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Gdańsk University of Technology **Publishing House**

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Gdańsk 2015

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Gdańsk University of Technology publications may be purchased at
http://www.pg.edu.pl/wydawnictwo/katalog

ISBN 978-83-7348-630-0

Gdańsk University of Technology Publishers

Edition I. Ark. ed. 6,0, ark. print 5,25, 150/804

Printing and binding: Totem.com.pl, sp. z. o.o., sp. k.
ul. Jacewska 89, 88-100 Inowrocław, tel. 52 354 00 40

ACKNOWLEDGEMENTS

The authors would like to thank their colleagues from ICTSA and from SafetyNet WP7 (Time-series Part), in particular Siem Oppe, Jacques Commandeur, Emmanuelle Dupont and Heike Martensen, for their collaboration in joint research efforts, their suggestions and comments. Special thanks go to Ariane Dupont and to Nicole Muhlrad, who helped bring this work to fruition through their careful rereading of the draft versions, to Shalom Hakkert for his helpful advice and encouragements and to the reviewers Sylvain Lassarre and Leszek Smolarek. Finally, the authors would also like to thank Rosalind Greenstein for her careful rereading of the English.

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[2] On 1 January 2011 INRETS merged with LCPC to create IFSTTAR.

CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

ARMA – Auto Regressive Moving Average (model)
ARIMA – Auto Regressive Integrated Moving Average (model)
BAC – blood alcohol content
BIVV – Belgian Road Safety Institute
CARE – Community database on Accidents on the Roads in Europe
COST – European Cooperation in Science and Technology
COST 329 – Models for traffic and safety developments and interventions
DaCoTA – "Road Safety Data, Collection, Transfer and Analysis"; project co-financed by the European Commission Directorate General for Mobility and Transport
DRAG – Road demand, accident, severity (in French: Demande Routière, Accident, Gravité)
DTU – Danish Transport Research Institute
ERSO – European Road Safety Observatory
ETSC – European Transport Safety CouncilGARCH – Generalized AutoRegressive Conditional Heteroskedasticity (model)
GDP – Gross Domestic Product
GNP – Gross National Product
GLM – Generalised linear models
GUT – Gdańsk University of Technology
ICTSA – International Cooperation for Time-Series Analysis
IFSTTAR – French Institute of Science and Technology for Transport, Development and Networks (ex. INRETS)
IMOB – Transportation Research Institute of Hasselt University in Belgium
IRTAD – International Traffic Safety and Data Analysis Database
KfV – Austrian Road Safety Board
KMS – kilometres
KSI – Killed and seriously injured
MUARC – Monash University Accident Research Centre, Australia
NTUA – National Technical University of Athens
POP – population
RMSE – Root mean square error
SafetyNet – "Building the European Road Safety Observatory"; Integrated Project funded by DG-TREN of the European Commission.
SWOV – Institute for Road Safety Research, The Netherlands
SARIMA – Seasonal Auto Regressive Integrated Moving Average (model)
vkt – Vehicle kilometres travelled
WHO – World Health Organisation

FOREWORD

Time-series analysis models serve as one of the main tools for measuring road safety progress on a macro-level, exploring relationships between road accidents/injuries, road traffic exposure and other risk determinants and assessing impacts of road safety interventions. The application of time-series analyses for road safety purposes began several decades ago, where over time various methods were suggested to handle the data structure and interrelationships.

This study considers the time-series analysis methods that were developed and applied for the analysis of road safety trends at national level, in various European countries, during the period 2000–2010. The models were developed by two working groups of road safety researchers, namely, the ICTSA group (2000–2006) and the SafetyNet project (2004–2008). Over a decade, a wide range of time-series model applications were developed both at a single-country level and for comparative analysis of country groups. However, the results of various case studies are distributed across various scientific reports and papers. This monography, written by two road safety researchers and statisticians who were directly involved in the international research activities mentioned above, provides a valuable overview and synthesis of the research findings over the last decade.

The study presents a common methodological framework underpinning the time-series analyses, by describing an underlying model of the road risk process, with risk indicators and risk factors involved, indicating data needs and limitations, and providing an effective summary of applicable statistical models. Furthermore, examples of time-series analyses carried out by selected countries (Austria, Belgium, Denmark, France, the Netherlands, Poland, Greece) are discussed, as well as the case studies of aggregative analyses of the groups of European countries. Most of the presented analyses are of an explanatory nature and therefore may be of interest for many countries, both within and outside Europe, where similar questions arise.

The authors advocate the use of autoregressive-type models and state-space models as dedicated time-series analysis techniques, thus enabling the time dependency of data to be accounted for explicitly. A primary need in exposure to risk considerations is emphasized. The possibilities of using surrogate measures of exposure (e.g. fuel sales) are demonstrated, in particular where a distinction between long-term and short-term analyses is made. It is suggested that, in the case of long-term analyses, the impacts of economic factors (e.g. unemployment rate, fuel prices) and demographic ones are to be considered, whereas for short-term analyses, the transitory factors (such as calendar characteristics or atypical weather conditions) are recommended for examination, due to their direct influence on mobility. In general, the document provides an up-to-date summary of findings of the European road safety research concerning the application of time-series analyses at a macro-level.

As fairly concluded by the authors, a real challenge lies in implementing time-series analysis models that take into account a small number of risk factors but which could assess the impact of major safety measures.

I would recommend this monography as a useful reading for road safety researchers and statisticians who are interested in the state-of-the art of time-series analyses in road safety research.

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INTRODUCTION

1.1. The road safety context

In spite of significant progress in prevention, road accidents are still the cause of death of more than 1.2 million people around the world. Every year they take an enormous toll on individuals and communities as well as on national economies (WHO, 2013). According to European Transport Safety Council's estimates a 9% reduction in road deaths observed in EU27 between 2011 and 2012 led to a reduction in costs valued at €5 billion (ETSC, 2013), which shows the huge potential of road accident prevention. This calls for continuous development of road safety management systems and their tools at European and national levels. As far as road safety trend analysis is concerned the special interest is to understand which factors influence safety and how they change.

By the early 1950s, the first research-based efforts had been made in several European countries to improve road safety at national level. Still, with intensified growth of road transport in the decades that followed, the number of accidents and victims were rising strongly. The need for a casualty reduction policy and the importance of statistical methods in road accident analysis and accident prevention became clear. The efforts asked to road safety analysts and statisticians in various countries were encouraged by the organisation of the symposium on the use of statistical methods (OECD, 1970). However, it was also clear that there were technical limitations in the data and in the methods used to analyse road safety trends at national level; furthermore, such limitations also existed when wishing to carry out comparative analyses of national trends between countries. This presupposes a common methodological framework for analysis and a common database, comprising the necessary data for each country in the same format.

In the early 1980s, the majority of road safety efforts in Europe were turned into strategic plans for the implementation of safety improvements in the future, on the basis of past knowledge (OECD/ITF, 2008). As a result, understanding safety developments, especially at national level, was of great interest not only for national decision-makers but also to researchers who could benefit significantly from comparisons of the tools and methods.

The challenge was to answer two questions:

- What are the factors which can explain the road safety trends in the past?
- How far can transport authorities intervene in order to influence the trends of injury accident risk and severity in the future?

Researchers in the field of road safety therefore started to develop appropriate tools in order to try to answer these questions. As it soon turned out, one of the most efficient directions of their studies was to apply time-series models to road safety indicators for the past (description and explanation) and for the future (forecasting).

The aim of this monography is to present an important part of their work in the form of a comprehensive overview of time-series analysis of road safety trends aggregated at national level, carried out over the period 2000–2010 and applied to national datasets covering a long-time period. The work was done by specific groups of researchers and practitioners working in the field of road safety.

1.2. COST 329

COST 329 was a first attempt to give researchers assistance in carrying out time-series analyses on traffic safety data. Tools needed to be developed to help politicians and administrators to describe and evaluate safety trends, to compare safety scenarios and to evaluate the effect of safety measures in order to improve safety programmes.

COST 329 was a three-year European project launched in 1995 in which 14 countries participated: Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Italy, the Netherlands, Norway, Portugal, Spain, Sweden and the United Kingdom. Its main objectives were to provide a specification of an efficient methodology for the analysis of past and future traffic safety developments and for the description of safety developments, their causes and underlying processes, in order to develop realistic quantitative safety targets and to specify or adapt safety programmes. The chairman of this group was Siem Oppe from the Dutch Institute for Road Safety Research (SWOV) and the vice-chairman was Sylvain Lassarre from the French National Institute for Transport and Safety Research (INRETS).

1.3. ICTSA

In the wake of the COST 329 project, the objective of the International Cooperation for Time-Series Analysis (ICTSA) group was to exchange know-how and expertise on ongoing research in the field of time-series analysis of road safety. The objective shared by the research institutes was the assessment of developments in road safety at national level. In order to achieve these objectives, two-day meetings were held twice a year, from 2000 to 2006.

Initially the group comprised researchers from the Monash University Accident Research Centre (MUARC) in Australia, the Institute for Road Safety Research (SWOV) in the Netherlands and the National Institute for Transport and Safety Research (INRETS) in France. It was then joined by additional members from the Danish Transport Research Institute (DTF), Gdańsk University of Technology (GUT) in Poland, the Austrian Road Safety Board (KfV) and the Transportation Research Institute (IMOB) of Hasselt University in Belgium. The group was chaired by SWOV (Siem Oppe followed by Jacques Commandeur).

This structure generated close collaboration between road safety institutes and university departments involved in road safety analysis, which resulted in several PhD theses (Table 1.1), and papers published in major international scientific journals, as well as the publication of a book based on experience gained from this collaboration (Commandeur, Koopman, 2007). For the purposes of this monography, however, only those results based on European examples are used. The Australian input is, however, not without interest: MUARC has developed applications intended to assess the effectiveness of the different road safety measures and programmes, of which the speed camera programme in the State of Victoria was particularly relevant. Although it has not been developed in any of the applications to data from European countries described here, a short note on their work can be found in section 4.1.4.

1.4. SafetyNet

In preparation of the European Road Safety Observatory, which was launched in 2008, the European Commission funded a project under the 6th Framework Programme for Research and Development called “SafetyNet – Building the European Road Safety Observatory”. This project, which ran from 2004 to 2008, was carried out in partnership by 23 road safety research bodies from the EU Member States.

One of its work packages (WP7) was dedicated to accident data analysis, whether multilevel analysis or time-series analysis. The Time-series part of WP7 was carried out with researchers from the Dutch Institute for Road Safety Research (SWOV), the French National Institute for Transport and Safety Research (INRETS), the Greek National Technical University of Athens (NTUA) and the Austrian Road Safety Board (KfV). Its aim was to provide a comparative analysis of trends at national level using appropriate time-series analysis techniques.

The analysis was developed in two stages. The first consisted in illustrating the use of different sorts of time-series analysis techniques applied to road safety datasets. The second involved applying appropriate methodologies to several datasets from EU Member States and carrying out a comparative analysis. This was in line with the main objectives of the SafetyNet project, one of which was to develop new statistical methods that could be used to analyse combined macroscopic and other road safety data as a tool for European Road Safety Observatory (ERSO).

1.5. The current monography

The current document covers the experience of two research networks, ICTSA and SafetyNet, working on time-series analysis in the period 2000–2008 and continuing their research up to the present day. The idea of developing this synthetic work comes from IFSTTAR (formerly INRETS), which was engaged in both of the research networks, and which Gdańsk University of Technology then decided to support. The aim is to gather and analyse the main results of the different research projects, to draw the relevant conclusions and then to publish this all in a single document as a guideline and set of best practices in the area of time-series modelling techniques and applications.

In this monography the reader will find the topics of interest already addressed in COST 329, further debated by the ICTSA group and pursued as part of the SafetyNet project: road safety modelling theories and time-series analysis techniques, applications to long-period data of injury accidents and casualties, aggregated at national level, as carried out during the last ten years. In addition, some analyses performed at the disaggregated level, mainly of the network, are also given. Academic approaches are also available under the form of several PhD theses (Table 1.1).

Table 1.1

PhD theses discussed and developed within the ICTSA (2000–2006) and SafetyNet (2004–2008) networks

Title	Results	Author
Econometric modelling of road crashes Monash University, Australia*)	A latent risk model is developed to measure the evolution of exposure to accidents, accident risk and accident severity in a multivariate setting. The generality and flexibility of the latent risk model is highlighted through applications to road safety and financial data.	Gould (2005)
Road safety, risk and exposure in Belgium Universitet Hasselt, Belgium	Regression-ARIMA models with GARCH residuals are created to measure direct and indirect effects of exposure for different types of injuries. "Subset" models are introduced to disaggregate outcomes by age and gender, type of road user and type of road, and disaggregated analyses based on Flemish travel survey data are carried out, showing the potential of this data for the analysis of the road safety of vulnerable road users.	Van den Bossche (2006)
Statistical modelling of traffic safety development Trafikdage pa Aalborg Universitet, Denmark	The thesis shows that the monthly observations of accidents are serially correlated and that this correlation can only partly be explained by the explanatory variables. It demonstrates that the general decreasing tendency in the accident series has its own slow pattern, which cannot be explained by recorded descriptive variables.	Christens (2003)
The use of explanatory variables in time-series modelling: applications to transport demand and road risk Paris-Est University, France	The thesis sets out a methodology that includes exogenous effects, measured by additional variables, in time-series modelling. The applications relate to transport and aim to account for short-term effects of both transitory and lasting nature	Bergel-Hayat (2008)
Time-series analysis in road safety research using state space methods Vrije Universiteit Amsterdam, the Netherlands	The thesis discusses multivariate structural time-series models by state space methods in the statistical analysis of the development of road safety. This approach reduces the statistical consequences of three issues in the analysis of such developments: dependence over time, the multivariate nature of road safety outcomes and the fact that most related data is subject to measurement error.	Bijleveld (2008)
Traffic risk modelling using time series Gdańsk Technical University, Poland	The thesis demonstrates the influence of economic changes, in the form of unemployment and GNP, on the number of traffic fatalities in Poland. In addition to economic changes the economic collapse in 2001/2002 was taken into account.	Żukowska (2003)

*) Australian researchers participated in ICTSA, in close cooperation with Dutch researchers on certain topics

The monography is organised as follows. Following this short introduction, section 2 provides a historical overview of approaches to road safety modelling and describes the methodological framework referred to in this document. Section 3 discusses different types of models, highlights their specific characteristics and statistical validity, and then recapitulates recommendations for their adaptation. Section 4 examines the concrete applications developed by the ICTSA group (2000–2006) and the WP7 of the European SafetyNet project (2004–2008) resulting from their research. In conclusion, section 5 summarises the relevant characteristics and results of the research work carried out by these two research groups and presents the on-going directions of research and recommendations for the future. Section 6 provides all references mentioned in this document, be they written in the framework of ICTSA and SafetyNet networks or from other research networks. Finally, section 7 provides those abstracts of research outputs which were readily available.

METHODOLOGY

2.1. Historical overview

2.1.1. Towards a systemic approach

It is generally accepted that the first road safety model was developed by Smeed (1949), who linked the annual number of fatalities in road traffic accidents in a country to the number of motor vehicles and the corresponding population and analysed the relation for 20 different countries.

Although Smeed's model has not fit the data since the 1970s (when the fatality trend reversed), this model marks the first appearance of a risk exposure variable in the form of the total number of motor vehicles in the country. The variable chosen to measure exposure to risk in Smeed's model is obviously not satisfactory for several reasons, but the related dataset was available for a large number of countries. The OECD symposium on the use of statistical methods (OECD, 1970) also highlighted other limits of a technical nature, with regard to both data and methods, for analysing road safety figures at national level in relation to certain factors and, in particular, for performing a comparative analysis of national figures between countries. OECD countries started their attempts at statistical modelling of national numbers of accidents and casualties in order to understand the phenomenon of road accidents and to reduce the consequences of the intense growth in motorisation. This was especially important since the reversal of road fatalities trends had shown that the increase in motorisation doesn't necessarily cause a proportional increase in the number of fatalities.

At that time different road safety measures were progressively introduced. After the first programme of measures that aimed to improve road safety in the United States was introduced in 1968, Peltzman (1975) set off a major debate by questioning their effectiveness. He developed a theory of driver behaviour by which the driver adopts a type of driving according to the level of risk: this adaptation to risk on the part of drivers was considered to be an explanation for the ineffectiveness of road safety measures. This debate led to an investigation into the causes of the improvements observed in the early 1980s in the United States and the United Kingdom: should these improvements be attributed to the effects of road safety policies, or to factors which are exogenous to road safety? A systemic approach became dominant: this involved considering the road safety system in its entirety, taking into account all the determinants of road risk. Comprehensive models using aggregate data were developed, with the dual purpose of evaluating the effect of road safety policies, and simultaneously estimating the impacts of the other determinants.

In 1990 Oppe and Koornstra explained the reversal in the trend of the number of road fatalities that was observed in the 1970s in developed countries by carrying out separate modelling of the fatality rate (the number of fatalities per vehicle-kilometre travelled) and the volume of traffic (the number of vehicle-kilometres travelled). By modelling the trend of fatality rates as an exponential decay function, they highlighted the importance of traffic as a risk exposure factor and its multiplicative effect on the number of fatalities (Oppe, Koornstra, 1990). This model, which was initially proposed for fatality rates, was then followed by a more general formulation in which the number of fatalities was modelled directly as a function of the traffic and was no longer considered to be necessarily proportional to it. In a similar way, the number of injury accidents is modelled directly as a non-linear traffic function. The main justification for this formulation is to be found in the results of microscopic studies of accidents.

The systemic approach resulted in the identification of a set of variables associated with risk factors by analysing a large number of models using aggregated data in the form of cross-sectional data or annual and monthly time series (Hakim et al. 1991). In addition to traffic volume or the size of the vehicle fleet, risk exposure was assessed with reference to economic activity (e.g. household income), the price of fuel, the structure of the population (e.g. the proportion of young drivers), and regulatory measures such as speed limits, the introduction of technical vehicle checks or the minimum legal age for consuming alcohol.

2.1.2. Different modelling approaches

Different modelling techniques may produce the same evaluations. In Great Britain for example, Scott (1986) estimated the effect on road safety of the 1974 oil price increase and the speed limit in rural areas, taking into account traffic volume, the price of fuel, the effect of climate via the temperature and rainfall, and the number of working days. He used a classical regression model. Also in Great Britain, Harvey and Durbin (1986) estimated the impact of the law on seatbelt wearing with a structural model, in the same way as Scott's taking into account the effects of traffic and the price of fuel. The innovative nature of their structural approach, based on the estimation of the trend and seasonality as random (or stochastic) components, sparked off an important debate. Scott, applying autoregressive models to the same data, confirmed Harvey and Durbin's estimates concerning the seatbelt legislation. Harvey's structural modelling, which is crucial for this document (as it opened the way for further development of this technique, which is commonly used today), was then used to compare aggregated data from a number of European countries.

The impact of major road safety measures on the levels and slopes of the trends of the annual number of fatalities was identified, with traffic volume as the sole determinant of the number of fatalities (Lassarre, 1996, 2001). More recently, structural modelling has also been applied in a multivariate framework: the simultaneous modelling of accident data and travel volume has made it possible to estimate the latent risk associated with this data (Bijleveld et al., 2008).

It must be said here that the most widely applied alternative approach to structural modelling is the use of autoregressive models, or models which amount to these. The monthly numbers of road accidents or fatalities are modelled while eliminating the trend and seasonality, but a small number of variables are included which measure traffic, economic activity and the price of fuel, weather conditions and the monthly calendar configuration, as well as intervention variables used to evaluate the effects of road safety measures and exceptional events (COST 329, 2004).

The most advanced explanatory autoregressive model for road risk was developed by Gaudry (1984). This is a structured representation of the road safety system that uses aggregated monthly data. This explanatory model operates at three levels and has a more elaborate form than the previous models. Gaudry modelled the number of casualties (fatalities, severe injuries and slight injuries) as the product of the number of kilometres driven, the accident rate (number of accidents per vehicle-kilometre) and the severity rate (number of persons who were killed, severely injured and slightly injured per accident). By using a very large number of explanatory variables, which were the same for each of the three levels, Gaudry was able to take into account both direct and indirect effects – via the kilometres travelled – of the determinants of accident risk and severity. By applying a Box-Cox transformation to the variables, the model took into account effects that were not strictly multiplicative. This modelling approach, known by its acronym DRAG (in French: Demande Routière, Accident, Gravité, i.e. road demand, accident, severity) has been adapted by other researchers, in both Europe and the United States, to the specific features of their countries (Gaudry, Lassarre, 2000). For France, for example, an additional level that represents risky behaviour measured by speed on the interurban network was created (Jaeger, Lassarre, 1999).

Although it is very seldom carried out, to complete the overview we should also mention modelling of daily road safety data. The high variability that affects accident statistics makes it extremely difficult to analyse short term changes in their trends. Daily data models serve two purposes: first, they help to understand transient effects caused by atypical weather or exceptional calendar events, and second, they make it possible to estimate and identify changes in a daily trend, which is thus corrected for the above-mentioned local effects. One example is the model for seasonal adjustment of daily traffic accident data developed using French data (Bergel et al., 1995). Consequently, the monthly trend remains the standard for monitoring short-term trends. The statistical analysis of monthly seasonally adjusted statistics, which is widespread in other fields, is starting to be used by public decision-makers for road safety purposes as well (ONISR, 2012).

2.2. The methodological framework

2.2.1. Towards an explanatory approach

Since the early 1980s road safety monitoring at national level has no longer been restricted to a straightforward conventional *descriptive approach* to the changes in the total amount of accident data but aims to quantify the influence of explanatory factors for accident frequency and severity and assess the effectiveness of road safety measures, within a *systemic approach* (Hakim et al., 1991).

Researchers refer to a methodological framework for the *road risk process*, in order to quantify the influence of *risk factors* related to the transport system, travel practices, the economy and road safety management (Lassarre, 1994) (COST 329, 2004) on pre-defined *risk indicators*. For each time unit considered of a calibration period, time-series models relate a measure of a risk indicator to measures of the chosen risk factors (the necessary data covering the so-called calibration period)[1)]. The time-series analysis techniques that are focused on in this document will be considered further in more detail.

[1)] In this monography, the authors focus on aggregated time-series models. Aggregation refers to the time interval, the geographical area, or to any topology of injury accidents or casualties of interest. Data is thus aggregated on a yearly, monthly or daily basis. The dependent variables are aggregated at area or network level, or according to the type of accident, the type of road user, their age and gender, etc.

2.2.2. The road risk process

The approach to risk analysis used in road safety considers the three dimensions (or levels) of the road risk process. As mentioned in the previous section it was introduced by Gaudry (1984): the first dimension relates to *risk exposure***,** the second one to *accident risk* and the third one to *accident severity.*

The concept of *exposure to risk* (or *risk exposure)*, first developed in the field of epidemiology, has since been extended to the field of road safety. Risk exposure is measured by the number of units in a population exposed to a given risk during a given period of time. In the field we are considering, the units exposed to accident risk include motor vehicles (or their occupants), two-wheelers (or their users) and pedestrians. The time these units are exposed can appropriately be replaced by the distance travelled, as the different types of road users are in movement. The research done by both the ICTSA and SafetyNet groups referred to risk exposure as a general concept; however the variables chosen for measuring it in the applications differed depending on the availability of the data.

The other two levels relate to th*e two types of road risk*, which are to be distinguished: first, the risk that an injury accident occurs and second, the risk of being injured in an accident (whether the driver, an occupant of a vehicle, or a person physically outside the vehicle).

2.2.3. Risk indicators and risk factors

Risk indicators and risk factors are defined for each of the three levels of the road risk process. The usual measure of risk exposure is an indicator that measures the traffic volume, i.e. the total number of *vehicle kilometres travelled* (*vkt*) on a road network. Other measures such as population, vehicle fleet or fuel consumption are also used when data on the mileage is not available. Having said this, mileage is in fact the most widely used and recommended measure at national level. An overview of the existing risk exposure data for European countries can be found in (Yannis et al., 2005) and (Papadimitriou et al., 2013).

The accident risk on a network is usually measured by the *accident rate* (i.e. the number of injury accidents per billion *vkt*), while the indicators used to measure accident severity are the *severity rates,* i.e. the number of casualties (fatalities, serious and slight injuries) per accident. In practice, the additional use of the *absolute number of accidents* as a function of *vkt* allows for the fact that this number may not be proportional to the traffic volume; and, similarly, *the absolute number of casualties* as a function of the number of injury accidents or directly of the traffic volume is also used. The absolute numbers of accidents and casualties are therefore also considered and used as indicators of accident risk and accident severity.

As indicated in Figure 2.1b, risk factors are classified either as *internal factors* that are related to the transport system, i.e. the vehicle, the driver and the infrastructure, or as *external factors* that are related to the environment, i.e. weather, economic, demographic and legislative factors (Gaudry, Lassarre (Eds), 2000).

2.3. The data

Three types of data relating to accidents and casualties, risk exposure and human behaviour need to be collected in order to monitor and analyse road risk at national level. The related databases from European countries need to be pooled and harmonised, which is a serious challenge since collecting each of the groups of data raises its own problems, each of a different character.

Regarding the data on accidents and casualties the main problem is its *unreliability*. It is widely recognised that the number of accidents and casualties is *under-reported* in most of the cases. Although for most countries this information is easily available either from the disaggregate CARE database, or extracted from the aggregate IRTAD database, only the number of fatalities can be considered to be fully reliable. Figure 2.1 presents the annual number of fatalities for the period 1970–2010, for seven European countries whose research bodies were part of the research networks covered in this document[2)]. To compensate for the under-reporting, some of the countries have started to use hospital data to model the number of injured victims.

In addition, the definition of injury severity differs from country to country, so that an accident or casualty which would be recorded in one country might not be recorded in another, while an accident or casualty which might be recorded as "serious" in one country might be recorded as "slight" in another. The result is that at present international comparisons of the level of road safety rely almost exclusively upon the analysis of data for fatal accidents and fatalities (Broughton et al., 2008).

The second kind of data – risk exposure data – is not being produced in a systematic manner in a way the accident and casualties data are. Exposure data is produced either by surveys or by traffic counts, or is approximated by modelling, and it requires significant means to count them regularly. Therefore in most cases it is collected only locally or periodically, which make comparisons on the aggregate level practically impossible (even if possible their validity would be questionable).

Although the advantage of this data is that whenever collected locally it is very detailed and precise, it needs to be harmonised. This has been recommended by Yannis et al. (2005).

Where there is no vkt data, population and vehicle fleet data are usually used for international comparisons at annual level when no other more satisfactory measures are available. In the case of modelling approaches, one of the most popular is to use fuel sales and approximate the number of vkt with estimates based on the sales counts (Jaeger, Lassarre, 1999)(Cardoso, 2005).

As for the data relating to human behaviour, only some datasets are available for a small number of countries and more efforts are required to make them available in the other countries. Furthermore, due to its very nature – this data is measurable at local level (individual) and is therefore difficult to aggregate with sufficient reliability. The standard data on behaviour covers information on: speed, seatbelt wearing rates, blood alcohol content (BAC), mobile phone usage, etc. Although the behaviour data cannot be aggregated at national level intervention analysis is commonly used to detect changes in human behaviour.

In addition, some other data measuring risk factors that are indirectly linked to road safety needs to be collected. This is carried out for each country independently. These factors are related to: the economy (GDP, industrial production, unemployment, cost of living), the transport system (infrastructure and vehicles), the weather and calendar or any other external event which may affect road safety (e.g. strikes, crisis situations, etc.).

[2)] Research bodies from these seven European countries had a leading role in encouraging road safety trend analysis at national level (within ICTSA and/or SafetyNet WP7 respectively).

Collecting each of the groups of data always remains a challenge for the researcher. The need for available appropriate data has been recently emphasized by a panel of experts (Muhlrad, Dupont, 2010).

2.4. Focus in the current monography

This monography focuses on the analysis at national level, including disaggregation, based mainly on network type. A few exceptions will be made, however, for disaggregation according to the type of accident, the type of road user and their age and gender.

In the case of risk exposure, the number of *vkt* was used when available. Regarding the accident and casualty data, our main focus is on the number of fatalities (for the reasons given in the previous section), followed by the number of serious injuries and the number of injury accidents. The applications presented in this research do not focus on human behaviour, with the exception of speed data in Australia; however, we mention intervention analysis to detect the effects of road safety measures adopted at a certain moment and/or for a certain period of time.

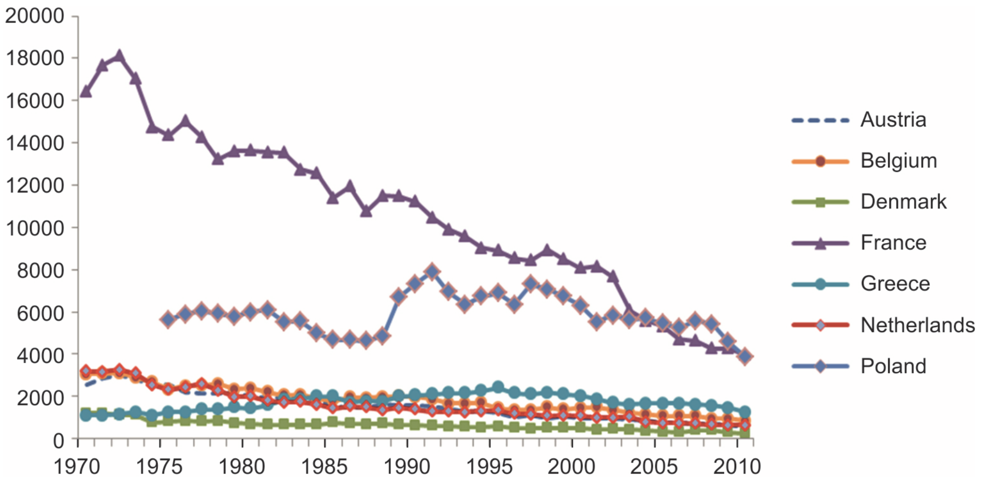

Fig. 2.1. Number of fatalities for seven European countries for the period 1970–2010
Source: IRTAD database

The document includes parts which have already been published by the authors, whether in (Bergel-Hayat, 2012), (Commandeur et al., 2013), (Bergel-Hayat, Żukowska, 2015).

TYPES OF TIME-SERIES MODELS

A literature survey of the time-series models used to analyse changes in road risk shows that they are of two types: descriptive models (with no explanatory variables other than time), and explanatory models (with other explanatory variables), which can be seen as descriptive models that have been extended by adding exogenous variables (explanatory or exogenous because they are used in an explanatory model for the endogenous variable). In this section each of these two types of model will be considered, referring to the way they have been used for aggregated analysis of the changes in road safety that have occurred in Europe since the early 1980s, after a brief review of the various structures of model that exist.

3.1. Structure of the models

When one is dealing with aggregate models, it should be borne in mind that Gaussian models will apply, which means it is being assumed that the modelled processes have *a normal distribution.* Different points of view can be adopted, leading to different definitions of time-series models.

A random process can be regarded as having a certain number of components: the cycle, trend, seasonal component and residual component. When only the process to be modelled can be observed – through one of its realisations – its components can only be estimated by means of a model. Thus, *unobserved component models* aim to provide estimates of each of these components, while a model usually aims to estimate only the variable that is to be modelled.

In the case where the unobserved components are estimated, the main components (all the components apart from the residual component, which is stochastic by nature) can be treated as being deterministic, random or even stochastic.

Finally, it should be noted that for a variety of reasons the observed process may be transformed prior to modelling. When the transformation is performed using a differentiating filter, the term *integrated components* is used.

To summarise, Gaussian time-series models can be divided into the following types:

- decomposition models, whose principal components are deterministic (for example, a decomposition model with a deterministic trend or seasonality);
- decomposition models, whose principal components are stochastic (for example, a decomposition model with a stochastic trend or seasonality);
- models with integrated components (an integrated model).

This basic structure can be enriched in a number of ways to provide additional information. For example, a reference to the past may be introduced (*autoregressive or moving average parts*), and / or a reference to the environment (*explanatory variables*). Finally, the form of the model, which is generally linear with regard to its parameters and components, may be extended by introducing non-linearity.

The model structure outlined above applies to each of the categories of model that will be discussed below. However, for each of them we shall pay particular attention to two types of structure which are very widely used to analyse changes in road risk: *decomposition* models and *autoregressive and moving average models* (ARMA and ARIMA), which can be described more briefly as *autoprojective* models (Gouriéroux and Monfort, 1990).

3.2. Descriptive models

Purely descriptive models have mainly been used to model one road safety indicator, the fatality rate. The objective of these decomposition models is to adjust the trend over time. The decomposition of an annual time series into a trend and a residual component has been extended to the decomposition of a monthly time series into a trend and seasonal and residual components. Both the trend and the seasonal component may be either deterministic or stochastic.

An example of a deterministic model for annual data is provided by Oppe (1991), who proposed a decreasing linear trend μ_t for the log-transformed fatality rate R_t (the number of fatalities per billion vehicle-kilometres):

$$R_t = \exp(at + b) \cdot u_t \tag{3.1}$$

with $R_t = \frac{F_t}{V_t}$,

where: F_t is the number of fatalities, V_t is the traffic volume and u_t is a residual noise.

The above formula for the trend of the fatality rate R_t was subsequently extended, and the traffic variable was subjected to a power transformation to take into account the fact that the number of fatalities is not proportional to the volume of traffic, with the additional parameter η representing the elasticity of the number of fatalities to the volume of traffic:

$$\frac{F_t}{V_t^{\eta}} = \exp(\mu_t) \cdot u_t \tag{3.2}$$

In both the previous formulas, the trend of the fatality rate was supposed to vary deterministically, as a function of time. The simplest function was linear: $\mu_t = a_t + b$. But the trend may also be random, in which case a specific error term is added to the model that fits the trend, to take this into account. More precisely, there are as many additional error terms as there are random components or parameters in the whole model.

A stochastic model for the temporal function μ_t was then proposed by Lassarre (1996), which becomes locally linear by implementing Harvey's (1989) basic structural model:

$$\begin{aligned}\log F_t &= \eta \log V_t + \mu_t + \varepsilon_t \\ \mu_t &= \mu_{t-1} + \beta_{t-1} + \eta_t \\ \beta_t &= \beta_{t-1} + \xi_t\end{aligned} \tag{3.3}$$

where β is the slope of the trend μ, and ε, η, ζ are white noises with variances σ_ε^2, σ_η^2 and σ_ζ^2, which are not mutually correlated.

In the case of monthly data, a seasonal component is added, which may also be either deterministic or stochastic. The larger amount of data in monthly time series means that additional exogenous variables can be used to estimate additional parameters.

As we have just seen, a descriptive model of the fatality rate can be treated as an explanatory model of the absolute number of fatalities, with a single explanatory variable – traffic volume. Explanatory models of this type with a single exogenous variable have been enriched with varying numbers of additional variables, and in fact explanatory models always take into account a larger number of risk factors. This kind of model will be discussed in the following paragraphs.

It should be noted that the formulas proposed for modelling the number of fatalities can also be used to model the number of accidents, as a function of traffic volume and additional variables.

3.3. Explanatory models

The literature review shows the following variables being used to measure risk factors:

- variables that measure risk exposure (population, vehicle fleet, traffic or fuel consumption when data on the traffic is not available),
- economic variables that represent transport supply and demand (economic activity, the price of fuel, the nature of the network),
- climatic variables and calendar variables – reference indicators for certain days of the year,
- intervention variables that are also used to model the effect of a road safety regulation or a specific event that is related to road safety.

As described for the modelling of the number of fatalities, risk exposure as measured by the number of vehicle-kilometres is the primary variable used to model the number of fatalities, and more generally the number of accidents and persons injured in accidents. A log-log specification is used, reflecting the multiplicative effect of traffic, and the elasticity of the number of accidents and casualties is assumed to be constant over time. The same hypothesis of a multiplicative effect is made when risk exposure is measured with other variables – fuel consumption, vehicle fleet or population – or variables that measure economic activity (income, industrial production, unemployment rate), or transport supply – the nature of the network, the price of fuel or the presence of motorway tolls.

Climatic variables are introduced in a semi-multiplicative fashion, with a log-linear specification. The same applies to the indicator variables for the days of the year when a specific calendar event occurs.

The other intervention variables that are used to model the effect of a road safety regulation, or a specific event that is related to road safety, are introduced in the same way.

3.3.1. Deterministic models

The model developed by Scott (1986) can be used as an example of a decomposition model with a deterministic trend and explanatory variables. Initially, he used an ARIMA structure to model the monthly number of accidents in the United Kingdom from 1970 to 1978, after having first performed regression on the data with exogenous variables measuring traffic volume, petrol price, temperature, rainfall and the number of working days (or alternatively regression with ARIMA residuals). Scott then demonstrated that the ARIMA structure for the residuals of the regression can be omitted, subject to modelling the trend and the seasonal component with a time variable and seasonal indicator variables in the regression equation:

$$\log A_t = a + bt + S_t + \sum \alpha_i \log X_{it} + \sum_j \alpha_j X_{jt} + \lambda\omega_{1t} + \lambda_2\omega_{2t} + u_t \tag{3.4}$$

where: A_t is the monthly number of accidents in the UK,
$a + bt$ is the trend,
S_t is the seasonal component, modelled with 11 indicator variables,
X_i, $i = 1, 2$ are the traffic volume for two kinds of vehicle and the price of petrol,
X_j, $j = 1, 2, 3$ are the two climate variables and the number of working days,
ω_{1t} and ω_{21t} are two indicator variables expressing the 1974 oil crisis and changes in rural speed limits.

3.3.2. Structural models

Harvey's structural model with explanatory and intervention variables is a more general type of stochastic decomposition model than the basic structural model. It was used on accident data in the United Kingdom and included two explanatory variables x_{it} (petrol price and the number of kilometres travelled) which have an effect on the trend of the observed variable, as well as the indicator variable $\omega_t = 1_{t \geq \tau}$ which is used to assess the effect $\lambda\omega_t$ of the introduction of the law on seat belt wearing.

$$\begin{cases} \log KSI_t = \mu_t + \gamma_t + \sum_{i=1}^{I} \alpha_i \log x_{it} + \lambda\omega_t + \varepsilon_t \\ \mu_t = \mu_{t-1} + \beta_{t-1} + \eta_t \\ \beta_t = \beta_{t-1} + \zeta_t \\ \gamma_t = \sum_{j=1}^{s/2} \gamma_{jt} \\ \gamma_{jt} = \left(\cos\frac{2\pi j}{s}\right)\gamma_{j,t-1} + \omega_{jt} \end{cases} \tag{3.5}$$

where: KSI_t is the monthly number of drivers who are killed or seriously injured,
β is the slope of the trend μ,
γ is the seasonal component fitted with a trigonometric model, with s even and $j = 1$ to $s/2$,
ε, η, ζ and ω_{jt} are white noises with variances σ_ε^2, σ_η^2, σ_ζ^2 and $\sigma_{\omega i}^2$, which are not mutually correlated.

Similarly, but using annual data, the most comprehensive formulation was proposed by Lassarre (2001) for the local linear trend model. It incorporated the dummy intervention variables ω_{it}, ω_{jt} and ω_{kt}, which may modify the irregular component, the level component and the slope component of the trend of the number of fatalities, respectively:

$$\begin{aligned} \log F_t &= \eta \log V_t + \mu_t + \sum_i \lambda_i \omega_{it} + \varepsilon_t \\ \mu_t &= \mu_{t-1} + \beta_{t-1} + \sum_j \lambda_j \omega_{jt} + \eta_t \\ \beta_t &= \beta_{t-1} + \sum_k \lambda_k \omega_{kt} + \xi_t \end{aligned} \tag{3.6}$$

This model has been applied to aggregate data from several European countries in order to assess the effect of the most important road safety measures. For France, for example, it was found that the major measures that were introduced in 1973 – the introduction of speed limits and compulsory seatbelt use – were responsible for a considerable reduction (17%) in the fatality rate starting from 1973. A further drop of 9.3% in 1978 resulted from the introduction of random roadside alcohol tests.

3.3.3. Integrated models

ARIMA models with explanatory variables have very often been used on monthly data, mainly to assess the effect of road safety measures. These models generally take into account recognised exogenous effects such as risk exposure or climate (by means of one or two meteorological variables) and calendar events. Transfer functions are applied when the explanatory variables are random and intervention models are used to evaluate road safety measures.

As examples we shall describe the models proposed for aggregate data in Spain and France. In Spain, three types of variables were used to model the number of injury accidents from January 1982 to December 1996 (Rebollo, Rivelott, Inglada Lopez de Sabando, 2004): two fuel sale variables (X_1 and X_2 for petrol and diesel) as a proxy for traffic, the number of weekend days in the month (*WEND*), and another intervention variable for taking into account a large number of road safety measures that have been gradually introduced since June 1992 ($LS^{6/92}$). The following model was used:

$$\begin{aligned} \log A_t &= \sum_i \beta_i \log X_{it} + \eta WEND + \gamma LS_t^{6/92} + N_t \\ (I-B)(I-B^{12})N_t &= (1-\theta_1 B)(1-\theta_{12} B^{12})\varepsilon_t \end{aligned} \tag{3.7}$$

where: A_t is the monthly number of accidents,
N_t is a first, non-stationary, residual,
$(1 - \theta_1 B)\ (1 - \theta_{12} B^{12})$ is a part of the model that accounts for its dynamic structure,
B and B^{12} are the delay operators of lag 1 and 12,
and ε_t is the final residual white noise.

The same type of model has been used on monthly accident and fatality data from France. While they include the effects of mileage and the speed, these models made it possible to evaluate the impact of major road safety measures such as the first speed limitation in 1973, the 1974 oil crisis and the 1978 legislation that introduced random roadside alcohol tests (Lassarre, Tan, 1994).

3.3.4. Non-linear models

Practice shows that multiplicative models have often been transformed into linear models by applying a logarithmic transformation to some of the variables, whether dependent or independent. This facilitates model estimation. The multiplicative relationship between risk exposure and the number of accidents and between risk exposure and fatalities is generally accepted. It is worth mentioning here, as an example, that the first national level aggregate model proposed by Smeed (1949) related the number of road injuries to the number of motorised vehicles and to the corresponding population in a multiplicative manner:

$$F = c(MP^2)^{\frac{1}{3}} \tag{3.8}$$

where: F is the annual number of fatalities,
M is the annual number of motor vehicles (in thousands),
P is the population of the year (in thousands of inhabitants),
and c is a real value.

Other transformations may be chosen in preference to the logarithmic transformation and applied to the observed data. One example is the three-level explanatory model constructed on a monthly basis, the DRAG-model proposed by Gaudry (1984) and mentioned above, which is based on a multiple regression structure with autocorrelated and heteroscedastic errors, and takes into account a type of non-linearity. The fact that numerous explanatory variables are introduced allows the trend and the seasonal component to be modelled, so they do not need to be filtered. The use of the Box-Cox transformation allows a more flexible formulation (linear, logarithmic or a compromise between the two) of the link between the endogenous variable and each exogenous variable.

Gaudry modelled the number of casualties (fatalities, severe injuries and slight injuries) as the product of the number of kilometres travelled, the accident rate (number of accidents per vehicle-kilometre) and the severity rate (number of killed, severely injured and slightly injured per accident). By using a very large number of explanatory variables, which were the same for each of the three levels, Gaudry was able to take into account both direct and indirect effects – via the kilometres travelled – of the determinants of accident risk and severity.

The DRAG approach is not always applied in full as creating monthly databases that cover a long period and contain a very large number of risk factors is an enormous task. It is also difficult to estimate a large number of parameters with a limited amount of available data and as a consequence to interpret it. In practice, researchers apply a simplified version of the DRAG approach.

3.4. Handling time dependency

Lastly, a very technical look at the types of time-series analysis techniques used in the field of road safety is worthwhile, as there were changes in the type of model specification during the eleven years covered in this document. This section provides a critical review of time-series techniques commonly used for analysing road safety trends at an aggregate level, taken from (Dupont, Martensen (Eds.), 2007). This will be rather theoretical and academic. Where necessary, we shall refer to the models discussed in sections 3.2 and 3.3 above.

The challenge here is how to handle time dependency in the observations of a variable adequately, whether through a dynamic model or, if not, by using a static model and adding some additional modelling which takes into account the remaining dynamics in its residuals. Different sorts of model were applied to several national datasets in Europe in order to illustrate the specific features of the techniques, their advantages and drawbacks. The classical regression model and its extensions – the generalised linear model (GLM) and non-linear models – are considered first, followed by two types of dynamic model: the autoprojective model and a special case of state space models, the structural model. The use of these dynamic models is recommended as they explicitly take the time dependency into account in the observations – and in particular its autocorrelation.

An interesting result of this review is the comparative modelling of the same national datasets with different types of time-series model. The applications are performed on recent national datasets of injury accidents or casualties, most generally the number of fatalities, in specific national contexts.

3.4.1. Time dependency

The hypothesis of independency in the residuals, which is a major constraint in a time-series modelling of an observed variable, may not always be satisfied and thus lead to bias and misinterpretation in the model's parameters. Not all types of model are appropriate when wishing to analyse changes in repeated measurements of casualty datasets in the field of road safety and to handle time dependency simultaneously.

As the authors show, time dependency in the observations is modelled in a satisfactory manner – concretely, the hypothesis of independency in the model's residuals is validated – when this dependency is explicitly modelled with a dynamic relationship or, if not, when a dynamic modelling of its residue is added to a static model.

Table 3.1

Summary of empirical examples for time-series analyses, inspired from
Source: Dupont, Martensen (Eds.), 2007

Statistical method	Example	Period	Law
Linear regression GLM	Number of Austrian fatalities Monthly variation of the effect of enforcement on road accidents in Greece	1987–2004	Normal
Non-linear	Macroscopic relation between accidents, population and vehicle fleet in the EU	1970–2002	Normal, discrete
ARMA-type models	Number of Norwegian fatalities Number of drivers killed or seriously injured in the UK Number of French fatalities	1970–2003 1969–1984 1975–2000	Normal
State space analysis	Number of Norwegian fatalities Number of drivers killed or seriously injured in the UK Finnish fatalities	1970–2003 1969–1984 1970–2003	Normal

For each application considered below in Table 3.1, a standard approach has been adopted to describe the successive steps in conducting the modelling: objective of the technique, model definition and assumption, dataset and research problem, model fit, estimation, diagnosis and interpretation of results. As can be seen from the review, static models used without sufficient care often show dependent residues.

Only some specific features of the modelling will be given next.

3.4.2. Classical techniques

Linear regression models

The *classical linear regression model* was applied to the Austrian monthly number of fatalities from January 1987 to December 2004. The decreasing trend was thus simply modelled as a linear function of time and the seasonal pattern was captured with the use of dummy variables. But the test based on the Gauss-Markov assumptions, in particular that of randomly distributed errors, failed, implying that the results of the tests regarding regression could not be trusted.

$$\log F_t = a + bt + S_t + u_t \tag{3.9}$$

where: F_t is the monthly number of fatalities in Austria,
$a + bt$ is the trend,
S_t is the seasonal component, modelled with 11 indicator variables,
u_t is the error term.

The problem could not be solved by performing the same regression over time on the data aggregated at annual level as, even without the seasonal component, the annual error term still appeared to be strongly autocorrelated. In both monthly and annual cases, the model specification appeared to be too simple, as it may logically be expected that significant risk factors should be accounted for in the regression.

On the contrary, another example of regression model which was used satisfactorily was the model applied to the monthly number of accidents in the UK from January 1970 to December 1978, presented in 3.3.1. By modelling the trend and seasonal component with a time variable and seasonal indicator, the regression residuals turned out to be satisfactory (stationary and uncorrelated, in other words to be a white noise).

Extensions of the linear regression model

Generalised linear models (GLM) (Dobson, 1990, Gill, 2000), are used in order to overcome some of the restrictions of classical linear regression – and in particular the fact that the response variable is assumed to follow a Gaussian law –, as the GLM framework allows for all distributions of the exponential family, including Poisson and negative binomial distributions. We will not discuss the GLM framework in detail as it typically applies to small size counts. More information can be found in (Dupont, Martensen (Eds), 2007).

Non-linear models (Bates, Watts, 1988) may be used for overcoming even more restrictions of the classical linear regression; and in road safety many processes are multiplicative by nature.

The non-linear relationship between the annual number of fatalities, vehicles and population at country level (Smeed, 1949) given in (3.8) was further investigated using annual data from 17 European countries between 1970 and 2002. The first 25 years of the data, i.e. 1970–1994, have been used to build the models while the last seven years have been used to validate them. It was first demonstrated that, using Smeed's strict original specification in a time-series framework, the assumption of independent (because correlated) disturbances was violated for most countries (Yannis, Antoniou, Papadimitriou, 2011). This relevant point could then be solved by modelling the residual as an autoregressive of order 1. In addition, by allowing for two unconstrained parameters, the extended specification turned out to be the most satisfactory in its non-linear form:

$$F = c(MP^2)^{\beta} + \varepsilon, \quad \varepsilon = \rho u \tag{3.10}$$

where: F is the annual number of fatalities,
M is the annual number of motor vehicles (in thousands),
P is the population of the year (in thousands of inhabitants),
ε is the first residual, u is the final residual,
and c, β and ρ are three real values.

3.4.3. Dedicated techniques

Dynamic modelling such as autoprojective modelling (ARMA or ARIMA)(Box, Jenkins, 1994, Brockwell and Davis, 1986, 1988), with the special case of DRAG analysis (cf. 3.3.4), and state space analysis (Harvey, 1989)(Durbin, Koopman, 2012) explicitly handle the temporal relationship between the observations.

Autoprojective models and state space models are two types of model that have been largely used for time-series analysis of road safety indicators (Bergel-Hayat, 2012). The first type of model typically consists in modelling an observed variable in reference to its past values, whereas the second one consists in disaggregating an observed variable into its fundamental (and unobserved) stochastic components: its locally linear trend, seasonal and residual.

Autoprojective modelling

ARIMA models have been illustrated on non-stationary time series of the road safety sector: the annual number of road fatalities in Norway from 1970 to 2003, and the monthly number of drivers killed or seriously injured (*KSI*) in the UK from January 1969 to December 1984.

Very simple specifications were used. The well-known ARIMA (0,1,1) was chosen for fitting the annual dataset. A SARIMA $(2,0,0)(0,1,1)_{12}$ with explanatory and intervention variables, very similar to the one given above in (3.7), was chosen to fit the monthly data as follows:

$$\Phi(B)(I - B12)\left[\log KSI_t - \sum_{i=1}^{I} \alpha_i \log Z_{i,t} - Step_t\right] = \mu + \Theta(B)a_t \tag{3.11}$$

where: KSI_t is the monthly number of drivers killed or seriously injured in the UK,
$Z_{i,t=1 \text{ to } I}$ is the car traffic index and the petrol price for the month,
$Step_t$ is a dummy variable equal to 1 starting February 1983 and 0 before,
$\Phi(B)$ and $\Theta(B)$ are the two polynomials of the delay operator B,
and a_t is a white noise.

State space models

State space models were first used with their simplest form for fitting the annual number of road fatalities as observed in Norway and in Finland for the period 1970–2003, which yielded a *stochastic level* model in the first case and a deterministic level and stochastic slope model (*the smooth trend model*) in the second case.

Second, the example already given above in section 3.3.2 and specification 3.5 was used to illustrate the case of a periodic series. A local linear trend model with a seasonal component, including the petrol price and an intervention variable to take into account the introduction of the seat belt law in February 1983, was fitted on the monthly numbers of UK-KSI drivers in the UK for the period January 1969–December 1984.

DRAG models

With the exception of a non-linear transformation of the variables, the *DRAG model* specially designed for road safety analysis (cf. 3.3.4) can be considered as an application of a special case of the ARIMA models, the AR (AutoRegressive) model with explanatory variables. The trend and the seasonal component are not removed by filtering but are modelled by the introduction of numerous explanatory variables, whether related to exposure, economic factors, transitory factors, behavioural factors or road safety measures. Although the DRAG model has a powerful theoretical framework, it requires in practice voluminous databases (Gaudry, Lassare (Eds), 2000) and therefore currently cannot appropriately be applied to EU road safety data.

Equivalences

Two examples of equivalencies between the ARIMA models and state space models described in section 3.4.3 were discussed, and the relationships between the model parameters were checked on the basis of their estimations[1)]. Nevertheless, as these equivalencies only hold between well-defined specifications, other close specifications may in practice be chosen.

With the first example, it was demonstrated that the log of the annual number of Norwegian road traffic fatalities could equally well be modelled with a local level model or with an ARIMA(0,1,1) model without constant; nevertheless, in practice, an ARIMA(0,1,1) with constants was chosen . With the second example, it was demonstrated that the log of the monthly number of UK drivers KSI could equally well be modelled with a local linear trend model with a seasonal component or with an ARIMA(0,1,1)$(0,1,1)_{12}$ model without constant; nevertheless, in practice, an ARIMA(2,0,0)$(0,1,1)_{12}$ model was chosen.

3.4.4. Recommendations

According to the recommendations drawn from this review of time-series analysis techniques as applied to road safety indicators at an aggregate level, given in SafetyNet D7.4 pp. 343–344 which are recalled below, only two specific types of model are appropriate for handling time dependency explicitly: Auto Regressive Moving Average or ARMA-type models and state space models. Manuals for classical linear regression (with an emphasis on the test of the model assumptions), ARMA-type, and state space analysis are also provided (SafetyNet D7.5).

These two types of model are not mutually exclusive as each type of model may also be written in different forms, and equivalencies between well-defined specifications have been empirically demonstrated. However, emphasis must be put on the main objective addressed for the model, which differs fundamentally regarding the two types of dedicated technique.

The introduction of exogenous variables in these models also responds to different objectives, whether for descriptive purposes mainly as in the case of the weather variables, or for policy purposes. In all cases, the performance of these explanatory models is significantly improved.

[1)] Provided by STAMP for the state space models and SPSS for the ARIMA models, see the manual in (Dupont, Martensen, 2007).

RESEARCH OUTPUT AND MAIN APPLICATIONS

This section covers all applications of time-series modelling techniques that have been developed within the ICTSA (2000–2006) and SafetyNet project (2004–2008) groups. The approaches worked on by researchers from Europe (Belgium, Denmark, France, the Netherlands and Poland) within the ICTSA group are detailed in section 4.1 and listed in Table 4.1. An effort has been made to classify the applications according to their main objective, which depended very much on the national context in which a road safety issue had emerged; this led to classifying the applications by country. We have reused the distinction between descriptive and explanatory models already mentioned in the previous sections and, in the case of explanatory models, both risk factors and road safety measures are taken into account.

The work carried out as part of the SafetyNet project was done by researchers from Austria, Belgium, Greece, France and the Netherlands. Their goal was either to illustrate the use of different methodologies and highlight their specificities, or to apply these methodologies to different road safety datasets and do a comparative analysis. The methodological concerns have been discussed above in section 3.4 and the applications to several datasets from EU countries are presented in sections 4.2, among other applications, and 4.3; they are listed in Tables 4.2 and 4.3.

4.1. Descriptive and explanatory analysis of trend

Between 2000 and 2006 a group of researchers representing a number of research institutions worked on time-series analysis methods and applications. The following five sections (4.1.1–4.1.5) cover the main research efforts undertaken by this group with respect to each of the countries involved. This section begins with a description of particular country and institute work concerning the main topics of interests of the analysis, goes on to expound on the method used for modelling purposes and, finally, discusses the main results achieved.

The reader will also find the references to the papers, reports and PhD theses which were published and inspired by the work undertaken by ICTSA. Some of these applications are also presented in sections 4.2 and 4.3.

4.1.1. A comprehensive analysis of the frequency and severity of road accidents in Belgium

The initial aim of the Belgian analysis in ICTSA was to develop an explanatory model of the frequency and severity of injury accidents, in order to quantify the impacts of both policy variables and factors that cannot be influenced. A two-level model (accident risk, accident severity) for the whole of Belgium has thus been calibrated for monthly data for the period 1986–2000. It was called the "Structural model for Belgium" (Van den Bossche, Wets, 2003). This research work raised the pertinent question of the role of exposure as missing data in the analysis based on monthly accident figures in Belgium. However, it was argued that the framework used for estimating this so-called structural model for Belgium – a regression model with ARIMA errors (Van den Bossche et al., 2004a) – allow for the missing variable and it was concluded that even without a variable such as exposure, statistically valid models can be found (Van den Bossche et al., 2004b).

Another analysis was carried out in which the exposure level (the first level of the risk model) was included. It was developed for the motorway network, since only there is exposure measured. As a result a three-level model (exposure/accident risk/fatality risk) to describe the changes in the number of deaths was produced (Hermans et al., 2006a). Among other risk factors that were considered are those of a transitory nature. The calendar configuration was accounted for in the analysis of monthly road crashes (Van den Bossche et al., 2006), and weather conditions in the analysis of daily crash counts (Brijs et al., 2008).

In the initial approach, the Belgian analysis was explanatory and called for regression-type methods. The initial work was further followed by an explanatory approach using state space methods, which allowed comparisons between regression models with ARMA errors and state space models (Hermans et al. 2006b). The noticeable result in the case of Belgium is the use of different sorts of techniques for analysing changes in road safety indicators over a long period, which provided different sorts of results, whether descriptive monitoring of risk indicator trends or assessment of risk factors and safety policies as well. Moreover, the approach was also disaggregated on the basis of certain available parameters (type of crash, type of road, type of road user). A disaggregation by age and gender of the road users showed differences both in the level and in the decrease in mortality risk of the disaggregated groups (Van den Bossche et al., 2007). An overview of the methods used and results relating to the analysis of accident datasets in Belgium was given in a PhD thesis (Van den Bossche, 2006).

4.1.2. An analysis of the limitations in the effects of influential accident factors in Denmark

The general purpose of the research effort undertaken by the Danish was to improve the insight into aggregated road safety methodology and to analyse advanced statistical methods designed to study developments of aggregated traffic accident series over time, including effects of some interventions in Denmark. The analysis was based on classical regression and state space modelling. For example, the evaluation of safety-related measures such as speed cameras (the Danish Automatic Mobile Speed Camera Project Experiment) and day-time running light was conducted using state space analysis. (Christens, 2003).

The research work highlighted the limitations in the data structure of influential factors such as changing traffic volumes and demographic and economic trends, in particular their strong covariance and slow development over time (Christens, Thyregod, 2003). Concerning the temporal dependency in the accident series, it has been shown that the monthly observations of accidents are serially correlated and that this correlation can only partly be explained by the explanatory variables. One should therefore use dynamic modelling techniques to analyse variations in accident series.

A PhD thesis (Christens, 2003) analysed advanced statistical methods to study developments over time. It investigated variations in aggregated Danish traffic accident data and demonstrates that the general decreasing tendency in the accident series has its own slow pattern, which cannot be explained by recorded explanatory variables.

4.1.3. An explanatory analysis of road safety trends in the short/medium term in France

The aim of French modelling was to analyse road safety trends in the short/medium term using an explanatory approach. All sorts of risk factors, whether of transient or of lasting nature, and safety-related events were considered for modelling the changes in the number of injury accidents and casualties, both on a daily and on a monthly basis. Efforts were made to include exposure data, whenever available, which makes it possible to control for traffic volume[1)]. The methodological approach was initially based on autoregressive-type modelling. ARIMA models were typically used with additional – so-called explanatory – variables that account for both risk factors and road-safety related measures (or related events). Results relate to the whole of France, and according to the category of network. As the number of *vkt* is solely counted on the main network (main roads and motorways) in the short-term, detailed results could only be found for these two network categories.

This first approach was followed by use of other techniques – mainly structural modelling. Within this analysis the influence of transitory factors, such as the weather and the calendar configuration, on road traffic and on road casualties has been highlighted both on a daily basis (Bergel, 2001), and directly on a monthly basis (Bergel, Depire, 2004b). The influence of exposure has been highlighted on a monthly basis on the main network (main roads and motorways), and the direct/indirect weather effects on the numbers of road accidents and casualties were estimated separately on these two types of network (Bergel, Depire, 2004a). As regards a safety-related event, it was demonstrated that there is a statistical link between the usually expected announcement of a presidential amnesty for traffic offences in France and road safety, measured by the total number of road fatalities (Bergel et al., 2002). The interest and potential applications of different kinds of modelling for analysing transport demand and road safety trends with different aims in the past twenty years in France was discussed in detail in a PhD thesis (Bergel-Hayat, 2008).

An overview of existing specifications led to the conclusion that different forms of model, which are equivalent, may provide similar outputs. As a consequence, the major difference between types of model is thus in their final practical use – and, by evidence, in the datasets at hand. Stochastic models with a small number of risk factors and a limited number of parameters have now been developed. As an example, a simplified version of the DRAG approach, applied to main roads and on motorways in France, remained significant when restricting the number of Box-Cox parameters in the specification (Bergel, Girard, 2000). However, the same three-level approach, performed on the same datasets using state space methods, provided identical estimations of the impact of risk factors (Bergel-Hayat, 2008).

[1)] to control for the changes in traffic volume

4.1.4. A multivariate descriptive analysis of trends of casualty data in the Netherlands[2)]

The analysis of trends by the Dutch researchers was descriptive, and based on state space methods. Their aim was to analyse changes in casualty data with focus on the following topics:

— taking into account the covariance structure in the analysis of casualty datasets of interdependent variables (Bijleveld, 2005);
— estimating risk, considered as a latent process, in a multivariate framework (Bijleveld et al., 2008);
— estimating both exposure and risk, considered as unobserved factors, and taking into account missing exposure data (Bijleveld et al., 2010).

The multivariate approach used for modelling risk exposure and the number of injury accidents together calls for a hidden variable: the latent risk of accident (number of injury accidents by unit of exposure to risk), which is assumed to have a local linear trend. The same hypothesis of a local linear trend prevails for estimating other ratios such as the mortality rate (number of fatalities by unit of exposure to risk) or the risk of being killed in an accident (number of fatalities by injury accident). These models were applied to datasets for the Netherlands, both aggregated and disaggregated according to the urban/rural network. Other types of disaggregation such as the type of accident, the mode (or type of road user) and the age and gender of the victim were also considered.

The main result is the descriptive multivariate analysis of trends, with the use of quarterly and annual datasets, both over the past and for the future. The observed road safety indicators (such as the number of vehicle-kilometres, the number of injury accidents and the number of casualties) are the starting point for an estimation of the unobserved components of interest (the risk and severity of injury accidents) using local linear model specifi-

[2)] An evaluation of the effectiveness of road safety programmes in Australia was performed by Australian researchers who participated in ICTSA, in close collaboration with the Dutch researchers on certain topics. In the case of Australian research, the main objective was to assess the effectiveness of the major road safety countermeasures. Efforts were made in the following directions: for measuring the effectiveness of police traffic enforcement in different police regions in Victoria (Diamantopoulo, Cameron, 2001; Oppe, Bijleveld, 2003); for assessing the speed camera programme in Victoria (Cameron, Delaney, 2008; Cameron, Newstead, Diamantopoulou, Oxley, 2003); for estimating the benefits of a vehicle replacement programme in Victoria (Oxley, Cameron, Newstead, 2003); and for measuring the influence of vehicle types on the total safety of the light passenger vehicle fleet in Australia (Newstead, Delaney, Watson, Cameron, 2004).The analysis was explanatory and calls for different methods, ranging from regression to state space methods. In particular, the use of state space methods is discussed in a Ph.D. thesis (Gould, 2005), where models with a range of socio-economic explanatory variables are applied to Victorian accident data. It shows that it is unrealistic to expect models to produce sensible regression relationships unless data is appropriately disaggregated and the model is carefully structured. Regarding the other analysis, the development of the procedure to measure traffic enforcement effectiveness (the Police Effectiveness Index and the Output Performance Index) was achieved using structural time-series regression techniques. It was concluded that the application of these techniques offers increased power and flexibility in the modeling of crashes compared to traditional multivariate regression methods. For the assessment of the speed enforcement programmes, the relationship between enforcement and publicity intensity and programme outcomes was analyzed. It was shown that both the measures had a statistically significant influence on the reduction of fatal accidents in Victoria.

cations. The analyses are basically descriptive, and based on state space methods (Bijleveld, 2008). They are extensively discussed in a PhD thesis by Bijleveld (2008) as well as in the book by Commandeur and Koopmann (Commandeur and Koopmann, 2007), which offers a step-by-step approach to the analysis of the salient features in time series and practical problems such as forecasting and missing values.

4.1.5. An explanatory analysis of a decreasing trend in the number of fatalities in Poland

The objective of the Polish research was to perform an explanatory trend analysis of the aggregate mortality, and in particular to explain the short-term reduction in the number of fatalities that occurred from 1998 onwards, which was specially marked in 2001 and which no specific road safety measure could explain. Due to the lack of exposure data, the possibility of controlling risk exposure by using economic factors was investigated, in a short/medium-term perspective. Research first focused on the link between the monthly number of fatalities and variables such as the unemployment rate (Żukowska, 2012) and, more recently, the industrial production index for a period including the recent economic crisis (Bergel-Hayat, Żukowska, 2014).

The analysis was based on state space methods. The results were totally satisfactory, as a significant negative (positive respectively) link was found between the mortality indicator and the unemployment rate (and the industrial production index respectively). These results are also promising, since forecasts in the short/medium terms can be made on the base of scenarios for these two economic indicators at the same time horizon.

Another study of the trends in Poland and other Central European countries (Holló et al., 2010) raises the question of the influence of road safety performance indicators on road safety analysis in certain areas. It is argued that not even these indicators can provide full understanding of road safety trends and that, if they are applied generally without the required background information, this could even lead to serious misinterpretation of the trends in road casualties. The analysed sudden breaks in long-term trends seem to be linked to the transition process and to certain legislative reforms. Exposure, the socioeconomic climate, and additional indicators describing organisational and structural aspects of road safety management system need to be considered in order to understand the development of road safety for individual countries.

The question of the influence of the economy on road safety data from Poland using state space methods is extensively discussed in a PhD thesis (Żukowska, 2003). It provides evidence that even sudden growth or a downturn in the economy (measured by factors like unemployment or GDP) can influence the road mortality level.

Table 4.1

ICTSA 2000–2006 – Descriptive and explanatory analysis of trends

Country of application	Technique	Aim of the application	Quantitative results	Authors
Belgium	Regression /ARIMA	Comprehensive analysis of the frequency and severity of road accidents	A comprehensive (structural) road accident model for Belgium Role of exposure in analysis of road accidents (a valid model without exposure data) A three-level model on motorways Accounting for the calendar configuration Disaggregating data by age group and gender Accounting for the weather conditions Comparison between state space and regression models	Van den Bossche, Wets (2003) Van den Bossche et al. (2004b) Hermans et al. (2006b) Van den Bossche et al. (2006) Van den Bossche et al. (2007) Brijs et al. (2008) Hermans et al. (2006a)
Denmark	State space	Explanatory analysis	Assessment of the influence of the changes in police reporting practices on injuries counts	Christens, Thyregod (2003)
France	ARIMA	Explanatory. analysis of trends in the short-medium term	The RES model by road type in France A model of temporary effect on road traffic and road risk Effect of presidential amnesty Functional form for a monthly analysis of aggregate road risk Aggregate relationship between weather, road traffic and road risk	Bergel, Girard (2000) Bergel (2001) Bergel et al. (2002) Bergel, Depire (2004a) Bergel, Depire (2004b)
The Netherlands	State space	Descriptive analysis of trends	Presentation of time series methods Accuracy of the var-covariance structure of accident-related outcomes A methodology for estimating latent risk and applications A non-linear model for estimating exposure and accident risk	Commandeur, Koopman (2007) Bijleveld (2005) Bijleveld et al. (2008) Bijleveld et al. (2010)
Poland	State space	Explanatory analysis of trends in Central Europe	Falling accident risk in Poland The influence of unemployment rate on the number of traffic fatalities in Poland Analysis of trends in Central European countries	Krystek, Żukowska (2003) Żukowska (2004)(2012) Holló, Eksler, Żukowska (2010)
Australia*)	Regression state space	Evaluation of effectiveness of road safety programmes in Australia (State of Victoria)	An index to measure police traffic enforcement effectiveness Speed enforcement: effects, mechanisms, intensity and economic benefits Interaction between speed camera enforcement and speed-related mass media publicity A model for considering the 'total safety' of the light passenger vehicle fleet Reanalysis of traffic enforcement data	Diamantopoulo, Cameron (2001) Cameron, Delaney (2008) Cameron et al. (2003) Oxley et al (2003) Newstead et al. (2004) Oppe, Bijleveld (2003)

*) Australian researchers participated in ICTSA, in close cooperation with Dutch researchers on certain topics

Table 4.2

SafetyNet 2004–2008 – Illustrations of time-series techniques

Country of application*)	Technique	Aim of the application	Quantitative results	Authors
Austria	Linear regression	Explanatory analysis	Trend analysis of Austrian fatalities	Brandstaetter, Gatscha (2007)
Greece	GLM Non linear	Explanatory analysis	Trend analysis of count accident data including effect of enforcement in Greece	Yannis et al. (2007)
17 EU coun-tries			Relation between accidents, population and vehicle fleet in the EU	Yannis, Antoniou, Papadimitriou (2011)
Different countries	All techniques	General overview	Presentation of existing time-series modelling techniques	Bergel-Hayat (2012)
Norway UK France	ARIMA	Descriptive analysis Explanatory analysis	Trend analysis of Norwegian fatalities UK – KSI drivers**) including traffic volume and petrol price Relation between presidential Amnesty and French fatalities	Bergel, Cherfi (2007)
Finland Norway UK	State space	Descriptive analysis Explanatory analysis	Trend analysis of Finish and Norwegian fatalities UK – KSI drivers**) including traffic volume and petrol price	Commandeur, De Blois (2007)
SafetyNet countries	All techniques		The use of dynamic models applied to road safety indicators	Commandeur et al. (2013)

*) the countries of application are listed in the same order as in the SafetyNet Deliverables

**) numbers of drivers killed or seriously injured in the United Kingdom

Table 4.3

SafetyNet 2004–2008 – Applications of time-series techniques to European road safety data

Country of application*) **)	Technique	Aim of the application	Quantitative results	Authors
16 EU countries	Linear regression	Descriptive trend analysis (ratios)	Identifying changes in European trends as regards annual fatality rates	Yannis, Antoniou, Katsochis, Papadimitriou (2008, 2011)
Athens region	GLM	Explanatory analysis using a risk factor	The inclusion of weather as a factor for the Athens region	Yannis et al. (2008) Bergel-Hayat et al. (2013)
France The Netherlands Athens region	State space	Explanatory analysis using a risk factor	The inclusion of weather as a factor for a number of European countries	Bergel, Debbarh (2008) Bergel-Hayat et al. (2013)
The Netherlands	State space	Descriptive trend analysis (ratios)	Measuring injury accident risk and accident severity in France and the Netherlands Dissagregating data by age and gender to measure mortality in the Netherlands	Commandeur et al. (2007) Commandeur et al. (2008) Stipdonk et al. (2013)

*) the countries of application are listed in the same order as in the SafetyNet Deliverables
**) with the exception of the Athens region

4.2. Relevant applications to a single country

This section describes two types of application developed at the level of a single country, in national contexts where no aggregate measure of risk exposure was available on a monthly basis and for the long period considered, and so other risk factors were used instead.

The first one takes two examples to illustrate how transitory factors representative of the driving conditions can be taken into account for analysing short-term changes in the aggregate number of injury accidents and fatalities in France.

The second investigates the short-term relationship between the number of fatalities and the economic activity in Poland, measured using the unemployment rate.

4.2.1. The importance of transitory factors on road traffic and road risk in France

Given the size of the daily number of injury accidents and injured for the whole of France, it was possible to implement their daily monitoring; this was done in the 1990s using short-term time series analysis models including daily traffic conditions (Le Breton, Vervialle, 1990), (Bergel et al., 1995), (Bergel, 2001), (ONISR, 2012). Direct monitoring of the monthly numbers of accidents and injured is also commonly performed, but their daily values vary so much within the month that to account for this variance within the monthly analysis improves it significantly. The interest of the monthly approach was not only to account for these daily traffic conditions in the form of monthly averaged variables, but also to capture the occurrence of extreme traffic conditions on certain days of the month in the form of monthly atypicality variables. Thus, variables measuring the calendar configuration and the weather conditions, in the form of average or dispersion around the average, were systematically included in the time-series analysis models fitted on the monthly numbers of injury accidents and injured. This was done either while controlling the traffic volume by including this variable in the model (i.e. under constant exposure) or without controlling it when the variable is not included in the model (i.e. under varying exposure).

In practice, increasing the number of exogenous variables in a monthly model leads to reducing the number of parameters in the econometric specification. Specifications with optimal functional form – using the Box-Cox transformation[3)] on the variables – have thus been replaced by linear forms, or forms that amount to these, once some variables have been Log-transformed. A good example is the model used for fitting the monthly number of injury accidents and fatalities on the French main road network (main roads and motorways considered separately) for the period 1975–1999 (Bergel, Depire, 2004a). In this example, the dependent variable (number of injury accidents or fatalities) and the independent exposure variable were Log-transformed whereas the three other independent variables measuring the weather conditions were not transformed. This specification proved to be the most satisfactory in different ways: for fitting the observed data the best, for interpreting the estimated coefficients and for ensuring the model's stability:

[3)] The Box-Cox transformation of parameter λ (Box, Cox, 1964) may be applied to each of the variables, whether endogenous or exogenous, in the econometric specification of the model, in order to optimize its fit. The use of the Box-Cox transformation may double the number of estimated coefficients in the model.

$$\log Y_t = \beta_1 \log Z_{1,t} + \sum_{j=2}^{J+1} \beta_j Z_{j,t} + \mu + \varepsilon_t$$
$$\phi(B)\varepsilon_t = u_t \qquad (4.1a)$$

where: Y is the number of injury accidents (or fatalities) on a given network,
Z_1 is the number of *vkt* travelled on the same network,
Z_j, ($j = 2, .., J + 1$) are the J secondary variables measuring the weather,
$\Phi(B)$ is a polynomial in B, the delay operator, which captures the dynamics of the corrected for the exogeneous effects process,
ε_t and u_t is a white noise, uncorrelated with the past of Y, and the Z_j $j = 1, \ldots, J$.

In this specification, the variables, whether Yor Z or Z_j $j = 1, \ldots, J + 1$ may have been filtered initialially, in order to guarantee the stationnarity corrected for the exogeneous effects process, ε_t.

This linear form was extended by adding variables measuring atypical weather and calendar variables, and was also extended to the whole of France by using a proxy for the monthly mileage. Exposure to risk either is or is not controlled (Bergel, Depire, 2004b). The following specification was first used including the weather variables measured as an average, and then including the atypicality weather variables as well:

$$\Phi(B)\left[\log Y_t - \sum_{i=1}^{I} \beta_i \log Z_{i,t} - \sum_{j=1}^{J} \beta_j Z_{j,t} - \mu\right] = \Theta(B)u_t \qquad (4.1b)$$

where: Y is the number of injury accidents (or fatalities),
Z_i, ($i = 1, ..., I$) are the I explanatory variables, which measure risk exposure,
Z_j, ($j = 1, \ldots, J$) are the J secondary explanatory variables measuring the factors of transitory nature,
$\Phi(B)$ and $\Theta(B)$ are two polynomials in B, the delay operator,
and u_t is a white noise uncorrelated with the past of Y, the Z_i ($i = 1, ..., I$) and Z_j ($j = 1, ..., J$).

As can be seen in the outputs of the model fitted on the total number of injury accidents in France for the period 1975–1999 (Table 4.4), the weather variables, measured as averages over the month, are significantly correlated to the number of injury accidents and fatalities. There is a positive significant correlation between rainfall, and average temperature, and the number of injury accidents; this significant result is not specific to the ARIMA structure used, as a state space model used on the same data provided very close weather coefficients – this will be presented in section 4.3.4. Furthermore, when additional atypicality variables are included in the model, the number of days with extremely low temperatures in the winter turned out to be more significant than the average temperature in the winter.
The same comments apply to the weather coefficients in the model fitted on the number of fatalities in France.

Table 4.4

Weather coefficients in the ARIMA model of the log number of injury accidents and fatalities in France, for the period 1975–1999

	RH (mm)	ST (°C)	WT (°C)	OF (days)	RH-S (days)	ST-S (days)	WT-I (days)	WT-S (days)	OF-S (days)
Injury accidents	0.03% ***	0.8% ***	1.2% ***	–0.3% **					
	0.01% **	0.8% ***	0.4% **	–0.2% *	0.1% *	0.1% *	–0.9% ***	0.1% *	–0.1% *
Fatalities	0,02% **	1,1% ***	2,2% ***	–0,7%					
	0.02% *	1,2% ***	1,0% **	0,14% *	0.05% *	0.6% *	–1,2% ***	0.2% *	–0.3% **

Significance of the parameters: ***(*t*-ratio > 2); **(1 < *t*-ratio < 2); *(*t*-ratio < 1)

where: RH is the amount (height) of rainfall,
ST is the temperature in the summer (April to September),
WT is the temperature in the winter (October to March),
OF is the number of days of frost,
RH-S is the number of days with extremely large amounts of rainfall,
ST-S is the number of days with extremely high temperatures in the summer,
WT-I is the number of days with extremely low temperatures in the winter,
WT-S is the number of days with extremely high temperatures in the winter,
OF-S is the number of days with extremely high occurrences of frost.

4.2.2. The effect of the prospect of a presidential amnesty on road fatalities in France

The last example that illustrates this approach is an application which estimates a counter-productive effect as regards road safety. The impact of the prospect of an amnesty for certain driving offences during the months preceding the presidential elections of May 1988 and May 1995 on the number of fatalities is assessed differently depending on whether or not factors of a transitory nature are included in the analysis.

The ARIMA model with exogenous (explanatory and intervention) variables was proved to be an efficient tool for analysing the development of the aggregate number of injury accidents and fatalities in France from January 1975 to December 2001, by taking into account risk exposure (measured using fuel sales as a proxy for monthly risk exposure for the whole of France), the car fuel price and transitory meteorological factors (the highest temperature of the day, rainfall and the occurrence of frost, averaged or aggregated over the month). The possible effects of two presidential amnesties for driving offences, in 1988 and in 1995, on the number of fatalities in France were also examined by the means of the intervention analysis, as was the effect of a fatal accident which received much attention in the media (a young woman, Anne Cellier, was killed by a drunk driver) (Bergel et al., 2002).

This same approach was extended to other risk indicators such as the number of injury accidents and fatalities on A-level roads and on motorways for the same period, and the preceding form (4.1.b) was extended to the following form including three intervention variables:

$$\Phi(B)(I - B12)\left[\log Y_t - \sum_{i=1}^{I} \alpha_i \log Z_{i,t} - \sum_{j=1}^{J} \beta_j Z_{j,t} - \sum_{k=1}^{3} \gamma_k Step_{k,t}\right] = \mu' + \Theta(B)a_t \qquad (4.2)$$

where: Y is the number of injury accidents or fatalities,
Z_i, (i = 1 to I) are the I variables measuring risk exposure and the economic factors,
Z_j, (j = 1 to J) are the J variables measuring the transitory factors,
$Step_{k,t}$, (k = 1 to 3), are the three dummy variables[4)] equal to 1 in [$T_{0,k}$, $T_{0,k}$, + n_k] and 0 elsewhere,
$T_{0,k}$ is the first month of the intervention period n_k,
n_{k+1} is the number of months of the intervention period n_k,
$\Phi(B)$ and $\Theta(B)$ are the two polynomials of the delay operator B,
and a_t is a white noise.

The exogenous parameters, the dynamics parameters and the goodness-of-fit criteria of all ARIMA models presented in this section, and given in (Dupont, Martensen, 2007) (Commandeur et al., 2013), are briefly commented now.

A first general remark is that, in addition to the dynamics parameters, numerous exogenous parameters appear to be highly significant. It should come as no surprise that the risk exposure indicator was the most significant when measured with the number of kilometres travelled on disaggregated networks (the French motorways and A-level roads).The climatic variables were found to have distinct effects at the aggregate level and on the main roads or motorways, as the weather effect is expected to differ (in intensity and sign) according to the type of network.

The intervention analysis made it possible to answer the main question raised in the application, which was to determine whether there was a statistical relationship between the number of fatalities in France and the prospect of an amnesty for driving offences committed some months before the presidential elections in 1988 and in 1995. The results suggested that fatalities increased by 7% per month on average during the ten months preceding the first presidential amnesty in 1988, and by 4% during the seven months preceding the second one in 1995. In absolute numbers, more than 500 deaths could thus have been attributed to the presidential amnesty in 1988. Conversely, the considerable media coverage of the Cellier case seems to have saved lives, as the number of fatalities was found to decrease by 6% per month on average during the seven months following this tragic accident. On motorways in particular, the number of fatalities increased in the same proportion in 1988.

Another general remark is that, regarding the models' fit, the introduction of exogenous variables in the pure ARIMA models significantly increased the part of variance explained by the model (between 2.1% and 24% according to the indicator) and significantly decreased the aerror made, (between 4.4% and 11.9% respectively, when measured with the root mean square error (RMSE).

[4)] In all three cases, the intervention effect was first modelled by a more general form, which turned out to be a step (constant every month within the intervention period, and zero outside).

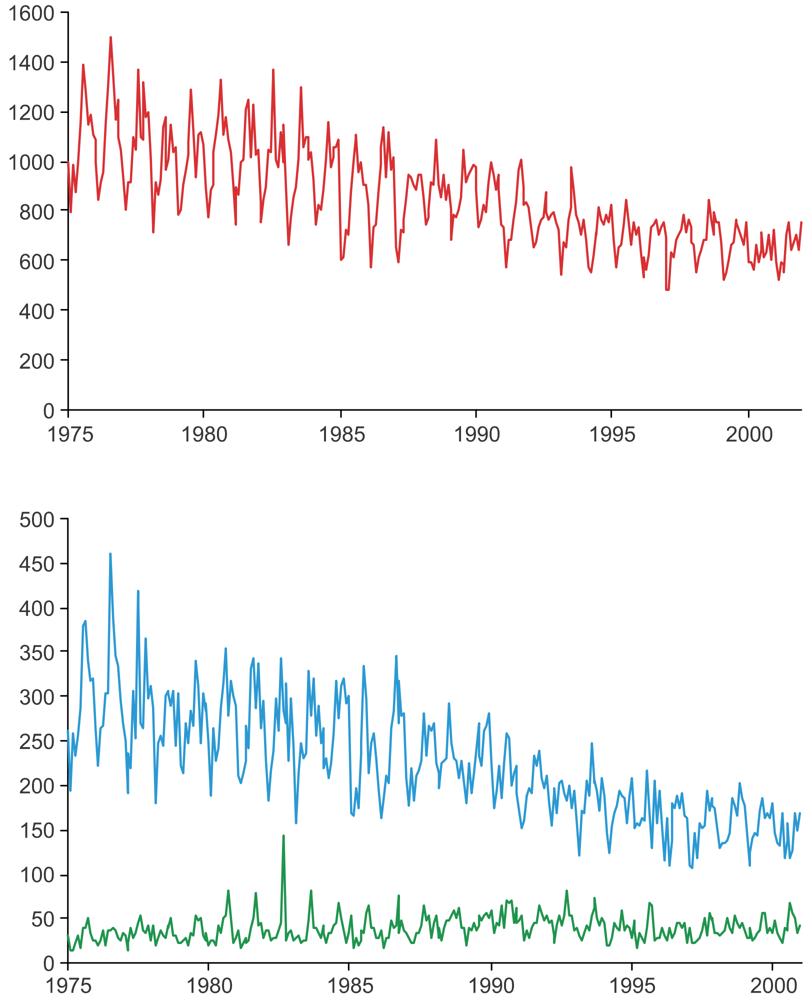

Fig. 4.1. The number of fatalities for the whole of France and for the main network A-level roads (top) and motorways (bottom) for the period 1975–2000.
Source: Commandeur et al, 2013

4.2.3. The relationship between road fatalities and the unemployment rate in Poland

At the beginning of the 21st century the number of fatalities had visibly decreased in Poland. In particular, 2001 was a year of an unexpectedly strong fall in the number of killed in road traffic accidents, after which the number of fatalities went back to its former level. Although some politicians tried to take advantage of this and claimed that the drop in fatalities was the result of their policy, no special road safety measures or road safety programmes were implemented in Poland at that time.

Road safety experts were sure that this decrease could not be due to any specific road safety activities but was just the result of some other socioeconomic factors that appeared in the country at the same period. One of their hypotheses was the influence of the sudden economic downturn which was observed in Poland in 2001 (Żukowska, 2003). The best way to confirm this was to find a relationship between exposure and the level of road safety but there was (and still is) very poor exposure data for Poland at national level. So it was decided to focus on certain economic factors to explain the decrease in the trend of road fatalities in 2001 in the country, and also the increase that followed at the beginning of 2002.

More generally, the influence of the economic changes on road safety in Poland was investigated over a longer period of time. A number of international studies state that there is a correlation between the number of traffic fatalities and the degree of public activity in the country (Thorensen et al., 1992), and some studies also mention the unemployment rate to support that argument (Brüde, 1995): as unemployment grows, miles travelled fall, a factor known to affect road safety (and vice-versa).

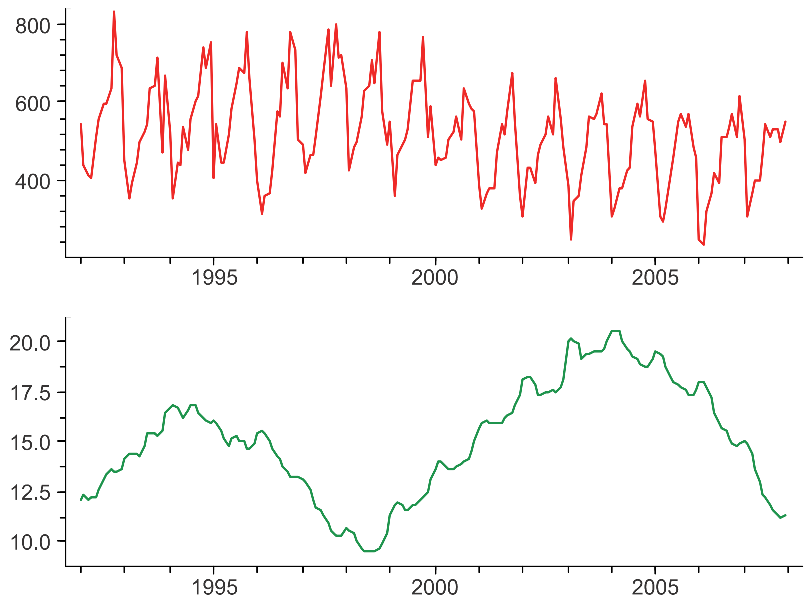

Fig. 4.2. Road fatalities (top) and the unemployment (bottom) rate in Poland for the period 1992–2007.
Source: Police data, Main Statistical Office data, 2009

In order to test whether this relationship was also valid for Poland, a model was developed to identify the relation between the monthly number of fatalities in Poland in the period 1992–2007 and the unemployment rate within that period. It is a local level model with a seasonal component, an explanatory variable (the unemployment rate) and two interventions. The interventions were included in the model to investigate the influence of the sudden economic crisis observed in Poland in 2001. This economic downturn was short-term, after which the economy went back on track in 2002. An exceptionally low value in the monthly number of fatalities was observed in December 2001 (outlier); and a change in the level of the trend was found from February 2002 onwards (structural break). So finally the model was written as follows:

$$\log F_t = \mu_t + \gamma_t + \beta \log x_t + \lambda_1 w_{t1} + \varepsilon_t, \quad \varepsilon_t = N(0,\sigma_\varepsilon^2)$$
$$\mu_t = \mu_{t-1} + b_{t-1} + \lambda_2 w_{t2} + \eta_t, \quad \eta_t = N(0,\sigma_\eta^2)$$
$$b_t = b_{t-1} \tag{4.3}$$
$$\gamma_t = -\sum_{j=1}^{s-1} \gamma_{t-j}$$

where: F_t is the monthly number of fatalities,
x_t is the unemployment rate in the month,
$w_{t,1}$ and $w_{t,2}$ are the two intervention variables (December 2001, February 2002),
μ_t is the trend in the form of a local level, with b_t the deterministic slope,
γ_t is the deterministic seasonal component in a dummy form,
ε_t and η_t are two error terms, with variances σ_ε^2 and σ_η^2, which are not mutually correlated for $t = 1, \ldots, n$.

The negative value of β (–0.28, in Table 4.5) indicates a negative relationship – and, in this case, a negative elasticity value – between the number of fatalities and the unemployment rate in Poland, which was expected. More precisely, a 1% increase in the unemployment rate resulted in a 0.28% decrease in the number of fatalities.

Concerning interventions, since $1 - e^{-0.3238} = 0.2766$, the number of fatalities decreased in December 2001 by 27%. Because this intervention was modelled by the impulse variable it means that the decrease was only for this single month. The second intervention was modelled as a structural break in the level of the series. The same calculation applied to the second intervention where the coefficient 0.213 indicates that the number of fatalities increased by 20% from February 2002 onwards. The explanation of this increase is most probably the quick return to economic prosperity after the short downturn in 2001.

Table 4.5

Coefficients in the state space model of the log number of fatalities
for the periods 1992–2007 (a) and 1991–2013 (b)

a)

Variable	Coefficients	R.m.s.e.*)	*t*-value**)
LUnemployment	–0.2778	0.1766	–1.5166 [0.1310]
Irr 2001.12	–0.3238	0.1118	–2.8942 [0.0042]
Lvl 2002. 2	0.2130	0.0825	2.5803 [0.0106]

b)

Variable	Coefficients	R.m.s.e. *)	*t*-value**)
LUnemployment	–0.23785	0.135680	–1.753 [0.0816]
Irr 2001.12	–0.29138	0.109640	–2.6575 [0.0087]
Lvl 2002. 2	0.20793	0.078384	2.6527 [0.0088]

*) rmse: the root mean square error
**) *t*-value: the value for *T* statistic in the Student test

The model's stability can be tested by changing the calibration period, as the model was also calibrated over the shorter period 1991–2003 (Table 4.5). The same parameter (whether β, λ_1, or λ_2) is thus estimated twice. Stability will be concluded if the parameter's first estimation is included in the 95% confidence interval of the second estimation, and vice-versa. Stability of all three parameters in the classical sense (95% confidence interval, l T-limit being 1.96) could thus be concluded.

4.3. Comparative applications within Europe

This section describes applications intended to provide a comparative analysis of trends of several groups of countries in Europe. Each of them was performed on different time scales (by year, by quarter or by month), according to objectives and the availability of data. These applications show, each with its own aim, different ways of taking into account risk exposure in the analysis of road risk, whether in the long, medium or short term.

In the case of a descriptive approach, the option is to use different ratios that measure accident risk and accident severity, rather than absolute numbers of injury accidents and casualties. This option was taken for identifying breakpoints in the long-term trends of annual fatality rates of five European countries in relation to changes in car ownership rates. It was also taken for measuring changes in accident risk and severity ratios on a quarterly basis in France and the Netherlands, as an extension of the research undertaken by SWOV, Hasselt University and IFSTTAR to implement the three-level approach to risk.

In the case of an explanatory approach, one option is to carry out disaggregated analyses as done by age and gender annual mortality rates in Belgium and in the Netherlands. Another option is to account for additional risk factors explicitly: this was done by including weather variables for analysing the changes in monthly numbers of injury accidents and fatalities in France, the Netherlands and the Athens' region, as an extension of the research undertaken mainly by IFSTTAR.

4.3.1. Classifying countries in Europe according to the changes in the trend of their fatality rates

The first application involves a comparative analysis of the long-term change in annual fatality rates (number of fatalities divided by the number of inhabitants) in sixteen European countries (Yannis, Antoniou, Papadimtriou, Katsochis, 2011). Then five countries (Belgium, the Czech Republic, Greece, the Netherlands and Spain) were chosen and the change in annual fatality rates was studied in relation to changes in car ownership rates (the number of cars per 1000 inhabitants) over forty-five years between 1960 and 2005. The adopted formula links the two rates in a linear piecewise manner.

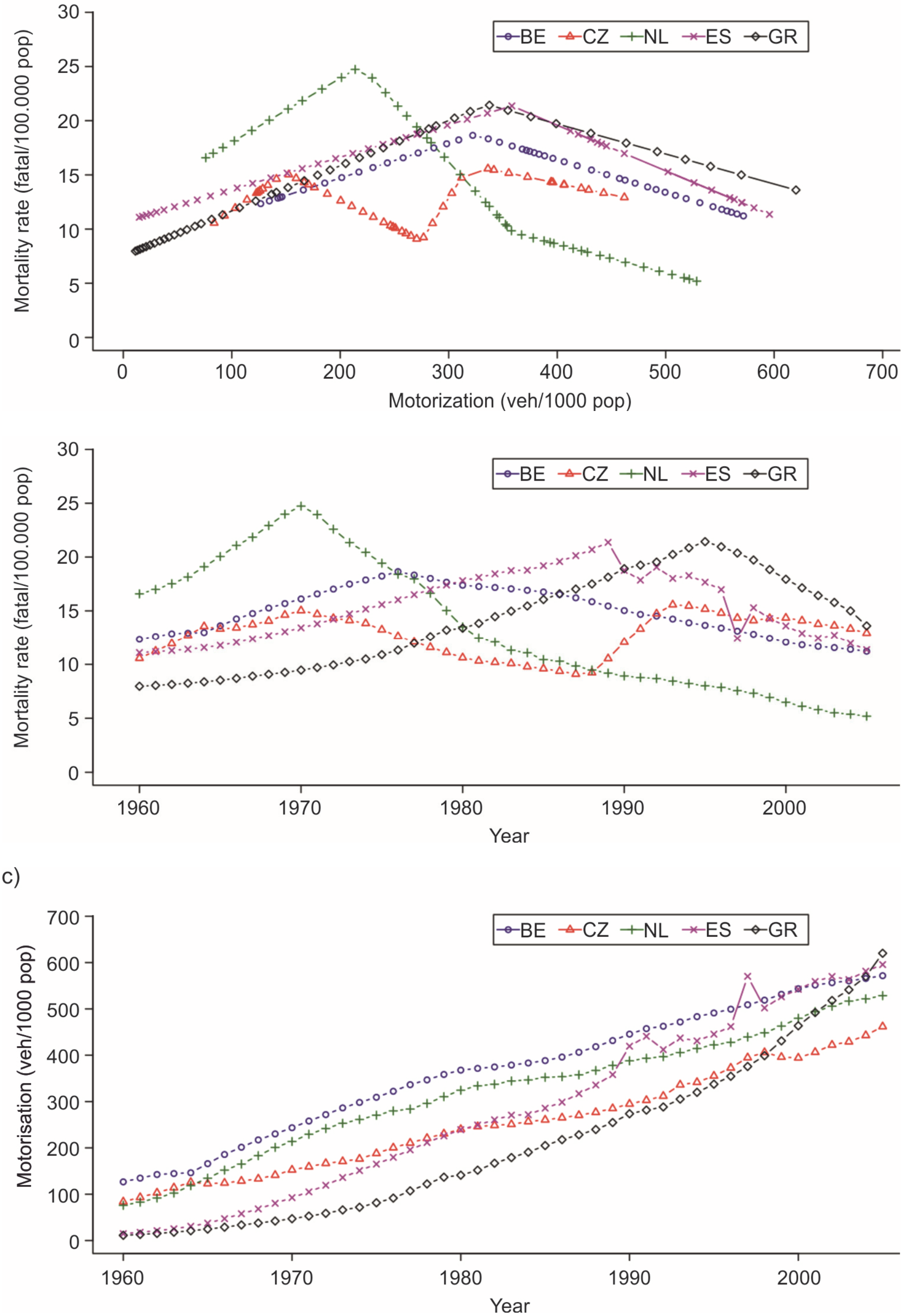

Fig. 4.3. Three subfigures for selected countries: Top: mortality rate v. motorisation, in the middle: mortality rate v. time, bottom: motorisation v. time.
Source: Yannis, Antoniou, Katsochis, Papadimitriou, 2008

$$\frac{F_i}{P_i} = \gamma_1 \frac{M_i}{P_i} + \gamma_2 \left(\frac{M_i}{P_i} - \varphi \right)_+$$
$$\left(\frac{M_i}{P_i} - \varphi \right)_+ = \left(\frac{M_i}{P_i} - \varphi \right) I \left(\frac{M_i}{P_i} > \varphi \right) \tag{4.4}$$

where: F_i, M_i and P_i are the numbers of fatalities per year, vehicles and inhabitants in a piece i, (i = 1 to I),
I is the number of pieces, where each piece is a period of years,
and $I(\cdot)$ is the indicator function which is equal to 1 when the hypothesis is confirmed and 0 when it is not.

Changes in trends occur at specific levels of car ownership, which varied between 210 and 370 vehicles per 1000 inhabitants. The main downward point of inflexion occurred in a narrow range between 320 and 370 vehicles per 1000 inhabitants, for countries where economic conditions are similar (Belgium, Greece, Spain). In the Netherlands, this occurred at the lower level of 210 vehicles per 1000 inhabitants, while in the Czech Republic the second downward point of inflexion occurred at 320 vehicles per 1000 inhabitants.

In the result of this analysis a narrow range of vehicle ownership rates was identified within which a change in the fatality rate trend has been observed and analysed. This range is not the same for different groups of countries. The result supports the need for forming groups of European countries with similar socioeconomic characteristics. The main goal that emerges from this is to anticipate the downward point of inflexion in those countries where it has not yet been observed.

4.3.2. Comparing injury accident risk and accident severity in France and the Netherlands

The second application involves a three-level analysis of the road risk process (road transport demand, accident risk and accident severity) conducted on quarterly aggregate data for France and the Netherlands, covering a thirteen-year period between 1987 and 2000 (Commandeur et al., 2007), (Bergel et al., 2008). In addition to risk exposure (measured by fuel sales for France and by the number of kilometres for the Netherlands), two ratios (the number of accidents per unit of exposure and the number of fatalities per accident) were used to measure accident frequency and severity. The parameters of interest are the level and slope of the trend, which is assumed to be locally linear, for these three indicators in the model below:

$$\log E_t = \mu^1{}_t + \gamma^1{}_t + \varepsilon^1{}_t$$
$$\mu_t{}^1 = \mu^1{}_{t-1} + \beta^1{}_{t-1} + \eta^1{}_t$$
$$\beta^1{}_t = \beta^1{}_{t-1} + \zeta^1{}_t$$
$$\gamma^1{}_t = -\sum_{j=1}^{3} \gamma^1{}_{t-j} + \omega^1{}_t$$

$$\log A_t = \log E_t + \mu^2{}_t + \gamma^2{}_t + \varepsilon^2{}_t$$
$$\mu^2{}_t = \mu^2{}_{t-1} + \beta^2{}_{t-1} + \eta^2{}_t$$
$$\beta^2{}_t = \beta^2{}_{t-1} + \zeta^2{}_t \qquad (4.5)$$
$$\gamma^2{}_t = -\sum_{j=1}^{3} \gamma^2{}_{t-j} + \omega^2{}_t$$
$$\log F_t = \log A_t + \mu^3{}_t + \gamma^3{}_t + \varepsilon^3{}_t$$
$$\mu_t^{\,3} = \mu^3{}_{t-1} + \beta^3{}_{t-1} + \eta^3{}_t$$
$$\beta^3{}_t = \beta^3{}_{t-1} + \zeta^3{}_t$$
$$\gamma^3{}_t = -\sum_{j=1}^{3} \gamma^3{}_{t-j} + \omega^3{}_t$$

where: E_t, A_t et F_t are the quarterly risk exposure indicators, numbers of injury accidents and numbers of fatalities,
$\beta = (\beta^1, \beta^2, \beta^3)$ is the slope of the trend $\mu = (\mu^1, \mu^2, \mu^3)$ of the vectorial indicator $(E, A/E, F/A)$,
and ε, η, ζ are the vectorial white noises with variances σ_ε^2, σ_η^2 and, σ_ζ^2 which are not correlated with each other.

The analysis was conducted on the aggregated data from each country. Similar analysis of the same indicators, broken down (disaggregated) for two types of roads in the case of France, and several types of accidents for the Netherlands, was also carried out.

Although these three-level indicators are not strictly comparable between France and the Netherlands, it was of interest to compare the way they have changed. In both countries, there has been an overall reduction in injury accident risk in spite of an overall increase in risk exposure. Accident severity has fallen steadily in the Netherlands, but only since 1997 in France. Moreover, in France accident severity has decreased on motorways but increased on other main roads. This application has shown that the hypothesis of a local linear trend that was adopted for these ratios makes it easier to detect reversals in trends.

4.3.3. Disaggregating data by gender and age to measure mortality in Belgium and the Netherlands

A first application was developed for Belgian annual data covering the 32-year period between 1973 and 2004 (Van den Bossche et al., 2007). The size of the population was used as measure of exposure, and thus the mortality rate (number of fatalities divided by the size of the population) was chosen as the mortality ratio. The data was disaggregated according to five age groups and to gender and the related mortality rates computed and estimated using state space methods. The results showed differences in risk according to the age group, and also that the risk is higher for men. The risk decreased over time for all age-gender groups, but the decrease was highest for the older and younger drivers.
The model used for the risk F/P is a local linear trend model, and is written as follows:

$$\log F_t = \log P_t + \sum_{i=1}^{I} \lambda_i \omega_{it} + \mu_t + \varepsilon_t$$
$$\mu_t = \mu_{t-1} + \beta_{t-1} + \eta_t \quad (4.6)$$
$$\beta_t = \beta_{t-1} + \xi_t$$

where: β is the slope of the trend μ of the risk indicator F/P,
F is the number of fatalities,
P is the size of the population, for the gender-age group considered,
ω_{it}, (i = 1 to I) are I intervention variables with fixed effect λ_i that account for outliers in the risk,
ε, η, ζ are the white noises with the variances σ_ε^2, σ_η^2 and, σ_ζ^2 which are not correlated with each other.

This first application was extended for Dutch annual data covering the nineteen-year period between 1987 and 2005. A number of ratios were used as mortality indicators (the number of fatalities in relation to distances or the population) to obtain the total number of fatalities. It was achieved by multiplying the mortality ratio by the risk exposure indicator. Unlike the preceding case, the risk exposure indicator was also modelled with the assumption of a local linear trend (Commandeur et al., 2008)(Stipdonk et al., 2012).

The structure of the model used to obtain the mortality rate is written as follows:

$$\log E_t = \mu^1{}_t + \varepsilon^1{}_t$$
$$\mu^1{}_t = \mu^1{}_{t-1} + \beta^1{}_{t-1} + \eta^1{}_t$$
$$\beta^1{}_t = \beta^1{}_{t-1} + \xi^1{}_t$$
$$(4.7)$$
$$\log F_t = \log E_t + \mu^2{}_t + \varepsilon^2{}_t$$
$$\mu^2{}_t = \mu^2{}_{t-1} + \beta^2{}_{t-1} + \eta^2{}_t$$
$$\beta^2{}_t = \beta^2{}_{t-1} + \xi^2{}_t$$

where: $\beta = (\beta^1, \beta^2)$ is the slope of the trend $\mu = (\mu^1, \mu^2)$ of the vectorial indicator (E, F/E),
F is the number of fatalities,
E is the selected risk exposure indicator,
ε, η, ζ are the white noises with the variances σ_ε^2, σ_η^2 and, σ_ζ^2 which are not correlated with each other.

The analysis was conducted on aggregated indicators, but the data was also broken down on the basis of the age group and gender of the drivers involved in the accidents. This revealed that travel behaviours differ according to age group and gender and that taking these differences into account makes it possible to reproduce changes in the aggregate number of fatalities more accurately. This disaggregation thus explains the sudden change in mortality levels observed in the Netherlands in 2005. Projections of the number of fatalities into the year 2040, by age class and gender, were made using data on travel behaviours or the population in order to measure risk exposure. In the case of the Netherlands, population data can usefully replace the travel data in order to accurately predict long term changes in the number of fatalities.

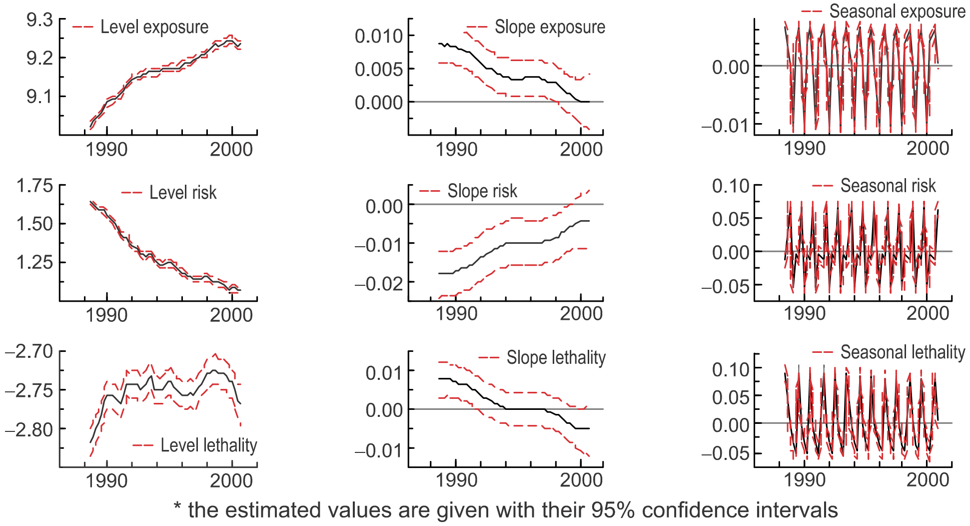

Fig. 4.4. Unobserved components: levels, slopes and seasonals (from left to right) for exposure, accident risk and fatality risk (from top to bottom) for France.
Source: Commandeur, Bijleveld, Bergel, 2007

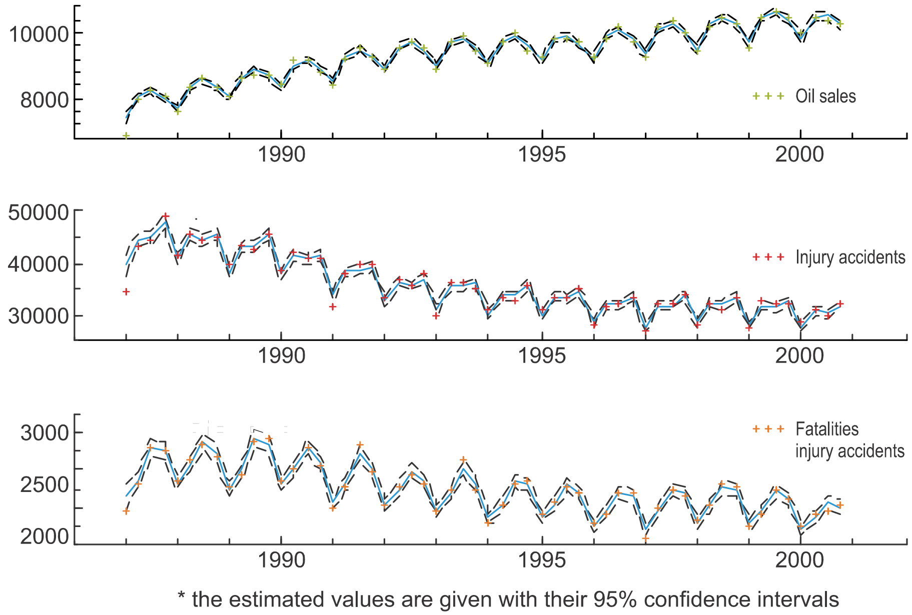

Fig. 4.5. Estimated and observed data, where the estimates are based on the results in figure 4.4 (1987–2000). Fuel sales (top panel), injury accidents (middle panel) and fatalities (bottom panel) for France. *Source*: Commandeur, Bijleveld, Bergel, 2007

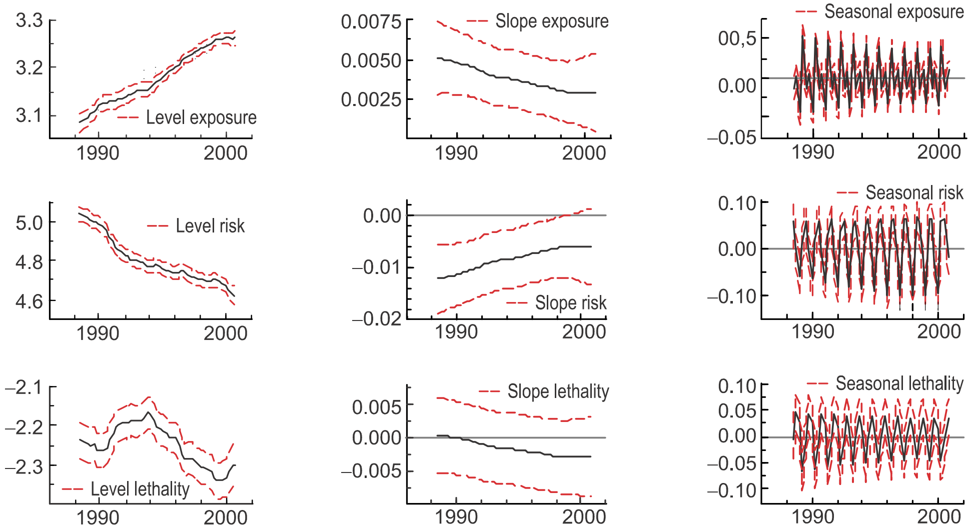

Fig. 4.6. Unobserved components: levels, slopes and seasonals (from left to right) for exposure, accident risk and fatality risk (from top to bottom) for the Netherlands. *Source*: Commandeur, Bijleveld, Bergel, 2007

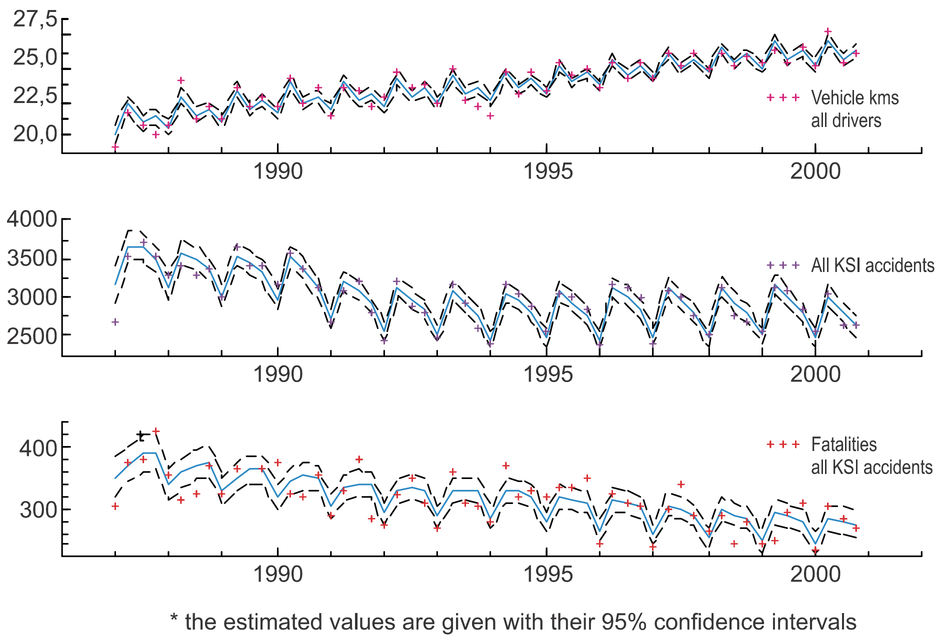

Fig. 4.7. Estimated and observed data, where the estimates are based on the results in figure 4.6 (1987–2000). Vehicle kilometres (top panel), KSI accidents (middle panel) and fatalities (bottom panel) for the Netherlands. *Source*: Commandeur, Bijleveld, Bergel, 2007

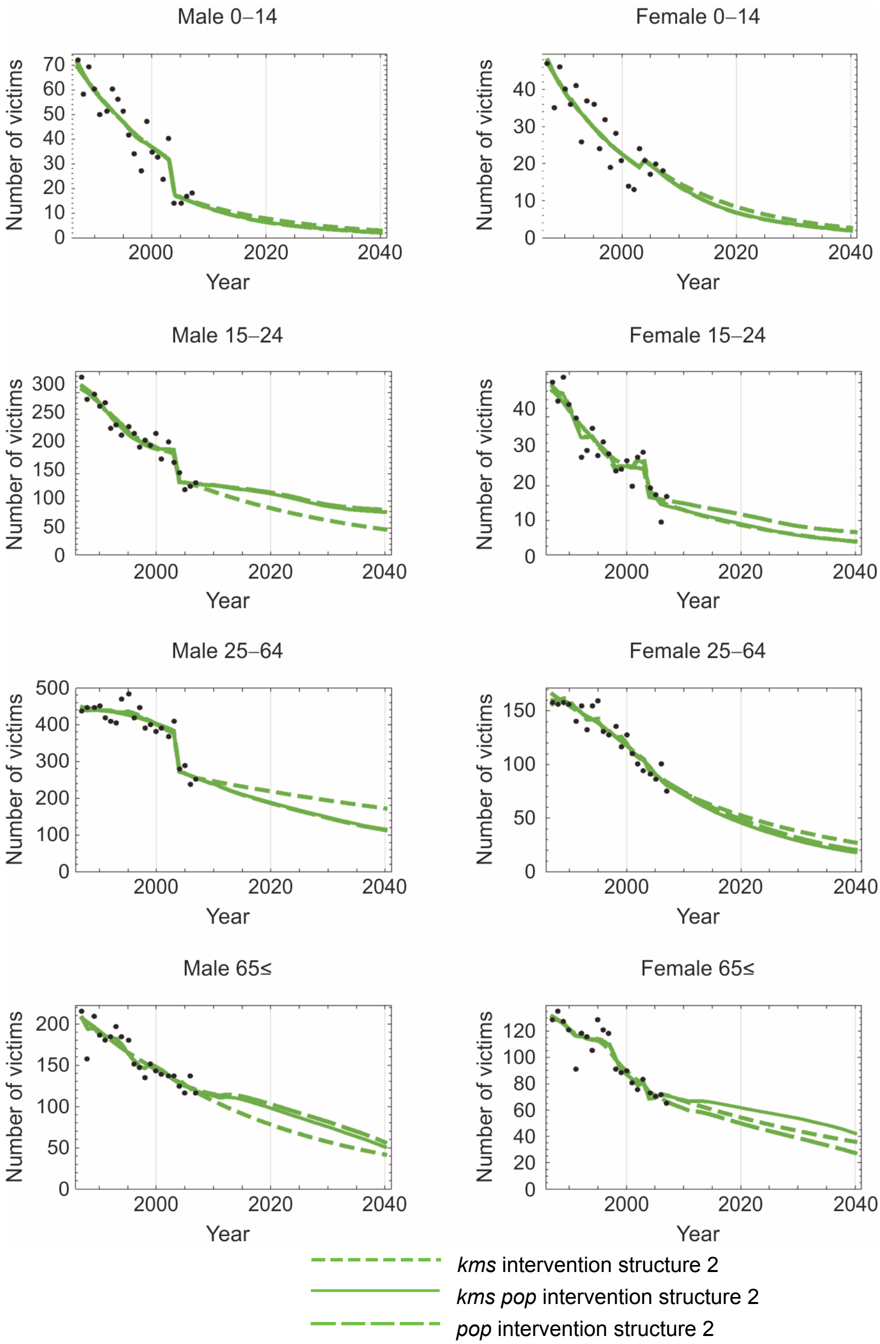

Fig. 4.8. Forecasts from 2007 onwards of fatalities in four age classes as obtained with mobility figures only, combined mobility and population figures, and population figures only, including intervention variables to capture the significant drop in the total number of fatalities in the Netherlands in 2004.
Source: Commandeur, Bijleveld, Stipdonk, 2008

4.3.4. Comparing the inclusion of weather as a factor for a number of European regions

Finally, an analysis of the effects of weather on accident and fatality data has been conducted for a number of European regions on the basis of traffic data, when available, and meteorological data (Bergel, Debbarh, 2008), (Yannis et al., 2008). The relevant meteorological phenomena are those that affect travel levels (mean temperatures accurately reproduce variations in travel levels during the year, and periods of very low temperatures reduce travel) and those which increase road risk at a given level of travel (rain, which is the most important meteorological explanatory factor, and frost). Three meteorological variables were adopted to measure the weather risk factor: rainfall, the occurrence of frost and the temperature, defined as the daily average for each weather station, then averaged over one month for a set of weather stations.

The following model has been fitted to monthly numbers of accidents. It can take two forms, depending on whether or not a risk exposure variable in addition to the weather variables is included, in which case exposure can be controlled:

$$\begin{aligned} \log A_t &= \sum_{k=1}^{K} \alpha_k Z_{kt} + \mu_t + \gamma_t + \varepsilon_t \\ \mu_t &= \mu_{t-1} + \beta_{t-1} + \eta_t \\ \beta_t &= \beta_{t-1} + \xi_t \\ \gamma_t &= -\sum_{j=1}^{11} \gamma_{t-j} + \omega_t \end{aligned} \tag{4.8a}$$

$$\begin{aligned} \log A_t &= \eta \log E_t + \sum_{k=1}^{K} \alpha_k Z_{kt} + \mu_t + \gamma_t + \varepsilon_t \\ \mu_t &= \mu_{t-1} + \beta_{t-1} + \eta_t \\ \beta_t &= \beta_{t-1} + \xi_t \\ \gamma_t &= -\sum_{j=1}^{11} \gamma_{t-j} + \omega_t \end{aligned} \tag{4.8b}$$

where: A_t is the monthly number of injury accidents,
E_t is a risk exposure indicator,
Z_{kt}, (k = 1 to K) are the K meteorological variables,
β is the slope of the trend μ,
γ is the seasonal component fitted with a dummy model,
η, ζ and ω_{jt} are the white noises with the variances σ_ε^2, σ_η^2, σ_ζ^2 and σ_ω^2, which are not correlated with each other.

Significant correlations were obtained between the meteorological variables and the aggregate number of accidents and fatalities. In the case of France and the Netherlands, there is a positive correlation between rainfall (and average temperature) and the number of accidents, and a negative correlation between frost events and the number of accidents. When analysis is limited to just one type of road (urban or rural) or a region (such as Athens which is mainly urban) these correlations may be marked, and even become reversed. Last, this research has shown up the indirect climatic effects on the number of accidents through the volume of traffic on the

French national network (motorways and main roads). It has been possible to distinguish between the meteorological effects that are due to variations in travel levels and those that are due to changes in road risk at constant levels of travel when a risk exposure measure is available. Thus, on French motorways and main roads, whereas rain reduces travel levels, it nevertheless increases the number of accidents with a given travel level.

Table 4.6

Weather coefficients in the state space model of the log number of injury accidents for France, the Netherlands and the Athens region, for the periods 1975–2000, 1987–2005 and 1985–2005 respectively. *Source*: Bergel-Hayat et al., 2013

	RH (mm)	ST (°C)	WT (°C)	OF (days)
France	0.02% ***	0.7% ***	1.2% ***	–0.3% ***
The Netherlands	0.02% **	2.4% ***	1.7% ***	–0.6% ***
Athens region	–0.05% ***	0.3% *	2.1% ***	
Motorways in France	0.08% ***	2.1% ***	0.8% *	0.5% **
Main roads in France	0.06% ***	0.2% *	0.4% *	–0.3% **
Motorways in the Netherlands	0.10% ***	1.6% ***	0.3% *	0.1% *
Rural roads in the Netherlands	0.00% **	2.8% ***	1.2% **	–0.1% *

Parameter's significance: ***(*t*-ratio > 2); **(1 < *t*-ratio < 2); *(*t*-ratio < 1)

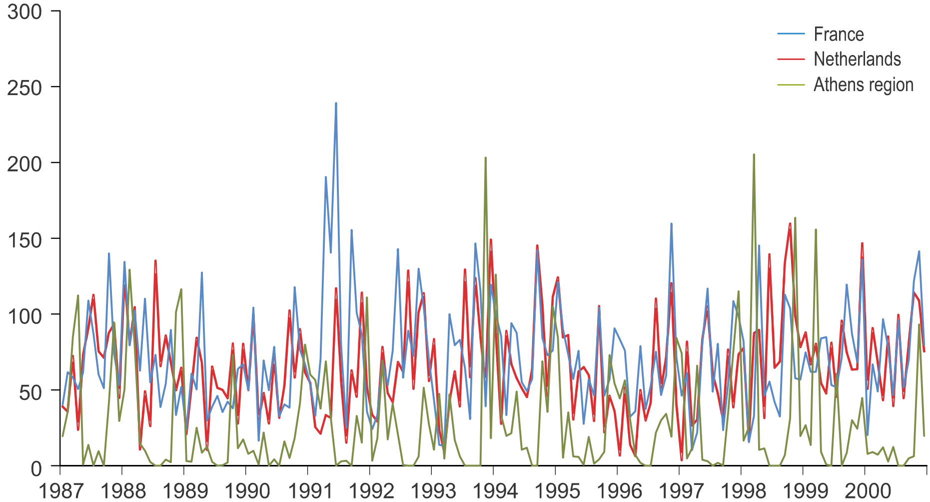

Fig. 4.9. Monthly rainfall in France, the Netherlands and the Athens region (mm) from 1987 to 2000. *Source*: Bergel-Hayat et al., 2013

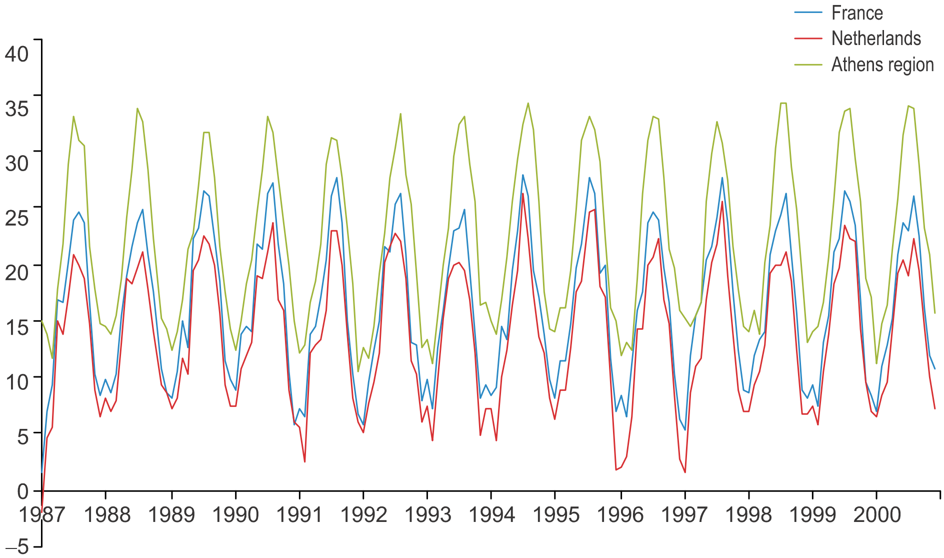

Fig. 4.10. Average monthly temperature in France, the Netherlands and the Athens region (°C) from 1987 to 2000. *Source*: Bergel-Hayat et al., 2003

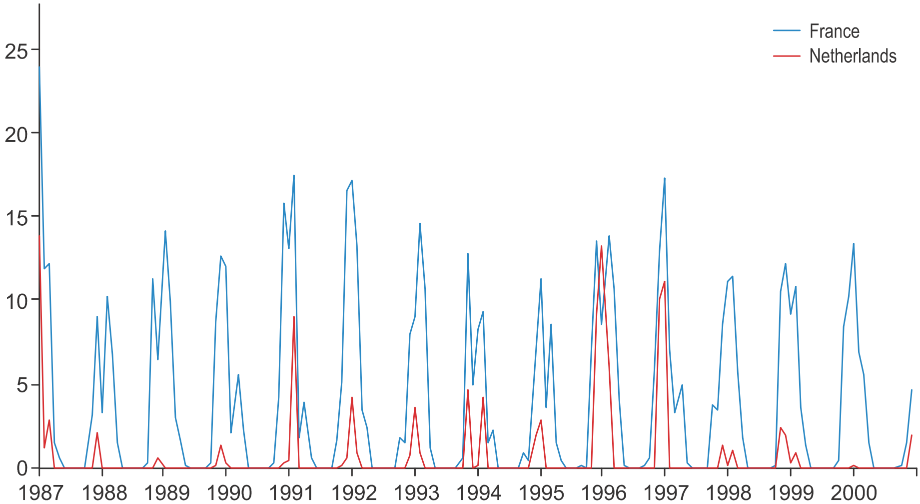

Fig. 4.11. Monthly number of frost days in France and the Netherlands from 1987 to 2000. *Source*: Bergel-Hayat et al., 2013

CONCLUSION AND OUTLOOK

This monography provides a methodological synthesis of time-series analyses of road safety trends at national level carried out during the period 2000–2010. Different models and their applications, based on long-term accident and casualty datasets from various European countries, were analysed by two working groups of road safety researchers and practitioners: ICTSA (2000–2006) and SafetyNet WP7 (2004–2008).

During this period a number of country-specific analyses were developed, and it was the SafetyNet project which helped to propose a common approach that could be applied to groups of countries. With time the methodological approach to trend analysis became more sophisticated for both descriptive and explanatory analysis. As a result, the analysis adopted a three-dimensional approach to the road risk process. The explanatory analysis examined a large number of risk factors (first of all exposure to risk) when assessing measures, or programmes of measures, linked to road safety. A noticeable result is that risk factors of a transitory nature, which originally were not systematically considered in the short/medium term analyses, now form a significant part of the analysis.

The major points of the conclusions presented in this review concern methodology, techniques and applications and are outlined below.

5.1. Methodology

While the relevance of some of the methods used to analyse road safety trends at national level during the period 2000–2010 was already underlined in the COST 329 report, the methods were not designed specifically for comparative analyses between countries or groups of countries. This issue was addressed more efficiently by SafetyNet. The methodological options proposed in COST 329 were further developed in the ICTSA network and finally formalised as part of the SafetyNet project. They all follow three principal objectives:

- a systematic use of a measure of risk exposure, the primary risk exposure factor;
- a three-level approach to the road risk process (exposure to risk, accident risk, severity risk);
- an analysis of rates rather than absolute numbers of injury accidents and casualties in order to measure accident and severity risks.

5.2. Techniques

General recommendations focus on the use of dedicated time-series analysis techniques that explicitly account for the time dependency of data (autoregressive-type models and state space models). Even if time-series models can be used in other equivalent forms, the choice of the type of model depends on its final use. In practice the availability of the data plays a role, too. Both types of model can be used for descriptive and explanatory analysis. Both can also be used for the past and the future.

Auto-projective models have mainly been used for monthly data analysis and to take into account a large number of risk factors and safety measures. In parallel, even if they only take into account a small number of risk factors, decomposition models based on stochastic trends (assumed to be locally linear) are being used more and more because they allow for a visible representation of the structure of a stochastic process.

5.3. Applications

The applications carried out in Europe were based on the same methodological assumptions and led to interesting applications which – if the necessary data is available – can in practice be carried out in any country (or region). For the purpose of this research, in the case of ICTSA the classification of the applications was done by country. This is because the data depends heavily on the national context in which a particular road safety problem has emerged. SafetyNet addresses the problem both by country and by group of countries.

5.3.1. Applications to a single country

The applications developed at country level reflected research questions specific to a particular country or to an issue already raised elsewhere and applied to the country in a new context; this provided new answers but also introduced new limitations. The modelling techniques used were both descriptive and explanatory.

Purely descriptive monitoring of road risk was carried out on Dutch data, both aggregated and disaggregated according to types of road network. The purpose was to estimate the latent risk (the ratio of the number of accidents by a measure of exposure) from observed exposure.

Explanatory analyses are also aimed at linking absolute numbers of accidents and casualties to exposure – the major risk factor – but with the additional aim of measuring elasticity with respect to a variable that describes exposure. The measure of risk exposure is either aggregated at national level, or disaggregated according to needs. This was done in Greece at national level where total mileage is not measured and the motorised vehicle fleet was used as exposure data. If the measure of risk exposure is available at a sub-level, then a disaggregated analysis is possible. For Belgium, aggregated analyses were done at national level without referring to any exposure measure and were still considered statistically valid. The three-level models using monthly kilometres driven could only be estimated for the motorway network. Similarly in France, monthly fuel sales were used to approximate the global number of kilometres driven monthly, while comprehensive models using monthly kilometres driven could only be developed for the main network of national roads and motorways.

Access to traffic measurements on networks equipped with automatic counters makes infra-monthly analyses possible, which leads to focus on short-term risk factors. Short-term relationships between traffic volumes and the numbers of accidents and casualties mostly vary according to the type of day in the year and in particular to inclement weather conditions. These transitory factors (calendar characteristics or atypical weather conditions) have a direct influence on mobility. It is to be noted that while the transitory factors influence the risk level through mobility, their separate direct and indirect effects on traffic accident and casualty figures have rarely been identified. Belgium and France are the only countries to identify calendar and weather-related effects on the numbers of injury accidents and casualties on daily and monthly bases.

Explanatory analyses also take into account economic factors related to transport supply (fuel prices, public transport fares) and demand (production, household consumption or unemployment measured at national level). The effect of petrol prices was demonstrated on monthly casualty figures in the UK; the effect of fuel prices (petrol and diesel) was identified in France in monthly accident and fatality figures. The unemployment rate, which evolves inversely to economic activity, was found to explain variations of fatality data in Poland with the expected negative elasticity.

Risk factors can also be identified through disaggregated analyses. This was done as mentioned above for particular road networks: on national roads and motorways in France, on motorways in Belgium, on urban and rural roads in the Netherlands. Disaggregation was also performed by type of vehicle involved in injury accidents on data from the Netherlands, and by age and gender of drivers on data from Belgium and the Netherlands.

Last but not least, as this is one of their major objectives, explanatory analyses serve to evaluate road safety measures or programmes. Good examples come from Australia, which is not within the scope of this review although it is a member of the ICTSA research network. For the State of Victoria a larger number of evaluation studies was carried out, on automatic speed enforcement in particular. The results are summarised in Cameron, Delanay (2008). In Europe, since the introduction of speed limits and compulsory seatbelts, the effect of other road safety measures adopted more recently has been less spectacular, except perhaps for automatic speed enforcement in France. One measure, however, was found to be counter-productive as regards road safety: the prospect of a general amnesty for traffic offences which usually followed presidential elections in France was shown to lead to a very significant increase in the number of fatalities, both in 1988 and in 1995.

5.3.2. Applications to several countries

The analyses carried out for more than one country were designed to compare individual countries or, in a broader view, to compare groups of countries with similar characteristics. Comparative analysis was possible by putting together a number of similar datasets measuring risk factors. In the case of harmonised datasets – following the same definitions or obtained through the same methodology – the analysis was reliable and identified groups of countries with similar characteristics. Comparative analysis was, however, limited when the datasets used were comparable but not harmonised. This emphasises the need for more efforts in order to obtain genuinely harmonised databases of risk factors.

Three applications that were developed for the long, medium and short terms illustrate different types of such comparative analysis.

A long-term analysis of the fatality rates in relation to motorisation rates in some European countries was carried out over the period 1960–2005. A narrow range of vehicle ownership rates was identified within which breakpoints in the fatality rate trend occurred. This range is not the same for different groups of countries, thus reinforcing the need to form groups of European countries with similar socioeconomic characteristics. The main goal that emerges from this is to anticipate the downward point of inflection in those countries where it has not yet been observed.

A three-level descriptive analysis of road risk was carried out in France and the Netherlands on a quarterly basis for the period 1987–2000. Trends in injury accident and fatality risk, assumed to be locally linear, were estimated. The aim was to detect reversals in the slopes or levels of the trends, as soon as they occur. Although some of the risk indicators were not strictly comparable due to different definitions in each country, it is still valid and of interest to compare their changes over the period, as indeed some differences were detected.

The weather condition factor was introduced in an explanatory analysis of monthly accident figures for a long time-period of over twenty years in France, the Netherlands and the Athens region. The main result obtained was a significant positive relationship between the average temperature and the amount of rainfall on the one hand, and the accident numbers on the other, except for the Athens region where the relationship in the case of rainfall was negative, probably due to reduced risk exposure on rainy days. Because the weather effect is not negligible, including it in the short-term monitoring of traffic accidents should improve standard monitoring considerably.

5.4. Outlook

The research carried out during the period 2000–2010 has clearly influenced the development of time-series modelling techniques and applications in Europe and opened the way for developing tools to be used in practice on each level of road safety policy and decision-making, especially by the European Road Safety Observatory or national road safety observatories in each country.

Although a lot has been done there is still room for a continuation of these efforts. Many questions that were already raised in COST 329 remain without a satisfactory answer, especially those related to the lack or inconsistency of data. Thanks to the research performed in the previous decades there is expertise in appropriate methods or techniques, which were applied and validated in many countries and cases. Currently the problem is still the lack of proper data. This calls for the need to continue research, especially in the context of road safety observation at European level, to enable a comparative analysis between European countries. For this reason common and harmonised accident databases have been developed. This is not the case, however, for exposure data or safety performance indicators related to driver behaviour.

The review shows that the challenge lies in implementing time-series analysis models that take into account a small number of risk factors but which could also assess major safety measures. From the European-level perspective this aim can only be achieved by first creating the necessary harmonised risk exposure databases without which no genuine comparative analysis of road safety trends among European States is possible. Other databases, which measure other transitory or lasting risk factors, could be created without difficulty regarding the method and with few resources. Therefore, depending on whether the short-term or medium/long term is concerned, research efforts could be pursued in two directions. First, taking into account transitory factors (weather and calendar configuration) in the analysis of short-term trends and second, taking into account demographic factors in the analysis of long-term trends. These orientations have also been highlighted through the consultation of a panel of experts regarding the lack of the necessary knowledge for assessing the road-safety policy which was carried out in the European DaCoTA project.

REFERENCES

Bates D.M., Watts D.G. (1988). *Nonlinear regression analysis and its applications*. John Wiley & Sons, Inc.

Bergel R. (2001). *A model of temporary effects on road traffic and road risk*. Proceedings of the PTRC Conference, Cambridge.

Bergel R., Debbarh M., Bijleveld F., Commandeur J., Bjleveld F. (2008). *Modelling the three levels of the road risk process at an aggregate level*. Chapter 2 in Stipdonk H. (Ed.) (2008), pp. 29–40.

Bergel R., Cherfi M. (2007). *ARMA-types models*. Chapter 3.4 in Dupont E., Martensen H. (2007), pp. 248–289.

Bergel R. (2007). *DRAG models*. Chapter 3.5 in Dupont E., Martensen H. (2007), pp. 290–294.

Bergel R., Debbarh M. (2008). *Modelling the weather effects on the numbers of injury accidents at an aggregate level in different regions*. Chapter 5.3 in Stipdonk H. (Ed.) (2008), pp. 79–85.

Bergel R. (2007). *Dedicated time series analysis in road safety research.* Chapter 3.3 in Dupont E., Martensen H. (2007), pp. 231–247.

Bergel R., Depire A. (2004a). *Recherche d'une forme fonctionnelle d'un modèle agrégé de risque routier* (*Functional form of an aggregate monthly model for road risk*). Proceedings, Inrets No. 90 of the 2001 work group of the Traffic Modelling Seminar, Arcueil (in French).

Bergel R., Depire A. (2004b). *Climate, road traffic and road risk: an aggregate approach*. Proceedings of the WCTR'04, Istanbul.

Bergel R., Girard B. The RES model by road type in France. In Gaudry M., Lassarre S. (Ed.) (2000). *Structural Road Accident Models – The International DRAG Family*. Pergamon, pp. 237–250.

Bergel R., Carnis L., Lassarre S., Le Breton P., Le Tertre A., Page Y., Thelot B., Uhry Z. (2002). *Amnistie présidentielle et sécurité routière* (*Presidential amnesty and road safety*). Report by a group of experts working for Inrets, Invs, Setra, Lab and the University of Reims Champagne-Ardenne (in French).

Bergel-Hayat R. (2012). Time-Series Models of Aggregate Road Risk and Their Applications to European Countries. *Transport Reviews: A Transnational Transdisciplinary Journal*, 32:5, pp. 653–670.

Bergel-Hayat R. (2008). *The use of explanatory variables in time-series modelling: applications to transport demand and road risk*. PhD Thesis, University Paris-Est (in French).

Bergel R., Girard B., Lassarre S., Le Breton P. (1995). *A model of seasonally corrected indicators of road safety.* Proceedings of the Conference on Road Safety and Strategic Highway Research Program (SHRP) and Traffic Safety on Two Continents, Prague, September 20–22.

Bergel-Hayat R., Debbarh M., Antoniou C., Yannis G. (2013). Explaining the road accident risk: Weather effects. *Accident Analysis & Prevention.* No. 60, pp. 456–465.

Bergel-Hayat R., Żukowska J. (2014). *Structural time series modelling of the number of road fatalities in Poland in relation with economic factors*. TRA 5th conference, Paris, 14–17 April 2014.

Bergel-Hayat R., Żukowska J. (2015). Road safety trends at national level in Europe: a review of time-series analysis performed during the period 2000–12. *Transport Reviews: A Transnational Transdisciplinary Journal*.

Bijleveld F.D. (2005). The covariance between the number of accidents and the number of victims in multivariate analysis of accident related outcomes. *Accident Analysis and Prevention*, 37, pp. 591–600

Bijleveld F., Commandeur J., Koopman S.J., van Montfort K. (2010). Multivariate non-linear time-series modelling of exposure and risk in road safety research. *Journal of the Royal Statistical Society* C 59(1), pp. 145–161.

Bijleveld F.D., Commandeur J.J.F., Gould P., Koopman S.J. (2008). Model-based measurement of latent risk in time series with applications. *Journal of the Royal Statistical Society* Series A, Royal Statistical Society, Vol. 171(1), pp. 265–277.

Bijleveld F.D. (2008). *Time series analysis in road safety research using state space methods*. PhD Thesis, Vrije Universiteit Amsterdam.

Box G.E.P., Cox D.R. (1964) "An analysis of transformations". *Journal of the Royal Statistical Society*, B(2):211–243.

Box G.E.P., Jenkins G.M., Reinsel G.C. (1994) *Time series analysis*, *forecasting and control*. 3rd edition. Prentice Hall, Englewood Cliffs, NJ.

Brandstaetter Ch., Gatscha M. (2007). *Classical linear regression models*. Chapter 3.2.1 in Dupont E., Martensen H. (2007), pp. 177–196.

Brijs T., Karlis D., Wets G. (2008). Studying the effect of weather conditions on daily crash counts using a discrete time-series model. *Accident Analysis and Prevention* 40(3), pp. 1180–1190.

Brockwell P.J., Davis R.A. (1986). *Time series: theory and methods*. Springer Verlag, New York.

Brockwell P.J., Davis R.A. (1988). *Introduction to time series and forecasting*. Springer Verlag, New York.

Broughton J., Amoros E., Bos N., Evgenikos P., Hoeglinger S., Holló P, Pérez C., Tecl J. (2008) *Final Report on Task 1.5* Deliverable D1.15 of the EU FP6 SafetyNet project. http://www.erso.eu.

Brüde U. (1995) What is happening to the number of fatalities in road accidents? A model for forecasts and continuous monitoring of development up to the year 2000. *Accident Analysis & Prevention*, 27, pp. 405–410.

Cameron M., Delaney A. (2008). *Speed enforcement – Effects, mechanisms, intensity and economic benefits of each mode of operation.* Proceedings of the National Conference on High Risk Road Users, Australasian College of Road Safety and The Travelsafe Committee of the Queensland Parliament, Brisbane.

Cameron M., Newstead S., Diamantopoulou K., Oxley P. (2003). *The interaction between speed camera enforcement and speed-related mass media publicity in Victoria*, *Australia.* Proceedings of the 47th Annual Scientific Conference, Association for the Advancement of Automotive Medicine, Lisbon, Portugal.

Cardoso J. L. (2005). The use of international data on fuel sales and vehicle fleet for the estimation of yearly national traffic volume. *Accident Analysis & Prevention*, 37(1), 207–215 AQ25.

Christens P.F. (2003). *Statistical modelling of traffic safety development*. PhD Thesis, Technical University of Denmark, Kongens Lyngky, Denmark.

Christens P.F., Thyregod P. (2003). *New methods for assessing the impact of traffic safety countermeasures*. Trafikdage på Aalborg Universitet.

Commandeur J., de Blois Ch. (2007). *State space models*. Chapter 3.6 in Dupont E., Martensen H. (2007), pp. 295–336.

Commandeur J., De Blois Ch. (2007). *Conclusion time series analysis.* Chapter 3.8 in Dupont E., Martensen H. (2007), pp. 341–344.

Commandeur J., Bjleveld F., Bergel R. (2007). *A multivariate time series analysis applied to SafetyNet data.* SafetyNet Deliverable D7.7 of the EU FP6 project SafetyNet. http://www.erso.eu.

Commandeur J.J.F., Bijleveld F., Bergel-Hayat R., Antoniou C., Yannis G., Papadimitriou E. (2013) On statistical inference in time series analysis of the evolution of road safety. *Accident Analysis & Prevention*. 60 (2013), pp. 424–434.

Commandeur J., Bijleveld F., Stipdonk H. (2008). *Disaggregation by age and gender*. Chapter 4 in Stipdonk, H. (Ed.) (2008), pp. 59–70.

Commandeur J.J.F., Koopman S.J. (2007). *An introduction to state space time-series analysis*. Oxford: Oxford University Press.

Commandeur J.J.F., Bijleveld F., Bergel-Hayat R., Antoniou C., Yannis G., Papadimitriou E. (2013). On statistical inference in time series analysis of the evolution of road safety. *Accident Analysis & Prevention*, 60(2013), pp. 424–434.

COST 329 (2004) *Models for traffic and safety development and interventions*. European Commission, Directorate General for Transport, Brussels, Final Report of the Action.

Diamantopoulou K., Cameron M. (2001). *Development of an index to measure police traffic enforcement effectiveness.* Proceedings, Road Safety Research, Policing and Education Conference, Melbourne.

Dobson A., 1990. *An Introduction to Generalized Linear Models*. 2nd edition. Chapman & Hall, London.

Dupont E., Martensen H. (Ed.) (2007). *Multilevel modelling and time series analysis in traffic safety research – Methodology and Manual*. Deliverables D7.4 and D7.5 of the EU FP6 project SafetyNet. http://www.erso.eu.

Durbin J., Koopman S.J., 2012. *Time Series Analysis by State Space Methods*. 2nd edition. Oxford University Press, Oxford.

ETSC (2013) *Back on track to reach the EU 2020 Road Safety Target?* 7th Road Safety PIN Report. European Transport Safety Council, Brussels

Fridstrom L. et al. (1995). Measuring the contribution of randomness, exposure, weather, and daylight to the variation in road accident counts. *Accident Analysis & Prevention*, Vol. 27, No. 1, pp. 1–20.

Gaudry M. (1984) *DRAG, un modèle de la Demande Routière, des Accidents et de leur Gravité, appliqué au Québec de 1956 à 1982*. Publication 359, Centre de Recherche sur les Transports, Université de Montréal.

Gaudry M., Lassarre S. (Eds.) (2000). *Structural Road Accident Models – The International DRAG Family*. Pergamon.

Gill J. (2000) *Generalized Linear Models: A Unified Approach*. No. 07–134 in Sage University Papers Series on Quantitative Applications in the Social Sciences. Sage University Papers, Thousand Oaks, CA.

Gould P.G., Bijleveld F.D., Commandeur J.J.F. (2004). *Forecasting road crashes: a comparison of state space models*. Paper presented at the 24th International Symposium on Forecasting, 4–7 July 2004, Sydney, Australia.

Gould P.G. (2005*). Econometric modelling of road crashes*. PhD Thesis, Monash University, Australia.

Gouriéroux C., Monfort A. (1990) *Séries temporelles et modèles dynamiques*. Economica.

Hakim S., Hakkert S., Hochermann I., Shefert D. (1991) A critical review of macro models for road accidents. *Accident Analysis & Prevention.* Vol. 23, No. 5, pp. 379–400.

Harvey A.C. (1989) *Forecasting structural time series and the Kalman filter*. Cambridge University Press, Cambridge.

Harvey A.C., Durbin J. (1986) The Effects of Seat Belt Legislation on British Road Casualties: A Case Study in Structural Time Series Modelling. *J. R. Statist. Soc*., Vol. 149 part 3, pp. 187–227.

Hermans E., Wets G., van den Bossche F. (2006a). The frequency and severity of road traffic accidents studied by state space methods. *Journal of Transportation and Statistics*, Vol. 9, No. 1, pp. 63–76.

Hermans H., Wets G., van den Bossche F. (2006b). Describing the Evolution in the Number of Highway Deaths by Decomposition in Exposure, Accident Risk and Fatality Risk. *Transportation Research Record – Journal of the Transportation Research Board*, N 1950, pp. 1–8.

Holló P., Eksler V., Żukowska J. (2010). Road safety performance indicators and their explanatory value: A critical view based on the experience of Central European countries. *Safety Science 2010*, 48, pp. 1142–1150.

Jaeger L., Lassare S. (1999) TAG, un modèle économétrique pour un suivi de l'insécurité routière *Recherche*, *Transport et Sécurité*. Arcueil: *INRETS*, n°, 65. pp. 3–20.

Krystek R., Żukowska J. (2003). *Falling accident risk in Poland*. KONBiN'03. The 3rd Safety and Reliability International Conference, Poland.

Lassarre S. (1994) *Cadrage méthodologique d'une modélisation pour un suivi de l'insécurité routière*. Synthèse INRETS, No. 26, Arcueil.

Lassarre S. (1996) *Quelles tendances dans l'évolution du nombre de tués pour quatre pays*: *Finlande*, *France*, *Grande Bretagne et Pays-Bas*? Document Cost 329, Inrets, Arcueil.

Lassarre S. (2001) Analysis of progress in road safety in ten European countries. *Accident Analysis & Prevention*. Vol. 33, pp. 743–751

Lassarre Tan, in Lassarre (1994) *Cadrage méthodologique d'une modélisation pour un suivi de l'insécurité routière*, Synthèse INRETS, n°26, Arcueil.

Le Breton P., Vervialle F. (1990) "Un modèle de suivi de la sécurité routière". Recherche, Transport et Sécurité. Arcueil: INRETS, No. 27, pp. 33–42.

Muhlrad N., Dupont E. (Eds.) (2010) *Consultation of a panel of experts on the needs for data and technical tools in road safety policy-making*, Deliverable 1.1/4.1 of the EC FP7 project DaCoTA.

Newstead S., Delaney A., Watson L., Cameron M. (2004). *A model for considering the 'total safety' of the light passenger vehicle fleet*. Proceedings, 2004 Road Safety Research, Policing and Education Conference, Perth.

NIST/SEMATECH (2006). *e-Handbook of Statistical Methods*, National Institute of Standards and Technology, http://www.itl.nist.gov/div898/handbook/ (accessed on 15 May, 2006).

OECD (1970) *Proceedings of the symposium on the use of statistical methods in the analysis of road accidents.* Crowthorne, April 1969. OECD, Paris.

OECD/ITF (2008) *Towards Zero*: *Ambitious Road Safety targets and the Safety System Approach*. OECD, Paris.

ONISR (2012). *La sécurité routière en France: bilan de l'année 2011*. La Défense: Ministère de l'Interieur.

Oppe S. (1991) The development of traffic and traffic safety in six developed countries. *Accident Analysis & Prevention.* Vol. 23, No. 5, pp. 401–412

Oppe S., Koornstra M.J. (1990) A mathematical model for related long-term developments of road traffic and safety. In Koshi, M. (Ed), *Transportation and Traffic Theory*. Elsevier, New York, pp. 113–133.

Oppe S. (2001). *International comparisons of road safety using Singular Value Decomposition*. SWOV Report D-2001-9. SWOV: Leidschendam.

Oppe S., Bijleveld F.D. (2003). *Reanalysis of traffic enforcement data from Victoria*. SWOV report D-2003-6. SWOV: Leidschendam.

Oxley P., Cameron M., Newstead S. (2003). *Estimation of the safety benefits of a vehicle replacement programme in Victoria.* Proceedings, 2003 Road Safety Research, Policing and Education Conference, Sydney.

Papadimitriou E., Yannis G., Bijveled F., Cardoso J. (2013). Exposure data and risk indicators for safety performance assessment in Europe, *Accident Analysis & Prevention*. Vol. 60, pp. 371–383.

Pelzman S. (1975). The effects of automobile safety regulation. *Journal of Political Economy*, 83(4), pp. 677–725.

Rivelott R., Lopez de Sabando I. (2004). *ARIMA and Box-Jenkins models for injury accidents in Spain*. In COST 329 (2004), pp. 159–171.

Scott P.P. (1986). Modelling Time Series of British Road Accident Data. *Accident Analysis & Prevention*, Vol. 18, No. 2, pp. 109–117.

Smeed R.J. (1949). Some statistical aspects of road safety research. *Journal of the Royal Statistical Society*, A 112(1), pp. 1–24.

Stipdonk H., Bijleveld F., van Norden Y., Commandeur J. (2012) Analysing the development of road safety using demographic data. *Accident Analysis & Prevention*, 60, 435–444.

Thorensen T., Fry T., Heiman L., Cameron M. (1992). *Linking economic activity, road safety countermeasures and other factors with Victorian road toll*. Report No. 29, Monash University Accident Research Centre, Clayton, Victoria AQ45.

Van den Bossche F., Wets G. (2003). *A structural road accident model for Belgium*. (RA-2003-21) Technical report, Policy Research Centre for Traffic Safety, Diepenbeek, Belgium.

Van den Bossche F., Wets G., Brijs T. (2004a). *A regression model with ARMA errors to investigate the frequency and severity of road traffic accidents*, in "Electronic Proceedings of the 83rd Annual Meeting of the Transportation Research Board", January 11–15,m 2004, Washington D.C., USA.

Van den Bossche F., Wets G., Brijs T. (2004b). Role of exposure in analysis of road accidents: a Belgian case study. *Transportation Research Record – Journal of the Transportation Research Board*. 1908, pp. 96–103.

Van den Bossche F., Wets G., Brijs T. (2006). *Predicting road crashes using calendar data*. Electronic Proceedings of the 85th Annual Meeting of the Transportation Research Board.

Van den Bossche F. (2006). *Road safety*, *Risk and exposure in Belgium*. PhD Thesis, Universitet Hasselt.

Van den Bossche F., Wets G., Brijs T. (2007). *Analysis of road risk per age and gender category: a time-series approach*. Electronic Proceedings of the 86th Annual Transportation Research Board Meeting, 21–25 January, Washington D.C, USA.

Washington S.P., Karlaftis M.G., Mannering F.L. (2003). *Statistical and Econometric Models for Transportation Data Analysis*. Chapman & Hall/CRC (2003).

WHO (2013). *Global status report on road safety 2013: supporting a decade of action*. World Health Organisation, Geneva.

Yannis G., Papadimitriou E., Lejeune Ph., Treny V., Hemdorff S., Bergel R., Haddak M., Holló P. Cardoso J., Bijleveld F., Houwing S., Bjornskau T. (2005). *State of the Art Report on Risk and Exposure Data*. SafetyNet Deliverable 2.1. http://www.erso.eu

Yannis G., Antoniou C., Papadimitriou E. (2007). Road casualties and enforcement: distributional assumptions of serially correlated count data. *Traffic Injury and Prevention*, Vol. 8, Issue 3, 2007, pp. 300–308.

Yannis G., Antoniou C., Papadimitriou E. (2011). Autoregressive non-linear time-series modelling of traffic fatalities in Europe. *European Transport Research Review* (2011) 3:113–127.

Yannis G., Antoniou C., Papadimitriou E., Katsochis D. (2011). When may road fatalities start to decrease? *Journal of Safety Research*, 2011; 42(1): 17–25.

Yannis G., Antoniou C., Katsochis D., Papadimitriou E. (2008). *Impact of meteorological variables on the number of injury accidents and fatalities in the Athens Region*. Chapter 5.2 in Stipdonk H. (Ed.) (2008), pp. 72–77.

Żukowska J. (2003). *Traffic risk modelling using time series*. PhD Thesis. Gdańsk University of Technology, Poland.

Żukowska J. (2004). *Traffic fatalities modelling using time series.* International Workshop on Rehabilitation of Existing Urban Building Stock. June 17–19, 2004. Gdańsk University of Technology, Poland.

Żukowska J. (2012). Road safety analysis in Poland using time-series modelling techniques. *Journal of Polish Safety and Reliability Association Summer Safety and Reliability Seminars*, Vol. 3, No. 1–2, 2012.

ANNEX

This annex provides a list of available abstracts, for an easy-to-read overview of the literature. The English of the original abstracts has been harmonised.

Monash University Accident Research Centre (MUARC)

Diamantopoulou K., Cameron M. (2001). *Development of an index to measure police traffic enforcement effectiveness*. Proceedings, Road Safety Research, Policing and Education Conference, Melbourne, Australia.

The aim of the research was to develop a procedure that would measure traffic enforcement effectiveness levels for each Victoria Police Region. The development of this measure of effectiveness referred to as the Police Effectiveness Index or the Output Performance Index was achieved using structural time-series regression modelling techniques. Relationships were developed that connected monthly crashes in each of the five Police Regions with monthly variations in variables representing exposure, enforcement activity and other factors for 1989–1997. Crash and enforcement data were obtained from the Victoria Police. The models developed for each region revealed the relative contribution of an increase in each enforcement operation to reducing the risk of casualty crashes. The reductions were found after the effects of exposure changes and other factors had been taken into account. A monthly output performance index for each region was developed for January–December 1998. Some variation was found in the monthly indices both between and within regions. Relative to the previous year, 1997, the police performed better than expected on average during the first quarter of 1998, but decreased their output performance for the rest of the year.

The value of the output performance index to police is that it specifies for which enforcement operations the police should increase their resources per region to reduce the risk of casualty crash. The index also allows for the assessment and comparison of the effect on road safety of different enforcement activities both within and among Police Regions. The application of a relatively new statistical analysis technique, structural time-series modelling, has offered increased power and flexibility in the modelling of crashes compared to traditional multivariate regression methods.

Cameron M., Delaney A. (2008). *Speed enforcement – Effects, mechanisms, intensity and economic benefits of each mode of operation.* Proceedings of the National Conference on High Risk Road Users, Australasian College of Road Safety and The Travelsafe Committee of the Queensland Parliament, Brisbane, Australia.

Significant programmes of speed enforcement have been in operation in a number of State and international jurisdictions for some time and many have been the subject of rigorous evaluation. Such programmes aim to reduce crash frequency and/or injury severity through reductions in mean speed and/or changes to the speed distribution. In broad terms, the speed enforcement programmes evaluated have been demonstrated to be beneficial in reducing road trauma. However, it is only by examining the individual characteristics of such programmes that the mechanisms of effect become evident and information useful for the development of new speed enforcement programmes can be obtained. This paper describes the speed enforcement programme evaluations and the information concerning the relationship between enforcement intensity and programme outcomes that they contain. Such analysis was conducted for all major speed enforcement modes, including mobile and fixed speed cameras operated overtly or covertly (including point-to-point average speed cameras), moving mode radar and hand-held laser speed detectors. An economic analysis of programme outcomes was also conducted for each of these modes. This analysis was used to inform the development of a new speed enforcement strategy for Western Australia (WA) that can be expected to reduce road fatalities by 25 percent in a cost-efficient way.

Cameron M., Newstead S., Diamantopoulou K., Oxley J. (2003). *The interaction between speed camera enforcement and speed-related mass media publicity in Victoria, Australia.* Proceedings of the 47th Annual Scientific Conference, Association for the Advancement of Automotive Medicine, Lisbon, Portugal.

The objective was to measure the presence of any interaction between the effect of mobile covert speed camera enforcement and the effect of intensive mass media road safety publicity with speed-related themes. During 1999, the Victoria Police varied the levels of speed camera activity substantially in four Melbourne police districts according to a systematic plan. Camera hours were increased or reduced by 50% or 100% in respective districts for a month at a time, during months when speed-related publicity was present and during months when it was absent. Monthly frequencies of casualty crashes, and their severe injury outcome, in each district during 1996–2000 were analysed to test the effects of the enforcement, publicity and their interaction. Reductions in crash frequency were associated monotonically with increasing levels of speed camera ticketing, and there was a statistically significant 41% reduction in fatal crash outcome associated with very high camera activity. High publicity awareness was associated with 12% reduction in crash frequency. The interaction between the enforcement and publicity was not statistically significant.

Oxley J., Cameron M., Newstead S. (2003). *Estimation of the safety benefits of a vehicle replacement programme in Victoria.* Proceedings, 2003 Road Safety Research, Policing and Education Conference, Sydney, Australia.

Australia is facing an ageing and polarising-market passenger vehicle fleet. Changes in the composition may have substantial road safety implications in terms of the fleet's overall crashworthiness. This study focuses on Victoria, and assessed the current and past passenger fleet composition in terms of vehicle age by market group. Based on current trends, such as population rates, new vehicle sales and market group trends, a scrap page function by age of vehicle has been estimated to project the vehicle fleet to 2012. By manipulating key inputs and outputs to the system, deviations from this baseline projection have been estimated from a range of scenarios, to examine changes in vehicle fleet composition from various external influences to the system. The overall purpose of this estimation procedure will be in estimating the crashworthiness, and intrinsic aggressivity, of those projected fleets to give an overall estimation of fleet crashworthiness under the various scenarios. This will help to determine the effect of a particular change to the system, for example a policy change, and to measure the effect on the overall safety of the vehicle fleet over time.

Newstead S., Delaney A., Watson L., Cameron M. (2004). *A model for considering the 'total safety' of the light passenger vehicle fleet*. Proceedings, 2004 Road Safety Research, Policing and Education Conference, Perth, Australia.

This paper described the results of research to develop and apply a comprehensive model to consider the influence of the mix of vehicle types in the fleet on the total safety of the light passenger vehicle fleet in Australia. Key inputs to the model are estimates of the crashworthiness and aggressivity of light passenger vehicles in the key crash types representing the majority of crashes in which these vehicles are involved. They include crashes between two light vehicles, single vehicle crashes, crashes with heavy vehicles and crashes with unprotected road users such as pedestrians and bicyclists. The model combines these key crashworthiness inputs with measures of crash exposure of each vehicle class in the fleet mix to estimate the average injury outcome in all crashes involving the light vehicle fleet. By varying the key parameters of the model, it is possible to examine the effects on the average safety of the light vehicle fleet resulting from changes to the mix of types of vehicles in the fleet. Application of the model is demonstrated through a number of scenarios varying the mix of vehicles in the fleet by broad market group classification. Scenarios considered include natural changes in market group mix of the fleet in recent times and projected over the next 10 years, elimination of various market groups from the fleet, homogeneous fleets composed of a single market group, and fleets composed of only vehicles with the best possible safety performance in each market group. Results of applying the model to the various scenarios considered point to how the vehicle fleet mix might best be manipulated in the future to optimise average safety outcomes. They are also able to quantify the safety outcomes resulting from recent current and projected future trends in vehicle fleet mix.

Gould P.G. (2005). *Econometric modelling of road crashes*. PhD Thesis, Monash University, Australia.

The aim of this thesis was to show how econometric time-series methods can and should be applied to road crash data, for the purpose of understanding and explaining the past and forecasting into the future. The unobserved components modelling framework is reviewed in detail, and popular model structures are estimated for Victorian and international data.

Models using a range of socioeconomic explanatory variables are applied to Victorian accident data. Results show that it is unrealistic to expect models to produce sensible regression relationships unless data is appropriately disaggregated and the model is carefully structured. As a result, a latent risk model was developed to measure the evolution of exposure to accidents, accident risk and accident severity in a multivariate setting. Although regression variables can be used, the latent risk structure explicitly models the evolution of key determinants of road safety without requiring an exhaustive list of (possibly correlated) covariates. The generality and flexibility of the latent risk model is highlighted through applications to road safety and financial data. The structure is shown to provide valuable insights into the risk of and exposure to Victorian road fatalities.

A univariate unobserved components model for signal extraction and forecasting of multiple seasonal data was developed and applied to hourly vehicle count data. The new model is shown to provide superior forecasts to other univariate models while also offering potential reductions in the number of seeds required for initialisation.

Transportation Research Institute (IMOB) of Hasselt University

Van den Bossche F., Wets G. (2003). *A structural road accident model for Belgium*. (RA-2003-21) Technical report, Policy Research Centre for Traffic Safety, Diepenbeek, Belgium.

The objective of this study was to enhance the understanding of the complex influence of various factors on the number of accidents and their severity. A database with a broad set of explanatory variables was created for Belgium for the years 1986 to 2000. The model expresses the number and severity of accidents in terms of a whole range of explanatory variables, using a structural multivariable approach. Apart from the use of advanced regression techniques, the model provides a means to quantify the impact of both policy variables and factors that cannot be influenced.

The model developed in this study consists of four equations to explain the frequency (the number of accidents with injuries and deaths), and the severity (number of injured and dead) of accidents. After an overview of the dependent and independent variables, some details on the methodology are provided. These are necessary to understand the discussion of the BC-GAUHESEQ modelling approach, which has been used here. In the section on results, the outcomes of the models are presented and discussed. Lastly, some general conclusions and topics for model improvement and further research are provided.

Brijs T., Karlis D., Wets G. (2008). Studying the effect of weather conditions on daily crash counts using a discrete time-series model. *Accident Analysis and Prevention*, 40(3), 1180–1190.

In previous research, significant effects of weather conditions on car crashes have been found. However, most studies use monthly or yearly data and only few studies analysing the impact of weather conditions on daily car crash counts are available. Furthermore, the studies that are available on a daily level do not explicitly model the data in a time-series context, thereby ignoring the temporal serial correlation that may be present in the data. In this paper, we introduce an integer autoregressive model for modelling count data with time interdependencies. The model is applied to daily car crash data, meteorological data and traffic exposure data from the Netherlands, with the aim of examining the risk impact of weather conditions on the observed counts. The results show that several assumptions related to the effect of weather conditions on crash counts are found to be significant in the data and that if serial temporal correlation is not allowed for in the model, this may produce biased results.

Van den Bossche F.; Wets G., Brijs T. (2004a). *Role of exposure in analysis of road accidents: a Belgian case study*. *Transportation Research Record – Journal of the Transportation Research Board*. 1908, 96–103.

Exposure is a key variable in traffic safety research. In the literature, it is noted as the first and primary determinant of traffic safety. In many cases, however, no valid exposure measure is available. In Belgium, monthly traffic counts for twelve years are available. This offers the opportunity to investigate the added value of exposure in models, alongside legal, economic and climatic variables. Multiple regression with autoregressive moving average (ARMA) errors was used to quantify the impact of these factors on aggregated traffic safety. For each dependent variable, a model with and without exposure was built. The models show that exposure is significantly related to the number of accidents with persons killed and seriously injured and to the corresponding victims, but not to the slightly injured outcomes. Moreover, the addition or deletion of exposure does not influence the effects of the remaining variables in the model.

The effects of exposure clearly depend on the type of measure used and on the time horizon considered. The framework of a regression model with ARMA errors allows for missing variables to be taken into account by the error term. Even without a variable such as exposure, valid models can be constructed.

Hermans E.; Wets G., Van den Bossche F. (2006a). *The frequency and severity of road traffic accidents studied by state space methods*. *Journal of Transportation and Statistics*, Vol. 9, N°1, pp. 63–76.

In this paper we investigate the monthly frequency and severity of road traffic accidents in Belgium from 1974 to 1999. We described the trend in the time series, quantified the impact of explanatory variables and made predictions. Laws concerning seat belts, speed and alcohol have proven successful. Furthermore, frost enhances road safety while sun has the opposite effect. Precipitation and thunderstorms particularly influence accidents with slight injuries. Economic conditions have a limited impact. The methodology used throughout the analysis is a state-space one. The results of this study are compared to those of an earlier research project applying a regression model with autoregressive moving average errors on the same data. A lot of similarities between these two approaches have been found.

Hermans H., Wets G., Van den Bossche F. (2006b). *Describing the Evolution in the Number of Highway Deaths by Decomposition in Exposure, Accident Risk and Fatality Risk*. *Transportation Research Record – Journal of the Transportation Research Board*, N 1950, pp. 1–8.

The general purpose of this research is to improve insight into road safety on Belgian motorways by means of a layered model. The monthly number of persons killed on motorways in Belgium was decomposed into three parts: exposure, accident risk, and fatality risk, and the evolution in each of these dimensions was investigated separately. More specifically, for each dimension a descriptive and explanatory analysis revealed the optimal unobserved components model, while the separate analysis of each dimension revealed different underlying developments. The impact of meteorological, socioeconomic, legislative and calendar factors on exposure, accident risk and fatality risk was investigated. The analysis indicates that, although for each dimension the same basic components are available, the optimal model of each dimension has its own unique structure of descriptive components and significant variables. Precipitation and snow enhance accident risk, while temperature plays a significant role for exposure. The fatality risk decreases in the case of an extra day with precipitation and was affected significantly by the child restraint law. The economic indicators mainly affect accident risk. When the three models are brought together, the number of motorway deaths between 1993 and 2001 is well reconstructed.

Van den Bossche F.; Wets G., Brijs T. (2006). *Predicting road crashes using calendar data*. Electronic Proceedings of the 85th Annual Meeting of the Transportation Research Board.

In road safety, macroscopic models are developed to support the quantitative targets in safety programmes. Targets are based on estimated numbers of fatalities and crashes that are typically derived from models. When constructing these models, typical problems are the lack of relevant data, the limited time horizon and the availability of future values for explanatory variables. As a solution to these restrictions, we suggest the use of calendar data. These include a trend, a trading day pattern, dummy variables for the months and a heavy traffic measure. In this paper we tested the relevance of calendar data for the explanation and prediction of road safety. ARIMA models and regression models with ARMA errors and calendar variables were built, predictions were made using both models, and the quality of the predictions was compared. We used Belgian monthly crash data (1990–2002) to develop models for the number of persons killed or seriously injured, the number of persons slightly injured and the corresponding number of crashes. The regression models fit better than the pure ARIMA models. The trend and trading day variables are significant for the outcomes related to killed or seriously injured persons, while the heavy traffic measure is significant in all models. The predictions made by the regression models are better than those from the ARIMA models, especially for the slightly injured outcomes.

Van den Bossche F. (2006). *Road safety, Risk and exposure in Belgium*. PhD Thesis, Universitet Hasselt.

The purpose of this research was to investigate the relation between road safety, exposure and risk in Belgium, using time-series data at various aggregation levels. The connecting thread is the decomposition of road safety into "risk" and "exposure to risk".
Introductory chapters present the Belgian road safety situation and an overview of available data sources for road safety analysis. In addition, a methodology is developed to create a monthly measure of exposure for Belgium. The research contribution consists of four parts. First, aggregated road safety models were developed for Belgium. Alternative functional forms and a non-proportional exposure-risk relation were introduced, and road safety interventions were tested in this setting.

Second, regression-ARIMA models with GARCH residuals were created to measure direct and indirect effects of exposure for different types of injuries. Stylised experiments visualised the turning points in the relation between exposure and road safety.

Third, "subset" models were introduced to disaggregate outcomes by age and gender, type of road user and type of road. A comparative risk analysis was performed for various types of road user, by means of relative risk curves and risk indices. For two-sided accidents, the importance of the ratio – instead of the levels – of exposure measures of different transport modes has been demonstrated.

Fourth, disaggregated analyses based on Flemish travel survey data were carried out, showing the potential of this data for the analysis of the road safety of vulnerable road users.

Van den Bossche F., Wets G., Brijs T. (2007). *Analysis of road risk per age and gender category: a time-series approach. Electronic Proceedings of the 86th Annual Transportation Research Board Meeting*, 21–25 January, Washington D.C, USA.

This paper introduces a road safety analysis for different age and gender categories of road users. In contrast with many previous studies, time series of road crashes per age and gender category were considered. The objective of the paper was to analyse Belgian data on the yearly number of fatalities per age and gender group, using a decomposition of the number of fatalities in terms of exposure and risk, from a time-series perspective. For each category, a state space time-series model was developed for the risk, which is defined as the number of fatalities divided by the size of population. It was found that road risk changes over the age groups following a U-shaped curve, and that men generally have a higher risk than women. Further, the risk decreases over time, but not at the same rate for all age-gender groups. The highest yearly reduction in risk was found for the oldest and youngest road users.

The models are also useful to assess the attainability of formulated road safety targets, which makes them useful policy instruments. Especially for young males, the reduction in risk is not in line with Belgian and Flemish policy expectations.

Danish Transport Research Institute (DTU)

Christens P.F. (2003). *Statistical modelling of traffic safety development.* PhD Thesis, Technical University of Denmark, Kongens Lyngky, Denmark.

Road safety is a major concern for society and individuals. Although road safety has improved in recent years, the number of road fatalities is still unacceptably high. In 2000, road accidents killed over 40,000 people in the European Union and injured more than 1.7 million. In Denmark in 2001 there were 6861 injury traffic accidents reported by the police, resulting in 4519 minor injuries, 3946 serious injuries, and 431 fatalities.

The general purpose of the research was to improve the insight into aggregated road safety methodology in Denmark. The aim was to analyse advanced statistical methods, which were designed to study developments over time, including effects of interventions. This aim has been achieved by investigating variations in aggregated Danish traffic accident series and by applying state of the art methodologies to specific case studies.

The thesis comprises an introduction to accident data, and influential factors such as changing traffic volumes and demographic and economic trends. It highlights the limitations in the influential factors data structure, in particular, their strong covariance and slow development over time.

An important issue in this thesis was to investigate the time dependency in the accident series. The thesis shows that the monthly observations of accidents are serially correlated and that this correlation can only partly be explained by the explanatory variables. One should therefore use dynamic modelling techniques to analyse variations in accident series. The thesis demonstrates that the general decreasing tendency in the accident series has its own slow pattern, which cannot be explained by recorded descriptive variables.

Christens P.F., Thyregod P. (2003). *New methods for assessing the impact of traffic safety countermeasures*. Trafikdage på Aalborg Universitet, Denmark.

This paper investigated new methods for assessing the impact of traffic safety countermeasures on the number of accidents or injuries. The primary aim of this paper was to show in general how statistical methods that take development over time into account may be used when assessing the impact on traffic safety data. A secondary aim was to specifically investigate the effect of a change in the police accident reporting routine in 1997 on the injury classification.

A salient characteristic in most monthly traffic safety data is a fluctuating trend and seasonal pattern. Some of the fluctuation can be explained, but in order to have a reliable assessment of the countermeasures the evaluation methods have to capture this fluctuation. State space models provide a framework, where these characteristics can be investigated and modelled explicitly. The change in police reporting practice led in 1998 to a 49% decrease [35%; 60%] decrease in the reported number of head injuries in Copenhagen and in 1997 to a 37% [27%; 46%] decrease outside Copenhagen. An estimate of the actual traffic safety in 1998 measured in the number of serious injuries could be the reported number corrected by an additional 670 injuries due to this change in reporting.

IFSTTAR and University Paris-1 Panthéon-Sorbonne

Bergel R., Depire A. (2004a) *Recherche d'une forme fonctionnelle d'un modèle agrégé de risque routier* (Functional form of an aggregate monthly model for road risk). Proceedings, Inrets N° 90 of the 2001 work group of the Traffic Modelling Seminar, Arcueil, France (in French).

This document presents a monthly model that explains changes in the numbers of injury accidents and fatalities on main roads and motorways in France. Two risk factors have been taken into account: exposure to risk, measured by a primary variable of traffic volume, and the climatic factor, measured by secondary variables relating to rainfall, temperature and occurrence of frost (sub-zero temperatures).

A model with logarithmic transformation on the endogenous variable and Box-Cox transformation on the principal exogenous variable was constructed for the period 1975–1993, then for the extended period 1975–1998. Different validation tests of comparison with two particular cases were used, over the two periods, and produced the same conclusions.

There is no significant difference between the model with Box-Cox transformation on the principal exogenous variable and the model with logarithmic transformation on the principal exogenous variable ($\lambda = 0$); therefore, for the sake of parsimony, it is possible to opt for the latter specification, which is widely used.

Nevertheless, using the optimal functional form makes it possible to relax the hypothesis of a constant elasticity and to take into account saturation effects of the traffic volume.

Bergel R., Girard B. The RES model by road type in France. In Gaudry M., Lassarre S. (Ed.) (2000) *Structural Road Accident Models –The International DRAG Family*, Pergamon, pp. 237–250.

This work presents a monthly model of the changes in the numbers of vkt, injury accidents and fatalities on main roads and toll motorways in France for the period 1975–1993, both with a univariate and with a bivariate approach. Several risk factors have been taken into account: exposure to risk measured by the traffic volume on each network, mobility factors measured by the final household consumption, fuel prices and the length of the motorway network, and the climatic factor, measured by secondary variables relating to rainfall, temperature and occurrence of frost (sub-zero temperatures).

First, a model with logarithmic transformation on the endogenous variable (whether the number of vkt, injury accidents or fatalities) and Box-Cox transformation on the exogenous variables was constructed and tests of comparison with two particular cases ($\lambda = 0$) and ($\lambda = 1$) were used. There was no significant difference with the first case whereas this happened with the second case, and the logarithmic transformation on the exogenous variables could thus be chosen for reasons of parsimony. Elasticity values wrt the exogenous variables were also provided. Second, the bivariate approach appeared to be more significant than the univariate one, as the interaction between the numbers of injury accidents on the two networks (fatalities respectively) was captured by the bivariate model. Simulations of the changes in the endogenous variables for some years ahead were provided, and the model worked well for the medium-term.

Bergel R. (2001). *A model of temporary effects on road traffic and road risk*. Proceedings of the PTRC Conference, Cambridge, UK.

This paper highlights the importance of temporary effects due to weather conditions and the calendar configuration on road traffic and road risk. These factors result in very great fluctuations in the volume of traffic and in the number of injury accidents and road traffic victims, which have to be evaluated on a daily basis since their effects are much weaker when evaluated on a monthly basis.

We proposed a method for quantifying the effect of weather conditions and the effect of the calendar. The effects of these factors on the numbers of vehicle-kilometres and the numbers of injury accidents and fatalities were evaluated using a model with a periodicity of a single day for the period 1985–1999.

Bergel R., Carnis L., Lassarre S., Le Breton P., Le Tertre A., Page Y., Thelot B., Uhry Z. (2002). *Amnistie présidentielle et sécurité routière (Presidential amnesty and road safety).* Report by a group of experts working for Inrets, Invs, Setra, Lab and the University of Reims Champagne-Ardenne, France.

The purpose of this work was to determine whether a relationship can be established between the presidential amnesty that is traditionally given to traffic offenders for offences committed in the run-up to the presidential election in France and the road safety level. The analysis is limited to the statistics of fatalities and to the 1988 and 1995 elections, for which the information about the amnesty was covered in the media.

Among different approaches, an ARIMA analysis including various seasonal and economic variables and interventions was chosen and conducted on the monthly number of fatalities for the period 1975–2001. The results suggested that fatalities increased by 7% per month on average during the ten months preceding the first election in 1988 and by 4% during the seven months preceding the second one in 1995. In absolute numbers, more than 500 deaths could thus be attributed to the first amnesty in 1988 and around 200 deaths in 1995.

Bergel-Hayat R. (2012). *Time-Series Models of Aggregate Road Risk and Their Applications to European Countries*, Transport Reviews: A *Transnational Transdisciplinary Journal*, 32:5, 653–670

This paper describes how time-series analysis of road risk has been conducted at national level in Europe since Smeed's seminal study of 1949. The first part of the paper surveys European applications of time-series analysis to road safety since the beginning of the 1980s. This is followed by a historical overview of the various approaches adopted, and the different types of model used to analyse changes in road risk are given, with reference to the historical overview. The last part of the paper presents recent modelling conducted in the framework of the EU FP6 project "SafetyNet – Building the European Road Safety Observatory", which ran from 2004 to 2008, the aim of which was to gather harmonised databases from the Member States and perform a comparative monitoring of trends. Recommendations for using dedicated models which handle time dependency when applied to road safety were given. Applications to a number of national datasets, including from France, Greece and the Netherlands, have shown different ways in which risk exposure can be included in the models in order to conduct a comparative analysis of trends. Research directions for extending these comparative analyses are also given.

Bergel R., Depire A. (2004b). *Climate, road traffic and road risk: an aggregate approach*. Proceedings of the WCTR'04, Istanbul, Turkey.

This paper analysed the influence of climate on the number of injury accidents and fatalities, aggregated for the whole of France, and for each main network category (main roads, motorways, secondary roads and urban roads).

A time-series analysis including exogenous variables was developed for each indicator of accident risk and severity, on a monthly basis for the period 1975–1999. Risk exposure, when available, and transitory risk factors such as climate and calendar configuration were taken into account. The climate variables measure rainfall and temperature. Both monthly averaged variables and atypical variables – which take into account the extreme climate values in the month – were used as climate variables.

The results of this analysis show significant links between the climate variables and the risk indicators, on the whole of France and on network categories as well. On main roads and motorways, the two road categories on which the traffic volume is measured on a monthly basis, the global effect of climate has been separated into two components: its direct effect on the number of injury accidents and fatalities, the traffic volume being constant, and its indirect effect via the traffic volume.

Variations of the risk level have been highlighted in certain situations, under the influence of rainfall and temperature variations. These aggregate results need to be analysed further on a daily basis, and the links with behavioural variables need to be studied, in order to complete these first results.

Bergel-Hayat R. (2008). *The use of explanatory variables in time-series modelling: applications to transport demand and road risk*. PhD Thesis, University Paris-Est, France.

This thesis sets out a methodology that includes time-series modelling exogenous effects measured by additional variables. This methodology is illustrated by a number of applications relating to transport. In these applications, time is measured in days, months, quarters and semesters (half years). The aim was to take into account exogenous effects which are either transitory or lasting and which manifest themselves in the short term.

The first part of the thesis deals with time-series modelling, with a typology of time-series models, and places the approach within it. It describes the approach used in ARMA modelling with explanatory variables and then in state space modelling with explanatory variables, paying special attention to structural time-series modelling.

The second and third parts bring together two groups of applications. The first group considers traffic datasets, for passengers and for freight, aggregated by mode and by main network type. The second group considers numbers of road injury accidents and casualties, aggregated by main network type. The longest period covered is 1970–2000.

Most of the applications address the transitory effects on transport demand and road risk of weather and calendar factors. The first detailed results are given; they demonstrate the significance of the weather factor on road safety in France, measured by numbers of injury accidents and fatalities.

Bergel-Hayat R., Christoforou Z., Ferrière S. (2013). *The impact of the economic crisis on road mortality: an explanatory approach for some countries in Europe*. Proceedings,of the ETC Conference, 30 October-2d November 2013, Frankfurt, AET.

In some European countries, the economic crisis seems to have resulted in a relevant improvement of their road safety level. As a consequence, a worsening of these levels is to be expected once the period of economic crisis comes to an end, and this is a major concern for the countries that are severely affected by the crisis. For all bodies which analyse road safety trends at international level (the European Road Safety Observatory, the IRTAD group from OCDE) – not only over the past but also in the future – this is a major challenge. This exploratory approach focuses on several countries in Europe including France, Greece, Italy, Portugal and Spain. The objective was to highlight how the changes in road mortality are related to the changes in economic variables. A comparative analysis of their development has been carried out, and the relationship between the number of road fatalities and two key economic variables – the GDP per capita and the unemployment rate – has been investigated.

National Technical University of Athens (NTUA)

Yannis G., Antoniou C., Papadimitriou E. (2007). *Road casualties and enforcement: distributional assumptions of serially correlated count data*, *Traffic Injury and Prevention*, Vol. 8, Issue 3, 2007, pp. 300–308.

Road safety data is often in the form of counts and is usually temporally correlated. The objective of this research was to investigate the distributional assumptions of road safety data in the presence of temporal correlation.

Using the generalised linear model framework, four distributional assumptions are considered: normal, Poisson, quasi-Poisson and negative binomial, and appropriate models are estimated. Monthly casualty and police enforcement data from Greece for a period of six years (January 1998–December 2003) were used. The developed models include sinusoidal latent terms to capture the temporal serial correlation of observations. Several statistical goodness-of-fit diagnostic tests were performed for the results of the estimated models, and the predictive capabilities of the models were investigated.

The residuals of the quasi-Poisson and negative binomial models do not show any serial correlation. The signs of the estimated coefficients for all models are consistent and intuitive. In particular, a negative coefficient value for the number of breath alcohol tests indicates that the number of persons killed or seriously injured decreases as the number of breath alcohol tests increases. The Poisson model fails to capture the over-dispersion in the data, thus underestimating the standard errors of the estimated coefficients.

The results suggest that the quasi-Poisson and negative binomial models outperform the normal and Poisson models in this application. The findings of this research demonstrate a clear link between the intensification of police enforcement and the reduction in traffic accident casualties. In particular, an increase in the number of breath alcohol tests in Greece after 1998 contributed to a reduction in the number of persons killed or seriously injured from traffic accidents.

Yannis G., Antoniou C., Papadimitriou E. (2011). *Autoregressive non-linear time-series modelling of traffic fatalities in Europe. European Transport Research Review* (2011) 3:113–127.

The aim of this paper was to provide a parsimonious model for linking motorisation level with the decreasing fatality rates observed across EU countries during the last three decades. A macroscopic analysis of road safety in Europe at country level is proposed through the application of non-linear models correlating fatalities and vehicles for the period between 1970 and 2002. Given the time-series nature of road safety data, these models result in auto-correlated residuals, thus violating at least one of the assumptions of non-linear regression. Autoregressive forms of the considered models that overcome these limitations and provide superior predictive capabilities were also considered.

Results show that an autoregressive log-transformed model seems to outperform the base autoregressive non-linear model in this respect. The use of these models made it possible to identify the best and worst performing countries. The proposed models can prove useful for assessing the road safety performance of the countries examined, as well as for obtaining some insight into the current and future trends of less developed countries.

Yannis G., Antoniou C., Papadimitriou E., Katsochis D. (2011). *When may road fatalities start to decrease*? *Journal of Safety Research* 2011; 42(1):17–25.

The comparative analysis of macroscopic trends in road safety has been a popular research topic. The aim of this research is to propose a simple and, at the same time, reliable multiple-regime model framework for international road safety comparisons, allowing for the identification of slope changes of personal risk curves and respective breakpoints. The method chosen was to examine the trends of road traffic fatalities in several EU countries through the temporal evolution of elementary socioeconomic indicators, namely motorised vehicle fleet and population, at country level.

Piece-wise linear regression models have been fitted, using a methodology that allows the simultaneous estimation of all slopes and breakpoints. The number and location of breakpoints, as well as the slope of the connecting trends, vary between countries, thus indicating different road safety evolution patterns. As for the impact on industry, macroscopic analysis of road accident trends may prove to be beneficial for the identification of best examples and the implementation of appropriate programmes and measures, which will lead to important benefits for society and the economy through the reduction of road fatalities and injuries. Best-performing countries and the related programmes and measures adopted may concern several safety improvements at the level of roads, vehicles and insurance industries.

Lessons from the analysis of past road safety patterns of developed countries provide some insight into the underlying process that relates motorisation levels with personal risk and can prove to be beneficial for predicting the road safety evolution of developing countries that may not yet have reached the same breakpoints. Furthermore, the framework presented here may serve as a basis to build more elaborate models, including more reliable exposure indicators (such as kilometre vehicle travelled, *kvt*).

Institute for Road Safety Research (SWOV) and University of Amsterdam

Bijleveld F. D. (2005). The covariance between the number of accidents and the number of victims in multivariate analysis of accident related outcomes. *Accident Analysis and Prevention*, 37, 591–600.

In this study several statistical issues involved in the simultaneous analysis of accident-related outcomes of the road traffic process were investigated. Since accident-related outcomes such as the number of victims, fatalities or accidents show interdependencies, their simultaneous analysis requires these interdependencies to be taken into account. One particular interdependency is the number of fatal accidents which is always lower than the number of fatalities as at least one fatality results from a fatal accident. More generally, when the number of accidents increases, the number of people injured as a result of these accidents will also increase. Since dependencies between accident-related outcomes are reflected in the variance-covariance structure of the outcomes, the main focus of the present study is on establishing this structure.

As this study shows, it is possible to derive relatively simple expressions for estimates of the variances and covariances of (logarithms of) accident and victim counts. One example reveals a substantial effect of the inclusion of covariance terms in the estimation of a confidence region of a mortality rate.

The accuracy of the estimated variance-covariance structure of the accident-related outcomes was evaluated using samples of real life accident data from the Netherlands. The effect of small expected counts on the variance estimate of the logarithm of the counts was also investigated.

Commandeur J.J.F., Koopman S.J. (2007). *An introduction to state space time-series analysis*. Oxford: Oxford University Press, UK.

Providing a practical introduction to state space methods as applied to unobserved component time-series models, also known as structural time-series models, this book does not require prior knowledge of time-series analysis or state space methods. The only background necessary is a basic knowledge of classical linear regression models, of which a brief review is provided. Several sections assume familiarity with matrix algebra but they may be left out without losing the flow of the presentation.

The book offers a step-by-step approach to the analysis of the salient features in time series such as the trend, seasonal, and irregular components, and treats practical problems such as forecasting and missing values in some detail. This book has been written for practitioners and researchers who use time series on a daily basis in areas such as the social sciences, quantitative history, biology and medicine. It also serves as an accompanying textbook for a basic time-series course in econometrics and statistics.

Bijleveld F., Commandeur J., Koopman S.J., van Montfort K. (2010). *Multivariate non-linear time-series modelling of exposure and risk in road safety research*. *Journal of the Royal Statistical Society* C 59(1), 145–161.

This paper presents a multivariate non-linear time-series model for road safety data. The model has been applied in a case study into the development of a yearly time series of numbers of fatal accidents (inside and outside urban areas) and numbers of kilometres driven by motor vehicles in the Netherlands between 1961 and 2000. The model takes into account missing entries in the disaggregated numbers of kilometres driven although the aggregated numbers are observed throughout. To analyse this data, a multivariate non-linear time-series model has been chosen. It consists of dynamic unobserved factors for exposure and risk that are related in a non-linear way to the number of fatal accidents. The multivariate dimension of the model is due to its inclusion of multiple time series for inside and outside urban areas. Approximate maximum likelihood methods based on the extended Kalman filter are used for the estimation of unknown parameters. The latent factors are estimated by extended smoothing methods. The way the salient features of the observed time series are captured by the model is considered to be satisfactory.

Bijleveld F.D., Commandeur J.J.F., Gould P., Koopman S.J. (2008). *Model-based measurement of latent risk in time series with applications*. Journal of the Royal Statistical Society A, 171(1), 265–277.

Risk is at the centre of many policy decisions for companies, governments and other institutions. The risk of road fatalities concerns local governments in planning counter-measures, the risk and severity of counterparty default concerns bank risk managers on a daily basis, and the risk of infection has actuarial and epidemiological consequences. However, risk cannot be observed directly and it usually varies over time. Measuring risk is therefore an important exercise. This paper introduces a general multivariate framework for the time-series analysis of risk that is modelled as a latent process. The latent risk time-series model extends existing approaches by the simultaneous modelling of (i) the exposure to an event, (ii) the risk of that event occurring and (iii) the severity of the event. First, existing time-series approaches for the analysis of risk which have been applied to road safety, actuarial and epidemiological problems are discussed. Second, a general model for the analysis of risk is presented and its statistical treatment based on linear state space methods is discussed. Lastly, the methodology is applied to time series of insurance claims, credit card purchases and road safety. It is shown that the general methodology can be effectively used in the assessment of risk.

Bijleveld F.D. (2008). *Time series analysis in road safety research using state space methods*. PhD Thesis, Vrije Universiteit Amsterdam, Netherlands.

This thesis discusses multivariate structural time-series models by state space methods in the statistical analysis of the development of road safety. This approach reduces the statistical consequences of three issues in the analysis of such developments: 1) dependence over time; 2) the multivariate nature of road safety outcomes and 3) the fact that most related data is subject to measurement error.

Issue 1) is a well-known issue that is addressed using structural time-series models. In addition, such models allow the researcher to implement a structure based on existing knowledge or to test a hypothesis on this structure. Harvey & Durbin (1986) introduced this approach to road safety analysis. Issue 2) is due to the fact that road safety is not measured just by counts of the number of crashes or victims. Influences affecting crash occurrence also affect the number of victims. Following the DRAG approach introduced by Gaudry (1984), the approach taken in this thesis decomposes the road safety problem into the three factors of exposure, accident risk and accident severity, thus allowing the researcher to appropriately model the effects of influences. Issue 3) is addressed by modelling explanatory variables as latent factors. It is demonstrated that the often-preferred measure of exposure traffic volume data, in particular when derived from surveys, can be subject to substantial (sampling) error. Treating such data as fixed and known may adversely influence the reliability of statistical analysis. The approach is applied in some road safety examples in the thesis.

Stipdonk H., Bijleveld F., van Norden Y., Commandeur J. (2012) *Analysing the development of road safety using demographic data, Accident Analysis & Prevention*, 60, 435–444

The purpose of this paper is to show that time series analyses of road safety and risk can be improved by using demographic data. We demonstrate that the distance travelled by drivers or riders of a certain age reflects the fluctuations over the years of the number of people of that age within the population. We further demonstrate that the change over time of per capita distance travelled, i.e. distance travelled per person, is often less subject to stochastic fluctuations, and therefore more smooth than the total distance travelled for drivers of that age. This smoothness is used to obtain forecasts of distance travelled, or to average out year-to-year fluctuations of data of distance travelled. Analysis of such data stratified by age group, gender or both reveals that, for most travel modes, per capita distance travelled is to a large extent constant or slowly changing over time. The consequences for the evaluation of risk, i.e. casualties per distance travelled, with and without the use of population data, are explored. Dutch data are used to illustrate the model concept. It is shown that the analyses and forecasts of distance travelled could gain substantially by incorporating demographic data, as compared to an analysis with data of distance travelled alone. The paper further shows that, for an analysis of risk and therefore for traffic safety forecasts in the absence of any data of distance travelled, stratified analysis of mortality, i.e. casualties per inhabitant, may be a reasonable alternative.

Gdańsk University of Technology

Żukowska J. (2004). *Traffic fatalities modelling using time series.* International Workshop on Rehabilitation of Existing Urban Building Stock. June 17–19, 2004. Gdańsk University of Technology, Poland.

1999's long-term traffic fatalities forecast for Poland assumed a monotone increase in public activity. However, in 2001 an economic crisis was observed. In spring 2001 the government informed the public about Poland's budget deficit, but the estimates of the deficit kept changing and ranged between 40 and 80 billion PLN. In this research it was assumed that this situation reduced the demand for transport in Poland, and thus led to a reduction in the number of journeys. This in turn resulted in fewer accident fatalities. Is it therefore safe to say that the subsequent years with their projected economic development and a drop in unemployment will see an increase in traffic risk? To answer this question structural time-series models were applied to see if there is a relation between public activity and road safety.

Krystek R., Żukowska J. (2003). *Falling accident risk in Poland*. KONBiN'03, The 3rd Safety and Reliability International Conference, Poland.

Over the previous few years optimistic trends in traffic risk development had been observed in Poland, where the number of fatalities had decreased by about 10% per year, bringing Poland closer to European Union standards. Nevertheless, in 2001 an unexpected, and bigger than forecasted, reduction in the number of casualties was observed. The reason was the economic downturn suffered across the country, resulting in reduced demand for transport. The danger lies in how that reduction is interpreted. The concern is that the government will see this as a pretext to cut GAMBIT spending, unless we are able to provide a reasonable explanation that the casualty reduction was brought about by the reduced mileage.

Żukowska J. (2003). *Traffic risk modelling using time series*. PhD Thesis. Gdańsk University of Technology, Poland.

While it is well known that road fatalities are caused by a number of factors, the difficulty lies in identifying those that have an effect on long-term trends. In this thesis it is assumed that the functioning of the transport system depends on the country's economy, which means that all fluctuations in this area influence the level of road safety. Consequently, from a short-term perspective, when the economy is bad, with a lower GNP and higher unemployment, people change their transport behaviour and preferences and this may reduce the number of kilometres travelled, which has a direct effect on road safety. There is evidence that even a sudden growth/decline in the economy can cause significant changes in the number of road accidents. This relationship seems to be true for Poland as well (considering for example the short-lived drop in the number of fatalities observed in 2001). A structural time-series model was applied to check this. Because of the dynamic nature of traffic safety developments it lends itself very well to modelling in this way. The analyses involved building a number of models: a model with the unemployment rate as an explanatory variable, a model with intervention variables and a model with GNP as an explanatory variable. Both the GNP and unemployment rate variables appeared to have an influence on the number of fatalities.

Żukowska J. (2012) *Road safety analysis in Poland using time-series modelling techniques*. *Journal of Polish Safety and Reliability Association Summer Safety and Reliability Seminar*s, Vol. 3, No. 1–2, 2012.

A number of international studies argue that there is a correlation between the number of traffic fatalities and the degree of public activity. Among other indicators the studies use the unemployment rate to support that argument. As unemployment grows, the number of kilometres travelled falls, a factor known to affect road safety. This relationship seems to be true for Poland, as well. The model presented in the paper, based on the data from 1992–2011, is intended to prove it. It is a structural time-series local level model with the explanatory variable (the unemployment rate) and some interventions. Because of the dynamic nature of traffic safety developments it lends itself very well to modelling in this way.

Holló P., Eksler V., Żukowska J. (2010). Road safety performance indicators and their explanatory value: A critical view based on the experience of Central European countries. *Safety Science* 2010, 48, p. 1142–1150.

Counts of road crashes and their victims represent essential information for road safety practitioners and this helps them to analyse their spatial and temporal aspects. However, they cannot provide details on the factors causing road crashes. As a result, various road safety performance indicators (RSPIs) have been introduced, making it possible to collect information on the effectiveness of interventions on road safety in given areas. However, analysis of the trends in road casualties in several Central European countries based on safety performance (measured by RSPIs) suggests that not even these indicators can provide full understanding of road safety trends and, if they are applied generally without the required background information, this could even lead to serious misinterpretation of the trends in road casualties. Sudden breaks in long–term trends seem to be linked to the transition process and to certain legislative reforms. The exposure and socioeconomic climate appear to have had a major impact on road crash outcomes. Various additional indicators describing organisational and structural aspects may therefore help better to understand and predict the development of road safety for individual countries.

IFSTTAR, NTUA, SWOV & GUT: Collaborative research

Bergel-Hayat R., Żukowska J. (2014). *Structural time series modelling of the number of road fatalities in Poland in relation with economic factors*. TRA 5th conference, Paris, 14–17 April 2014.

Comparing with other European countries Poland's traffic fatality risk rates still remain on very high levels. These last years the numbers of fatalities were around 3500 and the mortality rate reached about 9 killed per 100,000 population, which places Poland in a very bad position in Europe. This situation shows a strong need of intensified systemic and preventive work, which also prevails in the field of road safety analysis. The objective of this paper is to describe models that have been developed for analysing the short term changes in the aggregate number of fatalities in Poland, measured on a monthly basis between 1998 and 2012. The models account for the influence of economic conditions on the level of road mortality.

Bergel-Hayat R., Żukowska J. (2015) Road safety trends at national level in Europe: a review of time-series analysis performed during the period 2000–12. *Transport Reviews: A Transnational Transdisciplinary Journal*, DOI: 10.1080/01441647.2015.1030005.

This paper presents a review of time-series analysis of road safety trends, aggregated at a national level, which has been performed in the period 2000–2012 and applied to European national datasets covering long-time periods. It provides a guideline and set of best practices in the area of time-series modelling and identifies the latest methods and applications of national road safety trend analysis in Europe. The paper begins with setting the methodological framework adopted for aggregate time-series modelling that will be considered, and then discusses a number of relevant applications to long-period data aggregated at the national level, whether for countries alone, or for groups of countries. Some analyses, which were performed at the disaggregated level, are also provided, as they are being used more and more. Finally, the paper summarizes and discusses the significant changes in aggregate road safety trend analysis which occurred during the period and provides recommendations for continuing these research efforts.

Bergel-Hayat R., Debbarh M., Antoniou C., Yannis G. (2013) *Explaining the road accident risk: Weather effects. Accident Analysis & Prevention*, 60, 456–465.

This research aims to highlight the link between weather conditions and road accident risk at an aggregate level and on a monthly basis, in order to improve road safety monitoring at a national level. It is based on some case studies carried out in Work Package 7 on "Data analysis and synthesis" of the EU-FP6 project "SafetyNet – Building the European Road Safety Observatory", which illustrate the use of weather variables for analysing changes in the number of road injury accidents. Time series analysis models with explanatory variables that measure the weather quantitatively were used and applied to aggregate datasets of injury accidents for France, the Netherlands and the Athens region, over periods of more than twenty years. The main results reveal significant correlations on a monthly basis between weather variables and the aggregate number of injury accidents, but the magnitude and even the sign of these correlations vary according to the type of road (motorways, rural roads or urban roads). Moreover, in the case of the interurban network in France, it appears that the rainfall effect is mainly direct on motorways – exposure being unchanged, and partly indirect on main roads – as a result of changes in exposure. Additional results obtained on a daily basis for the Athens region indicate that capturing the within-the-month variability of the weather variables and including it in a monthly model highlights the effects of extreme weather. Such findings are consistent with previous results obtained for France using a similar approach, with the exception of the negative correlation between precipitation and the number of injury accidents found for the Athens region, which is further investigated. The outlook for the approach and its added value are discussed in the conclusion.

Commandeur J.J.F., Bijleveld F., Bergel-Hayat R., Antoniou C., Yannis G., Papadimitriou E. (2013). *On statistical inference in time series analysis of the evolution of road safety. Accident Analysis & Prevention*, 60, 424–434.

Data collected for building a road safety observatory usually include observations made sequentially through time. Examples of such data, called time series data, include annual (or monthly) number of road traffic accidents, traffic fatalities or vehicle kilometers driven in a country, as well as the corresponding values of safety performance indicators (e.g., data on speeding, seat belt use, alcohol use, etc.). Some commonly used statistical techniques imply assumptions that are often violated by the special properties of time series data, namely serial dependency among disturbances associated with the observations. The first objective of this paper is to demonstrate the impact of such violations to the applicability of standard methods of statistical inference, which leads to an under or overestimation of the standard error and consequently may produce erroneous inferences. Moreover, having established the adverse consequences of ignoring serial dependency issues, the paper aims to describe rigorous statistical techniques used to overcome them. In particular, appropriate time series analysis techniques of varying complexity are employed to describe the development over time, relating the accident-occurrences to explanatory factors such as exposure measures or safety performance indicators, and forecasting the development into the near future. Traditional regression models (whether they are linear, generalized linear or nonlinear) are shown not to naturally capture the inherent dependencies in time series data. Dedicated time series analysis techniques, such as the ARMA-type and DRAG approaches are discussed next, followed by structural time series models, which are a subclass of state space methods. The paper concludes with general recommendations and practice guidelines for the use of time series models in road safety research.

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