	D1	28	0.000	15.900	5.669	4.152
	D4	28	1.209%	4.848%	2.520%	1.025%
	A5	28	15.6245	510.5000	140.8585	108.3628
	D2	28	0.7600	7.7900	3.2661	1.9306
Offset	Population	28	13.3178	18.2332	15.9882	1.2972

Goodness of Fit[a]

	Value	df	Value/df
Deviance	47.471	19	2.498
Scaled Deviance	47.471	19	
Pearson Chi-Square	45.339	19	2.386
Scaled Pearson Chi-Square	45.339	19	
Log Likelihood[b]	-106.110		
Akaike's Information Criterion (AIC)	230.220		
Finite Sample Corrected AIC (AICC)	240.220		
Bayesian Information Criterion (BIC)	242.210		
Consistent AIC (CAIC)	251.210		

Dependent Variable: Fatality

Model: (Intercept), C1, A2, A3, A5, B3, D1, D2, D4 offset = Population

a. Information criteria are in smaller-is-better form.

b. The full log likelihood function is displayed and used in computing information criteria.

Tests of Model Effects

Source	Type III		
	Wald Chi-Square	df	Sig.
(Intercept)	2960.575	1	0.000
C1	25.883	1	0.000
A2	47.092	1	0.000
A3	16.981	1	0.000
B3	4.708	1	0.030
D1	15.147	1	0.000
D4	32.040	1	0.000
A5	9.765	1	0.002
D2	4.319	1	0.038

Dependent Variable: Fatality

Model: (Intercept), C1, A2, A3, A5, B3, D1, D2, D4 offset = Population

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence Interval for Exp(B)	
			Lower	Upper	Wald Chi-Square	df	Sig.		Lower	Upper
(Intercept)	-13.097	0.1167	-13.326	-12.868	12590.407	1	0.000	2.052E-06	1.632E-06	2.579E-06
[C1=1]	-0.227	0.0446	-0.315	-0.140	25.883	1	0.000	0.797	0.730	0.870
[C1=2]	0a							1		
A2	0.089	0.0130	0.064	0.115	47.092	1	0.000	1.094	1.066	1.122
A3	0.026	0.0062	0.013	0.038	16.981	1	0.000	1.026	1.014	1.038
A5	-0.008	0.0026	-0.013	-0.003	9.765	1	0.002	0.992	0.987	0.997
B3	-0.015	0.0069	-0.028	-0.001	4.708	1	0.030	0.985	0.972	0.999
D1	0.144	0.0371	0.072	0.217	15.147	1	0.000	1.155	1.074	1.242
D2	0.000	0.0002	2.422E-05	0.001	4.319	1	0.038	1.000	1.000	1.001
D4	0.077	0.0136	0.050	0.104	32.040	1	0.000	1.080	1.052	1.110
(Scale)	1b									

Dependent Variable: Fatality

Model: (Intercept), C1, A2, A3, A5, B3, D1, D2, D4 offset = Population

a. Set to zero because this parameter is redundant. b. Fixed at the displayed value.

Appendix 6c: SPSS Negative Binomial regression output (8 parameters included)

Model Information

Dependent Variable	Fatality
Probability Distribution	Negative binomial
Link Function	Log
Offset Variable	Population

Case Processing Summary

	N	Percent
Included	28	100.0%
Excluded	0	0.0%
Total	28	100.0%

Categorical Variable Information

		N	Percent
Factor C1	2	20	71.4%
	1	8	28.6%
	Total	28	100.0%

Omnibus Test[a]

Likelihood Ratio Chi-Square	df	Sig.
5.910	8	0.657

Dependent Variable: Fatality
Model: (Intercept), C1, A2, A3, A5, B3, D1, D2, D4, offset = Population

a. Compares the fitted model against the intercept-only model.

Continuous Variable Information

		N	Minimum	Maximum	Mean	Std. Deviation
Dependent Variable	Fatality	28	2	602	126.29	162.416
Covariate	A2	28	1.5988	14.4352	5.5105	2.9301
	A3	28	3.910%	27.615%	15.120%	6.151%
	A5	28	7.000%	67.000%	26.071%	13.447%
	B3	28	0.0000	15.9000	5.6685	4.1516
	D1	28	1.209%	4.848%	2.520%	1.025%
	D2	28	15.6245	510.5000	140.8585	108.3628
	D4	28	0.7600	7.7900	3.2661	1.9306
Offset	Population	28	13.3178	18.2332	15.9882	1.2972

Goodness of Fit[a]

	Value	df	Value/df
Deviance	0.652	19	0.034
Scaled Deviance	0.652	19	
Pearson Chi-Square	0.620	19	0.033
Scaled Pearson Chi-Square	0.620	19	
Log Likelihood[b]	-142.072		
Akaike's Information Criterion (AIC)	302.145		
Finite Sample Corrected AIC (AICC)	312.145		
Bayesian Information Criterion (BIC)	314.135		
Consistent AIC (CAIC)	323.135		

Dependent Variable: Fatality

Model: (Intercept), C1, A2, A3, A5, B3, D1, D2, D4 offset = Population

a. Information criteria are in smaller-is-better form.

b. The full log likelihood function is displayed and used in computing information criteria.

Tests of Model Effects

Source	Type III		
	Wald Chi-Square	df	Sig.
(Intercept)	33.894	1	0.000
C1	0.066	1	0.797
A2	0.783	1	0.376
A3	0.053	1	0.817
A5	0.260	1	0.610
B3	0.015	1	0.902
D1	0.648	1	0.421
D2	0.049	1	0.824
D4	0.199	1	0.655

Dependent Variable: Fatality

Model: (Intercept), C1, A2, A3, A5, B3, D1, D2, D4 offset = Population

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence Interval for Exp(B)	
			Lower	Upper	Wald Chi-Square	df	Sig.		Lower	Upper
(Intercept)	-13.033	1.3765	-15.731	-10.335	89.643	1	0.000	2.187E-06	1.473E-07	3.248E-05
[C1=1]	-0.137	0.5354	-1.187	0.912	0.066	1	0.797	0.872	0.305	2.489
[C1=2]	0a							1		
A2	0.099	0.1121	-0.120	0.319	0.783	1	0.376	1.104	0.886	1.376
A3	0.014	0.0618	-0.107	0.135	0.053	1	0.817	1.014	0.899	1.145
A5	-0.013	0.0256	-0.063	0.037	0.260	1	0.610	0.987	0.939	1.038
B3	-0.008	0.0615	-0.128	0.113	0.015	1	0.902	0.992	0.880	1.120
D1	0.201	0.2493	-0.288	0.689	0.648	1	0.421	1.222	0.750	1.992
D2	0.000	0.0019	-0.003	0.004	0.049	1	0.824	1.000	0.997	1.004
D4	0.058	0.1295	-0.196	0.312	0.199	1	0.655	1.060	0.822	1.366
(Scale)	1b									

Dependent Variable: Fatality

Model: (Intercept), C1, A2, A3, A5, B3, D1, D2, D4 offset = Population

a. Set to zero because this parameter is redundant. b. Fixed at the displayed value.

Appendix 7: Proposed risk domains and HGV-related indicators

Risky domains	Proposed HGV-related indicators
Seatbelts	Seatbelt wearing rates for HGV (front seats, whole country)
	Seatbelt wearing rate for HGVs (front seats, per road type and time of day)
Speed	Average (free flow) speed of HGVs per time of day
	Share of observed speeds of HGVs higher than the speed limit/Mean Speed/Speed deviation/V_{85} Speed on, ▪ Motorways with dual carriageway and median separation, ▪ Single carriageway rural roads, ▪ Single carriageway urban distributor roads (or 30km/h zones).
Alcohol and drugs	Share of drunk HGV drivers among those tested (above the legal limit)
	Share of drugged HGV drivers among those tested (national offence impairment level)
Driver Distraction	Share of HGV drivers using a handheld cell phone while driving (per time of day) on urban, rural, motorway roads
	Share of HGV drivers using a hands-free cell phone while driving (per time of day) on urban, rural, motorway roads.
Driver Fatigue	% of driving hours (daytime and night-time driving hours)
	daily rest of the driver
	daily driving time, weekly driving time, fortnightly driving time of the driver
	% of drivers using appropriate measures for fatigue prevention (by age groups)
	% of HGVs crashes with tachograph violations
	Number of rest stops with facilities for HGV drivers (average frequency per km)
Vehicle related indicators	% of HGVs failing the official vehicle inspection
	% of HGVs ≤5 years; 6- 10 years, 11-15 years and >15 years in the total registered HGVs
	% of HGV with ADAS in the total registered HGVs
	% of HGVs equipped with blind spots detectors in the total registered HGVs
Permissible maximum weights	Share of HGVs exceeding the maximum allowable lorry weights per country (urban, rural, motorway)
Post-Impact Care	Average length of stay of HGV crash victims in the hospital
	Share of HGV crash victims who are treated in intensive care units
	Share of HGV crash victims who died during hospitalization