Steunpunt Verkeersveiligheid bij Stijgende Mobiliteit

Macro Models in Traffic Safety and the DRAG Family: Literature Review

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Onderzoekslijn Kennis Verkeersonveiligheid

DIEPENBEEK, 2003.
STEUNPUNT VERKEERSVEILIGHEID BIJ STIJGENDE MOBILITEIT.

Documentbeschrijving

Rapportnummer:	RA-2003-08
Titel:	Macro Models in Traffic Safety and the DRAG Family: Literature Review
Ondertitel:	
Auteur(s):	F. Van den Bossche, G. Wets
Promotor:	Prof. dr. G. Wets
Onderzoekslijn:	Kennis Verkeersonveiligheid
Partner:	Limburgs Universitair Centrum
Aantal pagina's:	46
Trefwoorden:	macro-economics, econometric models, structural road accident models, autocorrelation, heteroscedasticity, Box-Cox transformations, accidents, gravity, demand for road use
Projectnummer Steunpunt:	1.3
Projectinhoud:	Analyse van de impact van mobiliteit op de verkeersveiligheid

Uitgave: Steunpunt Verkeersveiligheid bij Stijgende Mobiliteit, Februari 2003.

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Samenvatting

In deze tekst wordt een literatuurstudie gegeven van de verschillende modellen in de DRAG familie. Dit zijn macro-economische verkeersveiligheidsmodellen om de vraag naar weggebruik, ongevallen en de ernst ervan te voorspellen. De DRAG-modelstructuur deelt het aantal slachtoffers op in expositie, frequentie en ernst van ongevallen, wat het mogelijk maakt om risico-substitutie tussen deze drie dimensies in kaart te brengen. Het algoritme steunt op een regressiestructuur van meerdere vergelijkingen, aangevuld met Box-Cox transformaties, waarin gecorrigeerd wordt voor auto-correlatie en heteroscedasticiteit in de foutentermen. In deze tekst worden de DRAG modellen gesitueerd binnen de bestaande modellen voor verkeersveiligheid. Ook worden de algemene macro modellen in verkeersveiligheid besproken, and worden de voornaamste eigenschappen toegelicht. Het originele DRAG model wordt voorgesteld, samen met de uitbreidingen die in DRAG-2 werden toegevoegd. Deze beschrijving wordt aangevuld met een overzicht van andere modellen in de DRAG familie. Daarnaast wordt het gebruik van de DRAG modellen gekaderd binnen de context van het huidige onderzoek.

Summary

In this text, a literature review is given of the models in the DRAG family. These are macro-economic traffic safety models that describe the demand for road use, the accidents and their severity. The DRAG structure typically decomposes the number of victims into exposure, frequency and severity, which makes it possible to search for evidence of risk substitution among these three dimensions. The algorithm uses a multiple equation regression structure, enriched with Box-Cox transformations, that corrects for auto-correlation and heteroscedasticity in the residuals. In the text, the DRAG models are situated within the existing models for traffic safety. Also, macro models in general in traffic safety are discussed, and the major characteristics are highlighted. The original DRAG model is introduced, together with the extensions added in DRAG-2, and followed by an overview of other models in the DRAG family. Apart from the model descriptions, the use of the DRAG models is placed in the context the current research.

Contents

1. INTRODUCTION

Road traffic unsafety is a major social and public health problem. Since traffic and mobility are indispensable parts of everyday life, policies should be directed towards an increasing level of road safety. Successful road safety policies and effective road accident countermeasures should therefore be based on, amongst others, scientific road safety research. The quality of safety research results may to a large extend be determined by the level of use of models and theories.

A model is meant to describe, explain and/or predict a certain phenomenon. In addition, it may be useful to incorporate policy variables. These variables can be manipulated by policy makers in order to bring about a desired change. In road accident models, the objective is, more specifically, to identify those factors that can be manipulated in order to increase traffic safety.

One specific class of accident models is known under the common name DRAG (Gaudry 1984, 2002). These are macro models to describe the demand for road use, the accidents and their severity. The DRAG structure typically decomposes the number of victims into exposure, frequency and severity, which makes it possible to search for evidence of risk substitution among these three dimensions. The dependent and explanatory variables are analysed on a monthly basis. The algorithm uses a multiple equation regression structure, enriched with Box-Cox transformations, that corrects for auto-correlation and heteroskedasticity in the residuals.

Within the "Flemish Research Centre for Traffic Safety", the relationship between traffic safety and mobility will be investigated. It is expected that the degree of mobility in society will have an impact on traffic safety and on the number of kilometres driven. The use of macro-econometric models is justified as a means of explaining the relation between traffic safety and mobility. For example, the level of traffic accidents is in some way related to the number of cars. If there are no cars on the road (this is a complete absence of mobility), there won't be any accident. Increasing the number of cars on the road will first increase the number of accidents, but an ever increasing number of cars will eventually cause the number of accidents to fall, because they are blocked to move. It would be interesting to know the turning point in this relationship. Moreover, one can expect this relation to be different for different types of accidents. The relationship between traffic safety and mobility is not straightforward at all. In the DRAG-Stockholm-2 model (Tegnér et al. 2000), it is shown that road accident risk and severity increase together with mobility and activities. The demand for activities creates a demand for mobility, which in turn affects the demand for road use, the number of accidents and their severity. These interesting relationships deserve further attention.

The DRAG model can help in quantifying the impact of different mobility-related variables on traffic safety. If traffic safety can be reduced by changing road user's mobility, government could introduce tailor-made actions and adjust its policy accordingly. Since policy makers are interested in increasing the level of traffic safety in the long term, they should get an idea of the impact of different treatments. This can be done in a DRAG like model. Moreover, the level of traffic safety is also determined by phenomena that are not under the influence of any policy program or regulation, like weather or demographic evolution. Also these elements can be quantified in the model, and their impact can be measured.

For these reasons, the DRAG model has been built on the data of different countries (Quebec, Germany, Norway, France, California), and applied to regional data. In Quebec, the DRAG model has become the official traffic safety model. It is extensively used to explain and forecast road accidents, and the model is continuously updated in order to reflect the most recent traffic situation. In France, a committee of insurers and experts of the ministry are considering the possibility of applying the TAG-1 model

(Jaeger and Lassarre 1997) as official model. Also the TRULS-1 model (Fridstrom 2000) for Norway has been used for forecasting purposes.

In this text, a literature review is provided for this class of models, without pretending to be complete. The focus is on the specific issues and on the results of macro models. The text is structured as follows. In a first section, the DRAG models are situated within the existing models for traffic safety. Next, the class of macro models in traffic safety is introduced, and the major characteristics are highlighted. Then, the original DRAG model is introduced, together with the extensions added in DRAG-2, and followed by an overview of other models in the DRAG family. To conclude, the main ideas are put together, and some motivation is given for the use of DRAG models.

2. MODELS IN TRAFFIC SAFETY

In road traffic research, there are four main groups of accident models (OCDE 1997): descriptive models, predictive models for aggregated data, risk models for non-aggregated data and accident consequence models. Each model will use and present the accident data differently. The four groups of models will be briefly discussed, based on OCDE (1997). For more details the interested reader is referred to this document.

2.1 Descriptive Models

The road safety problem can be described and modelled using three dimensions: exposure, accident risk and injury consequence. The magnitude of the problem is the product of these three factors. These models are built based on accident and injury data sources (police reports, hospital and insurance company statistics, …). The basic task in most road safety work is to describe the current magnitude of the road safety problem. To compare and rank road safety problems, one should not only focus on the number of accidents, injuries and fatalities, but also on the magnitude and character of the activities that generate the problems (the exposure). Exposure data are gathered much too seldom and often for other purposes. Methods to measure exposure are traffic counting and travel habit surveys.

Another possibility for estimating exposure is to use traffic conflict techniques (Hydén 1987). This method is based on defining near accidents (conflicts), and can also be used as a substitute for accident registration. The advantage is that data can be collected quite quickly (there are more conflicts than accidents). The disadvantage is that the validity is lower than for accidents, observation is time consuming and observers have to be trained. In the Netherlands, Kraay, van der Horst and Oppe (1986) developed and used the conflict technique DOCTOR (Dutch Objective Conflict Technique for Operation and Research). In their work, attention is given to methodological aspects like reliability and validation of the results, and to the application of the method in practice.

2.2 Predictive Models for Aggregated Data

The major factors that cause changes in accident occurrence can be grouped into six classes. First, there are four groups of variables, namely external, socio-economic, transportation and data collection variables. Apart from these groups, accident occurrence is also influenced by randomness and countermeasure intervention. To eliminate the effects of the four groups of variables and to estimate the effect of a certain countermeasure, multivariate statistics (econometric modelling) can be used.

Studies can be directed to the impact of a single intervention variable. These impact studies may be useful for research or policy-making purposes, but they are of a limited scope, assuming that all other affecting variables remain constant (Hakim et al. 1991). One can also analyse simultaneously a number of intervention variables. In such a study it is possible to identify the most important factors for reducing the number or the severity of accidents. Apart from intervention variables, also non-controllable variables, like the weather, the state of technology or the population size, can be added. The pool of explaining variables in a statistical model should contain all factors that may explain some systematic variation in the dependent variable.

The DRAG model (Gaudry 1984; Gaudry et al. 1995), described in this text, belongs to the class of macro models. The objective of these models is to explain the development of aggregate exposure, accidents and their severity over time. Apart from the very large number of explanatory variables taken into account, the DRAG model is characterized by the extensive use of Box-Cox transformations to relax the linearity assumption of the regression model (OCDE 1997).

2.3 Risk Models for Non-Aggregated Data

Another way to analyse the risk factors behind road accidents is to focus on the individual level (driver, vehicle, road). The purpose is to understand and to predict road user behaviour. Most of the risk models within traffic safety are in fact "sub-models" since they focus on one limited aspect of the total road traffic situation. It is possible to separate between action models, behaviour models, risk models and technical models.

Action models are one major group of behavioural models. They are based on road user task analysis, usually focused on the variables "user disposition" (suitability, qualification, capability), "user assimilation" (attitudes, assimilation of information, motor skills) and/or "user situation" (routine situations, complex situations). Road user actions are regarded as the result of more or less adequate behavioural controls (OCDE 1997). A generally accepted structure for action models is based on Rasmussen's hierarchical model, differentiating between knowledge-, rule-, and skill-based errors. Within the decision process, eight steps are defined and then linked to potential errors (Rasmussen 1987). Other action models can be found in Reason (1994) and Ranney (1994).

Another class of human factor models attempts to find relationships between accident involvements and more dynamic variables such as attitudes and various behaviours. These behavioural models deal with a range of variables regarding behavioural phenomena. Michon (1989) classified the behaviour models into input-output models, task analysis models and functional models (based on mechanical, adaptive, motivational or cognitive mechanisms).

Behavioural risk models focus on how subjective risk is estimated and handled by road users and the resultant behaviour. These models focus on the problems experienced by road users in perceiving, accepting and controlling the risk. A well-known behavioural risk model is Wilde's risk homeostasis model (Wilde 1988, 1994). Wilde relates risk perception to risk acceptance. The objective risk perceived is evaluated and compared to the accepted risk.

Technical risk models study user behaviour and risk in specific physical situations. The vehicle (e.g. size, brakes, stability), the road (e.g. geometry, surface, intersections), and the traffic (e.g. volume, speed, gaps) may be considered as situational stimuli to driver behaviour. Most of these models, however, are on the aggregated level. Very few technical risk models focus on the individual driver on a non-aggregated level, considering vehicle and road infrastructure at the same time. Examples of this kind of studies can be found in Wasielevski (1984), Fontaine and Gourlet (1994) and Cohen (1996).

2.4 Accident Consequence Models

The consequences of road traffic accidents can be described in different terms. Historically, they have been viewed as a road safety problem with the description based on fatalities and injuries. Another way is to view them as a public health problem with the description based on the seriousness of the consequence of each victim or the loss of health. Finally the consequences may be described in economic terms such as medical costs, rehabilitation costs, loss of production costs, human costs, damage to property costs and administration costs.

There are many factors that influence the consequences of accidents, like the type and age of the user or the vehicle, the manoeuvre type, speed, mass of the car, use of alcohol and drugs,…

The consequences of accidents can be studied on the aggregated level using statistical methods, or the individual level using case studies, experiments or simulations. Biomechanical models increase the understanding of accidents, and thereby prevent events which cause severe traumas to human body. These models have mainly developed through experiments and simulated collisions. They facilitate the detection, understanding and prevention of serious injuries. Today, knowledge of biomechanics allows to simulate the human body for most of the common collisions and the injuries caused. Studies can be found in Olkkonen (1993), Thomas (1993) and Norin (1995). Olkkonen (1993) found that moped, motorcycle and bicycle helmets are helpful in reducing severe and fatal head injuries.

3. MACRO MODELS IN TRAFFIC SAFETY

This section gives an overview of the most important aspects of macro models in traffic safety. It is mainly based on the work of Hakim et al. (1991), who published a very comprehensive comparison of different macro models. The objectives of these authors are the identification and establishment of the significance of policy and socio-economic variables affecting the level of road accidents, and the identification of the variables associated with effective policies and interventions to enable decision makers to improve the level of road safety. This second objective is also a key issue in the models themselves.

In a first part, a description is given of the specific issues in macro models estimation. These include the dependent variables, cross-sectional and time-series analysis, collinearity and the error term structure. Next, some empirical studies are reviewed. For more details on the presented results, the reader is referred to Hakim et al. (1991).

3.1 Macro Models Estimation

In general, the form of a macro model can be written as $Y = F(X)$, where Y is the number of accidents or an accident rate, and X is the vector of explanatory variables (driving, demographic or economic parameters). Sometimes intervention variables are introduced, to show the effect of an intervention or policy change. In this section, several important aspects of macro models are reviewed.

3.1.1 Dependent Variables

The dependent variable in a macro model may be the number of accidents with fatalities or injuries, or the number of injuries or fatalities itself. The variable can be stated in the form of raw numbers or as rates. The use of a rate as the dependent variable in a model assumes a linear relationship between the number of accidents and the factor used for rating. Therefore, the use of standardized variables or rates can only be justified if this assumption is acceptable. Mostly, the use of raw numbers is preferred and the exposure factor should be included as an explanatory variable.

The use of all accidents with fatalities or injuries as the dependent variable introduces a mishmash of effects. For example, multi-vehicle accidents mostly occur in different circumstances compared to single-vehicle accidents (in terms of volume and speed). Also changes in economic or demographic factors or in various kinds of legislation may affect these types of accidents differently. Therefore, often subsets of more uniform events are analysed (Hakim et al., 1991).

3.1.2 Cross-sectional versus time-series analysis

Although most macro-analysis studies use time-series data in a monthly form (Cooper 1986; Wagenaar 1984; Scott 1986; Harvey and Durbin 1986; Gaudry 1984; Blum and Gaudry 1992; Jaeger 1998), or annually aggregated (Peltzman 1975; Zlatoper 1984; Eshler 1977; Joksch 1984; Partyka 1984), some researchers have used cross-sectional data (Loeb 1987; Sivak 1983; Peltzman 1975). In Fridstrom and Ingebrigtsen (1989) and Fridstrom (1999), a macro accident model is empirically estimated using pooled monthly time-series and cross-sectional data.

Cross-sectional analysis has the advantage that most of the data is available for analysis, but is restricted by the fact that some variables that vary across states and have an impact on road accidents (such as topography, climate, life style) may be hard to measure. This may create spurious associations between the number of accidents and some explanatory variables, resulting in an ambiguous interpretation of the results.

In time-series analysis, variables such as topography and life-style remain relatively constant within the state over time and thus can be omitted from the analysis. Yearly data require a long time-series to provide enough observations to render a statistical estimation at the desired confidence level. Monthly data, on the other hand, allow shorter time-series and provide more observation points. Monthly time-series strike a good balance between availability of data on all explanatory factors and variance of data. Higher aggregation kills variance; lower aggregation voids the structural explanation in aggregate models (OCDE 1997). In practice, however, monthly data is not always available for all variables of interest.

In general, if certain variables are omitted from the analysis, a systematic error may be brought into the model due to misspecification. Therefore, the techniques used should allow for unexplained systematic variation in the residual terms. If relevant explanatory variables are omitted from the model, great caution is required in the interpretation of the results. Yet another problem with the data is the possible presence of heteroscedasticity (unequal variance of the error term), which makes ordinary least squares regression techniques less suited for the analysis of such data sets. A generalized linear interactive model (GLIM) ought to be preferred. More details can be found in Fridstrom and Ingebrigtsen (1989) and in Gaudry and Lassarre (2000).

3.1.3 Collinearity

Collinearity means that some of the explanatory variables tend to change simultaneously. In such a case, some explanatory variables may be very well predicted by others, indicating that they contain, to a certain extend, the same information. If variables are highly correlated, it is impossible to come up with reliable estimates of their individual effect on the dependent variables. Collinear independent variables will lead to biased coefficient estimation and unexpected coefficient signs. Collinearity, however, does not affect the ability of an equation to predict the response, but it makes it impossible to estimate the contributions of individual predictors (Neter et al. 1996).

Yearly time-series data of economic, demographic and driving related variables usually exhibit high collinearity, which may render the identification of the effect of explanatory variables difficult. More specifically, if different factors tend to change simultaneously over time, it will be difficult to assess the individual effect of a factor on the number of accidents. Monthly time-series data usually exhibit greater variability, since variables are not averaged over a year. As a result, correlations are lower and the effects of individual explanatory variables may be better estimated.

3.1.4 The structure of the error term

Models based on monthly time-series often have dependent error-term structures. This is mainly caused by seasonality and trend effects and also from the unmeasured effect of changes taking place in one month upon subsequent months. Dependence in the error terms could result in biased estimates of the coefficients. Procedures such as ARIMA (Box and Jenkins 1970) and structural analysis (Harvey and Durbin 1986) are useful in producing an unbiased estimate of the error variance in the presence of serially correlated variables.

Hoxie et al. (1984) applied a traditional ad hoc method to achieve independent error terms, using seasonal dummies and first-order autocorrelation correction. Scott (1986) included a linear time-trend variable and seasonal dummies in a simple regression model. He has found only little difference between the results of an ARIMA model and those of the structural regression model. Wilson (1986) also reported almost identical results to those obtained through structural analysis using a specific ARIMA model (the "airline" model).

3.2 Review of selected empirical results

In macro models for traffic safety, the objective is the long-term explanation of road accidents, injuries and/or fatalities. Given the high number of explaining variables used in macro models, it is obvious that some of them are not statistically significant. Although these variables may be interesting, they are not reported here. The outcomes of the different models should allow decision makers to get a better understanding of the phenomenon of road accidents.

3.2.1 Economic Factors

Unemployment rate is often used as a proxy for economic conditions. Other possible economic indices are disposable income, automobile production, gross national product, manufacturing production, consumption per capita, retail sales and interest rates. All these variables express the same phenomenon. For reasons of collinearity, not all economic variables should be included in the model.

Economic factors appear to be negatively related to accidents with injuries. The economic conditions negatively affect the traveller's ability to pay for travel. This effect is less pronounced for work trips, but is quite clear for young drivers and recreational trips (Wagenaar 1984; Partyka 1984; Peltzman 1975; Hoxie et al. 1984). Hoxie and Skinner (1985) found that, in periods of recession, the number of fatalities with young drivers is significantly lower, even without a significant reduction in miles driven. They also mention that higher-risk groups are more sensitive to changes in economic conditions. Peltzman (1975) uses a demand-oriented explanation for the negative relationship between economic growth and the number of road accidents. As income rises, the demand for safer cars increases, which leads to fewer accidents. On the other hand, higher income on the supply side increases the budget for investment in infrastructure and road maintenance. In the DRAG-2 model (Fournier and Simard 2000), the ratio of the number of unemployed to the number of people with driver's licences is included. An increase in this ratio results in a decrease in the distance travelled and in the number of accidents. In Blum and Gaudry (2000), household income is used as an economic indicator. A rise in the income results in an increasing vehicle ownership, which in turn increases road use demand and the number of accidents. Also the current rate of interest affects road use, accidents and victims. Unemployment has a small but highly significant negative effect on road use, but only a moderate significant effect on casualties. Tegnér et al. (2000) show that an increase in the number of employed results in a higher number of vehicle-kilometres. In Jaeger and Lassarre (2000), it is seen that the increase in traffic risk caused by a rise in unemployment is negligible. This result is not in accordance with most of the other models, and indicates differences in measured variables and in social protection systems.

3.2.2 Change in Gasoline Prices

Hoxie et al. (1984) and Land and McMillen (1980) report an inverse relationship between gasoline car accidents and gasoline prices, the average price of gasoline and the number of non-work-related trips. Note that the effect of gasoline price changes on accidents is not direct. The price of gasoline determines its demand, which in turn affects the number of accidents. Similar results are obtained in Fournier and Simard (2000). Also the number of kilometres driven decreases with a rise in gasoline prices (Tegnér et al., 2000; Jaeger and Lassarre, 2000). McCarthy (2000), however, did not find any impact of the real gasoline price on the demand for travel. This is explained by relating the gasoline price to the opportunity cost of travel, which is a generalised cost, including monetary and time costs. In the same model, the number of accidents does decrease with a rise in the gasoline price.

3.2.3 Violence and Aggressiveness

Variables that may be used to express economic and/or social stress are rates of net out-migration, levels of violent and property crimes, police calls for domestic disputes, rates of suicide and worker strikes. Note that these variables are much wider than aggressive behaviour in traffic. Sivak (1983) found that, as violence and aggressiveness rise, the number of injuries in road accidents increases.

3.2.4 Young Drivers

Young drivers are considered as a high-risk group, having a higher probability of involvement in car accidents with injuries. Also in Fournier and Simard (2000), an increase in the number of young drivers, between 16 and 24 years old, results in a rise in the number of road accidents. Quite often, the topic of young drivers has been related to the effect of the minimum legal drinking age (MLDA) on accidents. Wagenaar (1983) stated that approximately 20% of all alcohol-related crashes involving young drivers can be prevented by removing legal access to alcoholic beverages. Hoxie and Skinner (1987a) showed that raising the minimum drinking age can save a considerable amount of young lives.

3.2.5 Legislation

Most researchers are interested in analysing the possible long-term effects of legislative intervention measures while statistically controlling for non-intervention variables hypothesized to be associated with accidents. Sometimes, however, one is interested in the effectiveness of a particular intervention. This is done in partial studies (before-after or treatment-control). Some of the possible intervention variables are discussed below.

SPEED LIMITS AND SPEED VARIANCE

Several authors (e.g. Partyka 1984) showed that reducing the speed limits appears to be related to a reduction in fatalities. Also the severity of injuries is positively related to the allowed speed. Blum and Gaudry (2000) obtained similar results in their model for Germany. According to McCarthy (2000), however, increased speed limits slightly reduce risk exposure. In his model for California, higher speeds have no effects on fatal crashes, but a strong positive impact on the frequency of non-fatal injury crashes. Keeping all else constant, there were fewer fatalities per fatal crash and fewer injuries per non-fatal injury crash after the increased speed limits law. But if a crash occurs, a higher speed results in more serious injuries.

Lave (1985) investigated the effect of speed variance rather than speed limit on highway fatality rate. According to Lave, there is a strong statistical relationship between fatality rate and speed variance. However, Levy and Asch (1989) concluded that efforts should be directed to slowing down high-speed drivers rather than speeding up slower drivers. The empirical studies of Fowles and Loeb (1989) and Snyder (1989) also reject the importance of speed variance; they report on a positive and statistically significant effect of speed on fatalities. Later, Jaeger and Lassarre (2000) consider speed as a description of the incidence of traffic risk of an individual’s behaviour in terms of control over the vehicle. They conclude that speed limits have significant effects, but these effects are due more to a reduction in the dispersion of speeds than to a drop in average speed.

PERIODIC MOTOR VEHICLE INSPECTIONS

According to Zlatoper (1984) and Loeb (1987), the periodic inspection of motor vehicles reduces the number of road fatalities. White (1986) showed that the probability of accident involvement increased with the length of time between inspections. Schroer and Peyton (1979) stated that the inspected vehicles have a lower accident rate than the uninspected vehicles. Also, the accident rate of inspected vehicles decreases after inspection. Poor mechanical condition is a significant factor in motor-vehicle accidents. Fournier and Simard (2000) include in their model an index of maintenance costs for vehicles. According to this model, an increase in vehicle maintenance costs would result in a decrease in the distance travelled and in the number of road accidents. Crain (1980), on the other hand, concluded that vehicle inspection programs have minor impact on highway safety. Random inspections are more effective and less expensive than periodic inspections.

DRINKING AND DRIVING

Zlatoper (1984), Loeb (1987) and Hoxie and Skinner (1985) found that the consumption of alcohol is positively related to accidents with fatalities. Blum and Gaudry (2000) state that beer consumption is both a social variable (thereby increasing road demand) and a factor changing the frequency and severity mix of accidents. Increased beer consumption increases the number of fatalities, but decreases the frequency of accidents. Most of those that drink and drive, have only consumed little and compensate to prevent accidents, while those who drink a lot may increase their risk. A similar conclusion for wine consumption is obtained by Jaeger and Lassarre (2000). An increase in wine consumption per adult implies, ceteris paribus, an increase in the demand for road use for recreational purposes. Also the number of injuries and accidents increases with higher wine consumption. In his model for Norway, Fridstrom (2000) found positive relationships between alcohol consumption and accidents of every degree of severity, thereby concluding that the restrictive Norwegian alcohol policy has prevented road accidents and fatalities. Tegnér et al. (2000) found that low consumption levels of alcohol seem to reduce the number of light and severe injuries. At higher levels of consumption, the accident risk augments rapidly.

Two independent macro studies (Gaudry 1984; Fridstrom and Ingebrigtsen 1989) investigated the effect of three types of alcohol beverage on accidents: beer, wine and spirits. Results from an additional study in the first DRAG model show that increased beer consumption would result in higher number of victims killed, but an increase in wine consumption would result in a decline in the number of victims killed and injured. The higher consumption of spirits increases all categories of accidents (Gaudry 2000). To support his findings, and given the limitations of aggregate data, Gaudry examined the disaggregate results of the Grand Rapids study (Borkenstein et al. 1964, 1974). In this study, it is found that the relative accident probability, as a function of blood alcohol concentration, seems to be J-shaped. It is Gaudry's opinion that the literature too often concentrates exclusively on the strongly rising part. Gaudry (1989) therefore states the following conjecture: "*When aggregate consumption of alcohol increases from relatively low per capita levels, the overwhelming majority [of drivers] drink a little, which reduces their risk below that prevailing when they do not drink – perhaps because they compensate or are less aggressive; this reduction may more than offset the increase in risk for the minority [of drivers] who drink more heavily, depending on their relative proportion on the road*". If the risk curve is J-shaped, the net effect of higher alcohol consumption will depend on its distribution among drivers (Gaudry 1993).

Also McCarthy (2000) investigated the effect of beer, distilled spirits and wine consumption on traffic safety. Only the beer consumption increased the demand for road use. A rise in consumption of distilled spirits per capita leads to more fatal crashes and more fatalities per fatal crash. The wine consumption per capita increases the frequency of non-fatal injury and material only crashes.

In several studies (Loeb 1987; Cook and Tauchen 1984), a negative relationship was found between both the number of accidents and the severity of injuries and the minimum age for purchasing alcohol. Hoxie et al. (1984) used the minimum age for the legal drinking of alcohol as an intervention variable, and found it to be statistically significant in explaining fatalities. Evans (1990) suggests that eliminating alcohol drinking may significantly reduce traffic fatalities. McCarthy (2000) studied the availability of alcohol. An increase in the number of alcohol licences per month generates an increase in non-fatal injury and materials only crashes.

MANDATORY SEAT BELT USE LAWS

Several empirical studies have shown that seatbelt legislation can significantly reduce the number of fatalities and the severity of injuries (Hoxie and Skinner 1987b; Campbell and Campbell 1986, 1988; Harvey and Durbin 1986; Rutherford 1987; Friedland et al. 1987; Williams and Lund 1988; Ceder et al. 1989). Friedland et al. (1987) concluded that safety belts provide full protection against fatalities in accidents that occurred at speeds lower than 60 mph. He also found that seatbelt use leads to serious reductions in injuries to drivers and front-seat passengers. Moreover, it reduces the number of brain injuries. Hoxie and Skinner (1987b) have shown that many occupant fatalities can be avoided when seat belt use laws are mandated.

Blum and Gaudry (2000) found that seat belt use reduces both the frequency and the severity of bodily injury accidents, but increases the frequency of material damage accidents. According to the results of Fridstrom (2000), an increase in the number of car drivers not wearing the seat belt will increase the number of car occupant injuries and the number of fatalities. Seat belts seem to be more effective in preventing less severe injuries than in saving lives. Results of Jaeger and Lassarre (2000) show that there is a risk compensation effect, since the use of seat belts leads to an increase in speed. This is known as driver behaviour retroaction. In the model of McCarthy (2000), seat belt use did not affect the frequency of fatal crashes, but increased the incidence of non-fatal injury and material only crashes. When a fatal crash occurs, more persons are killed, but when an injury crash occurs, fewer individuals suffer an injury.

4. THE ORIGINAL DRAG MODEL

In this section, the main thoughts and results of the first DRAG model are presented. First, the model structure, together with the dependent and (categories of) independent variables are considered. Next, notes are added on the econometrical formulation and interpretation of the model and the results. The section is concluded with some major results. The discussion is entirely based on the reference work of Gaudry (1984, 2002). Further details can be found in his document.

As mentioned in Gaudry (1984, 2000, 2002), the objective of the DRAG study is to explain the road use demand, the accidents and their severity. The main interest is the explanation of the number of victims, and the demand for road use will be considered in order to explain this number. Furthermore, the road demand itself is explained in order to explore the influence of various factors on road safety by taking into account their impact on road use.

4.1 Model Structure

The original DRAG model (Gaudry 1984) consists of a five-layer procedure to explain the impact of various factors on the monthly demand for road use and the number of road accident victims in Quebec. Data was available for a period from December 1956 until December 1982.

The first layer of the procedure consists of a model of total motor vehicle fuel sales (*DC*), for gasoline and diesel, from which fuel sales for road use (*DR*) are obtained. The total sales of fuels are a combination of the unobserved fuel sales for off-highway (*DNR*) and highway (*DR*) uses, and is explained by means of a set of explanatory factors of the sales for off-highway ($X^{(dnr)}$) and highway ($X^{(dr)}$) uses. The term $e^{(dr)}$ indicates the residual error. The fuel sales for road use, being a measure of transportation demand, are further explored in the second layer. The first two layers therefore consist of the "Road Use Demand Equations".

The accident types and severity are explained respectively in the third and the fourth layer of the procedure. The fuel sales for road use, obtained in the second layer, appear together with the group of victims-related explanatory variables $X^{(vi)}$ for both the number of accidents by type (material damages, non-mortal and mortal) in the third layer and their severity (morbidity and mortality rates) in the fourth. Results from the demand, accident and severity equations are combined in a fifth layer, containing only identity equations. Here, the effect of the explaining factors on the number of victims (persons injured and/or killed) is quantified. The layers 3, 4 and 5 contain the "Safety-Performance Equations".

In summary, the DRAG model is an explanation of a structure composed of an explanatory part of the road use demand and of an explanatory part of the safety-performance of the road network. These sets of layers of equations, together with the dependent variables, are grouped in the figure below.

ROAD USE DEMAND EQUATIONS

Layer 1: Total Gross Sales of Fuels (*DC*)

(D-1) $DC = (DNR + DR) = \sum_i \beta_i X_i^{(dnr)} + \sum_j \beta_j X_j^{(dr)} + e^{(dr)}$

(D-1.1) *GA* = gross sales of gasoline for highway and off-highway use

(D-1.2) *DIC* = gross sales of diesel for highway and off-highway use

Layer 2: Demand for Highway Use (*DR*)

(D-2) $DR = (X^{(dr)})$

(D-2.1) *GAR1* = gross sales of gasoline for highway use

(D-2.2) *DICR1* = gross sales of diesel for highway use

SAFETY-PERFORMANCE EQUATIONS

Layer 3: Total Number of Accidents (*AC*)

(P-3) $AC \leftarrow (DR, X^{(vi)})$

Three accident categories

(P-3.1) *MA* = accidents with material damages only

(P-3.2) *NM* = accidents with at least one injured person

(P-3.3) *MO* = accidents with at least one person killed

Two aggregations of categories

(P-3.4) *COR* = *NM* + *MO* = accidents with bodily injuries; corporal accidents

(P-3.5) *ACC* = *MA* + *NM* + *MO* = total number of accidents

Layer 4: Accident Severity (*GR*)

(P-4) $GR \leftarrow (DR, X^{(vi)})$

(P-4.1) *MBC* = *HT*/*COR* = Morbidity Rate = (Persons injured)/(Corporal accidents)

(P-4.2) *MTC* = *DE*/*COR* = Mortality Rate = (Persons killed)/(Corporal accidents)

Layer 5: Total Number of Victims (*VI*)

(P-5) *VI* = *AC***GR*

(P-5.1) *HT* = (*NM* + *MO*)**MBC* = number of people injured

(P-5.2) *DE* = (*NM* + *MO*)**MTC* = number of people killed

(P-5.3) *VI* = *HT* + *DE* = number of victims

Figure 1: Structure of the original DRAG model

The explanatory variables used in the different layers of the DRAG model structure, can be grouped into 7 large categories. These are depicted in the table below.

Category	Variable	Description
1	D	Dependent
2	P	Price
3	M-Q	Motorization - quantity
	M-C	Motorization - vehicle characteristics
4	N-L	Networks - laws, regulations, police
	N-T	Networks - levels of services of transports modes
	N-I	Networks -- infrastructure, climate
5	Y-G	Consumers - general characteristics
	Y-A	Consumers - age
	Y-S	Consumers - sex
	Y-E	Consumers - ebriety or vigilance
6	A	Final economical activities and intermediates
7	ET-AD	Et cetera - administrative decisions that affect the measurement
	ET-AG	Et cetera - aggregation: month composition
	ET-SC	Et cetera - seasonal and constant

Table 1: DRAG – Independent Variables Categories

Of course, not every variable is used in all the equations. For example, the measurements of road demand (D) are used only in the performance equations.

4.2 Econometrical Formulation

MODEL FORMULATION

As explained in Gaudry (1984, 2002), a distinction is made for each equation between the model that links the dependent variables to the independent variables (the "fixed part"), and the error model (the "random part"). The fixed part will be, for all observations *t*:

$$y_t^{(\lambda_y)} = \sum_{k=1}^{K} \beta_k x_{tk}^{(\lambda_x)} + u_t$$

where u_t is the error model and K is the number of independent variables. The Box-Cox transformation of the variables is defined as:

$$y^{\lambda} = \begin{cases} \dfrac{y^{\lambda-1}}{\lambda} & ,\lambda \neq 0 \\ \ln(y) & ,\lambda \to 0 \end{cases}$$

In these expressions, both the dependent (y) and the independent (x) variables may be Box-Cox transformed. The model is further generalized, by allowing heteroscedasticity and autocorrelation structures to be specified for the error model.

$$u_t = \left[\exp\left(\delta_0 + \sum_{m=1}^{M} \delta_m z_{tm}^{(\lambda_m)} \right) \right]^{-\frac{1}{2}} v_t$$

$$v_t = \sum_{l=1}^{L} \rho_l v_{t-l} + w_t$$

Here, z_{tm} ($m = 1, \ldots, M$) are the heteroscedasticity factors. The v_t are homoscedastic, but possibly autocorrelated. This is captured in the expressions of v_t, where the index L is the order of the autoregressive part and where w_t represent the independent and normally distributed disturbance terms with equal variances.

This formulation assures that the error variance is constant and that the residual errors are not correlated in time ("white noise"). The model combines two modelling tendencies, namely a (non-linear) regression model and a (Box-Jenkins) time-series analysis. Further details on the econometrical formulation can be found in Gaudry (1984, 2002), Liem et al. (2000) and Fridstrom (1999).

SIGNIFICANCE OF VARIABLE COEFFICIENTS AND ELASTICITIES

To identify the functional form of the equations and the presence of heteroscedasticity, the "likelihood ratio test" is used. To evaluate the contribution of the particular variables and to find out if the considered coefficient is different from zero, the "Student t" is calculated. In linear models, a coefficient is assumed to be different from zero with a high probability level if its absolute t-value is greater than 2. This measure, however, has a lack of power if the true value of the coefficient is close to zero. Moreover, if a model is considered as linear while in reality it is not, the Student t (as all other model parameters) is biased and not convergent. Therefore, the Student t should be used with great caution. In the DRAG models, they are handled as relative signification indexes between variables.

From an economical viewpoint, the variable coefficients itself are of limited interest, because they do not take into account the units of measurement of the variables. Instead elasticities are considered. The elasticities present the ratio of the effect of a variation of a given factor (in percentage) on the dependent variable and the variation of this factor (in percentage). They give a clear number, and therefore they are more useful to assess the underlying results.

4.3 Results

Each equation of the DRAG model consists of a large number of components that could be described in detail. In this section, the results of the demand and safety-performance equations will be briefly discussed. Only the main results are summarized, and no percentages or exact elasticities are given. The results presented here should allow the reader to get an insight in the kind of output that can be obtained from a DRAG-like model.

Some specific results can be mentioned for the first layer. The tax evasion (which consists of people purchasing their fuel in one region rather than in another because it is beneficial) can reduce the diesel sales in the region with the highest prices. However, the use of colouring in heating oil, as a means of fraud reduction, partly reduced the tax evasion. Diesel sales are also affected by several off-highway activities, such as agricultural activities, engineering construction and forestry. Agricultural activity has a big impact on gasoline sales. Increases in these activities result in a growth in diesel sales and, to a lesser extend, in gasoline sales.

Next to the specific results for the first layer, the other outputs are summarized below. A large number of explaining variables are to be found in more than one layer of the model structure. The results are structured in the categories of independent variables show before.

DEMAND

The rises in gasoline consumption increase the total number of deaths more than proportionally and the number of injured persons less than proportionally. The rises in diesel consumption slightly increase the total number of injured and dead persons. At a number of kilometres similar to other vehicles, heavy trucks increase the number of injured and dead persons less than proportionally. This is possible since the low severity of their accidents compensate for accidents rates per kilometre that are higher than those of cars.

PRICE

An increase in the real price of gasoline reduces the number of injured persons and the number of persons killed. An increase in the real price of diesel reduces the total number of victims and seems to have a disproportionate effect on the number of deaths. A rise in the real cost of vehicle maintenance reduces proportionally the number of deaths and less than proportionally the number of injured persons. A rise in the price of public transit slightly increases the number of victims. An increase in the cost of goods other than transportation encourages the gasoline consumption, because the relative gasoline price has dropped, and indirectly increases the number of victims.

MOTORIZATION

On average, additional cars are less used than the ones already in use. The additions to the utility vehicles, which run on gasoline, are two times more used than the already exiting vehicle fleet. The structure of the DRAG model shows that every additional utility vehicle has two times more influence on accidents and their consequences than the additional passenger cars. Despite the fact that small cars added to the fleet are on average two times less used than bigger ones, an increase of their part in the market increases considerably the number of deaths and a bit less the number of injuries. The availability of the seatbelt and the shoulder belt has probably increased the number of all accident categories, reduced their average severity and increased the number of dead and injured persons.

NETWORKS - LAWS, REGULATIONS, POLICE

The law on the mandatory use of seatbelts and shoulder belts, combined with the reduction of speed limits, has reduced the number of injured and dead people. The reduction of casualty accidents has more than compensated the increase of the severity of accidents. The law on breathalysers has reduced the number of injuries, but practically not the number of deaths. The penalty point system and the new Highway Code have reduced both the number of injuries and the number of deaths.

NETWORKS - LEVELS OF SERVICES OF TRANSPORTS MODES

The strikes of the common carriers have significant effects on gasoline and diesel consumption. Strikes of the entire network of the Montréal public transport increase the number of victims, but strikes of the global Québec public transport reduce them considerably, especially the people killed.

NETWORKS - INFRASTRUCTURE, CLIMATE

Highways raise the fuel consumption and the number of fatal accidents, but reduce the number of injuries and deaths. Severe weather reduces the number of deaths and has mixed effects on the number of injuries. Cold weather increases a lot the number of material accidents, and reduces considerably the number of fatal accidents.

CONSUMERS - GENERAL CHARACTERISTICS

A rise in the number of driving licenses per car reduces the number of accidents with material damages and the number of injuries, but increases the number of persons killed. A rise in unemployment reduces the gasoline demand and, for a given gasoline demand, the number of accidents of all categories and their severity. The compensation law of road victims has increased the level of material accidents and the number of injuries, but reduced the number of deaths. The Automobile Insurance Act, which imposed several insurance obligations, has increased the number of material accidents, injuries and deaths.

CONSUMERS – AGE AND GENDER

The lowering of the required driving age has increased the number of material accidents, injuries and deaths . Material and fatal accidents, as well as mortality, are influenced by changes in the proportion of drivers between 18 and 24 years old. Also, there are good reasons to believe that pregnancy raises the material accidents but reduces the casualty accidents and the victims. Fragile indexes suggest than women might have more accidents per kilometre than men.

CONSUMERS - INEBRIETY OR VIGILANCE

A rise of the number of hours worked per week in the manufacturing sector reduces significantly the number of material accidents and increases the number of injuries and deaths. A rise in drug consumption increases all categories of accidents and victims. For a given fuel consumption, alcohol reduces the number of fatal accidents, the mortality and the number of deaths, but it increases the material damages and the number of injured persons. There is no effect on the total number of accidents. Fuel consumption increases with beer and wine and diminishes with spirits. Wine reduces all accidents, severity and victim categories, especially the number of people killed. Beer is the only kind of alcohol that increases mortality and the number of deaths while reducing the number of injured people. Spirits have the opposite effect. Details on these measurements can be found earlier in this document and in Gaudry (1984, 2002).

FINAL ECONOMICAL ACTIVITIES AND INTERMEDIATES

The employment, the retail sales, vacations and manufacturing deliveries determine the level of gasoline sales. The level of diesel sales for highway uses is mainly determined by retail sales and manufacturing deliveries. The trip purposes influence the driving behaviour. Travelling for shopping purposes produce proportionally more deaths than travelling for employment purposes, which cause relatively more injuries and victims.

5. THE DRAG-2 MODEL FOR QUEBEC

5.1 Introduction

To better understand all aspects of road safety and trends in road accidents, Gaudry (1984) worked on an effective means of road safety analysis. This initiative led to the first version of the DRAG econometric model. Given the valuable results and the potential of the system, the implementation of the model, on demand of the SAAQ (Société de l'Assurance Automobile du Québec), led to the development of the DRAG-2 model. This model was intended to be used for official analyses and policy evaluations. It should be considered as an improved version of the first DRAG model, directly applicable for use by policy and decision makers. The objective was twofold. In the first place, the model should help in identifying the factors that influence changes in distances travelled in a vehicle, accidents and victims, together with measurements on the direction, intensity and certainty of that impact. The second objective was to forecast changes in distances travelled and in the number of accidents and victims over the coming years. To do so, parameter values for the model must be available, as well as data for independent variables covering the forecast period. By applying data from independent variables for the future to the parameters of the model, forecasts can be obtained.

This part of the text contains a summary of the major aspects of the DRAG-2 model. After a description of the model structure, some main results are presented. Next, a few details are given on the forecasting objective.

5.2 The Structure of the DRAG-2 Model

The DRAG-2 model essentially consists of two levels. Level 1 focuses on exposure to risk of accident based on distance travelled. It consists of two equations: one for the distance travelled by gas-powered vehicles and one for the distance travelled by diesel-powered vehicles. The monthly data is based on fuel sales of gas and diesel (expressed in litres), which are associated with the energy efficiency of the vehicles using these fuels. Also the influence of cold winters is taken into account, and changes in the types of vehicles are considered.

At level 2, seven equations are used to explain the frequency of accidents (fatal, bodily injury and property damage only), their severity (mortality and morbidity) and the number of victims (killed and injured). Morbidity is defined as the number of victims injured divided by the number of fatal and bodily-injury accidents. The definition of mortality is the ratio of the number of victims killed by the number of fatal accidents.

LEVEL 1		
INDEPENDENT VARIABLES		**DEPENDENT VARIABLES**
➢ Prices ➢ Total vehicles on road ➢ Vehicle characteristics (only for gasoline) ➢ Laws, regulations and various measures ➢ Strikes ➢ Weather ➢ Road system (only for diesel) ➢ Drivers (only for gasoline) ➢ Medication and alcohol ➢ Reasons for travel ➢ Economic conditions (only for gasoline) ➢ Administration (only for gasoline) ➢ Roadside check (only for diesel) ➢ Aggregation	➔	➢ **Distance travelled by gas-powered vehicles** ➢ **Distance travelled by diesel-powered vehicles**
LEVEL 2		
INDEPENDENT VARIABLES		**DEPENDENT VARIABLES**
➢ Exposure ➢ Prices ➢ Total vehicles on road ➢ Vehicle characteristics ➢ Laws, regulations and various measures ➢ Strikes ➢ Weather ➢ Drivers ➢ Medication and alcohol ➢ Reasons for travel ➢ Economic conditions ➢ Administration ➢ Roadside check ➢ Isolated cases ➢ Aggregation	➔	➢ **Frequency of accidents** • Fatal accidents • Bodily-injury accidents • Accidents with property damage only ➢ **Severity** • Mortality • Morbidity ➢ **Victims** • Victims killed • Victims injured

Figure 2: Structure of the DRAG-2 model

The model was built on a monthly basis, for the period of December 1956 to December 1993. This sums up to a total of 445 observations. In the mathematical calculations, each equation includes Box-Cox transformations. For each equation, the same transformation parameter is used for the dependent variable and the independent variables. The parameter is different, however, for each equation. Also an error autocorrelation structure is introduced in each of the equations.

5.3 Results

In this section, some results of the DRAG-2 model are described. The focus will be on the direction of the effects, and not on the econometric results. The autocorrelation structure and the Box-Cox transformation values are not presented in this overview.

First, the results are presented for six common variables in the models of the DRAG family. These are total distance travelled, gas prices, temperature, legislation to reduce highway speed limits, together with mandatory seat belt use, alcohol consumption and retail sales.

The effects of these covariates on the dependent variables are shown in the table below. Columns 2 up to 7 contain the effects of each covariate on the dependent variables, depicted in the rows. The arrows in the table show the direction of the changes in the dependent variables (rows) for an increase in the independent variables (columns). The exact elasticities will not be considered here, only the directions will be indicated. As an example, if a 10% increase in gas prices results in a 4.6% decrease in the distance travelled by gas-powered vehicles, then the corresponding entrance in the table will show the downward arrow "↓".

The stars in the table are used to show the statistical significance of the relationships. A "*" indicates that the Student t-value for the test of the coefficient being different from zero is very low (lower than 1). In this case, effects are uncertain, and the scope of these results is limited. If "**" is indicated, the Student t-value is between 1 and 2, and the effects are said to be of average certainty. The indication "***" means that the effect is different from zero in all likelihood. In this case, the statistical relationship is highly significant. The results are discussed in more detail below the table.

10 % increase in …➔	Total distance travelled	Gas prices	Temperature	Legislation on speed limits and seatbelt use	Alcohol consumption	Retail sales
Distance travelled by gas vehicles		↓ ***		↑ *		↑ ***
Distance travelled by diesel vehicles			↑ **		↓ *	↑ *
Accidents with property damage only	↑ ***	↓ *	↓ ***	↑ *	↑ ***	↓ *
Bodily-injury accidents	↑ ***	↓ ***	↓ ***	↓ ***	↓ *	↑ ***
Fatal accidents	↑ (lin)/↓ (quad) ***	↓ ***	↑ ***	↓ ***	↓ *	↑ **
Morbidity	↓ **	↑ *	↓ **	↓ *	↑ **	↓ **
Mortality	↑ (lin)/↓ (quad) *	↓ *	↓ **	↓ *	↓ ***	↑ **
Victims injured	↑ ***	↓ ***	↓ ***	↓ ***	- *	↑ **
Victims killed	↑ (lin)/↓ (quad) ***	↓ ***	↑ ***	↓ ***	↓ **	↑ **

Table 2: Drag 2 - Results for Six Common Variables

TOTAL DISTANCE TRAVELLED

An increase in total distance travelled would result in an increase in property-damage accidents, accidents with injuries and victims injured and a slight decrease in morbidity.

From the results of the first DRAG model, it became clear that the effect of total distance travelled on fatal accidents, mortality and victims killed may be represented by a quadratic form (inverted "U" shape). Therefore, the effect is parameterised with a linear term (Box-Cox transformation value of 1) and a quadratic term (Box-Cox transformation value of 2). With this model specification, an increase in total distance travelled resulted in an increase in the linear term and a decrease in the quadratic term for fatal accidents and victims killed. These results also apply for mortality, although much less significant.

GAS PRICES

Increases in gas prices (in constant dollars to travel one kilometre) have a significant (negative) influence on the distance travelled by gas-powered vehicles, on the accidents with injuries and on the fatal accidents. There is also a significant drop in the number of victims injured and killed. At the same time, there is a smaller effect on property damage accidents (decrease), morbidity (increase) and mortality (decrease).

TEMPERATURE

An increase in temperature (measured in degrees Fahrenheit) would result in a moderate increase in distance travelled by diesel-powered vehicles. Higher temperatures also significantly reduce the number of accidents with property damage and the number of victims injured. On the other hand, the number of fatal accidents and the number of victims killed increases with temperature. Also a moderate decline is noticed in number of bodily injured accidents and the morbidity and mortality rates.

LEGISLATION FOR HIGHWAY SPEED LIMITS REDUCTION AND MANDATORY USE OF SEATBELTS

The legislation to reduce highway speed limits, introduced together with mandatory seatbelt use, is incorporated in the model by means of a dummy variable. The legislation resulted in a very small increase in distance travelled by gas-powered vehicles (almost zero effect) and in the number of accidents with property damage. Morbidity and mortality only slightly decrease. The number of bodily-injury accidents and the number of fatal accidents, together with the number of victims killed and injured declined significantly.

ALCOHOL CONSUMPTION

To take into account the alcohol consumption for drivers, one ideally uses the percentage of impaired driving individuals. This number, however, is not available, and another procedure had to be followed. Starting from the sales of products containing alcohol, figures of pure alcohol per adult were obtained. When using these figures, three remarks should be made. First, it is assumed that monthly fluctuations in alcohol purchases for the entire population can represent drunk driving rates for the drivers population. Second, alcohol products purchased in a certain month are assumed to be consumed in the same month. Third, changes in consumption of different types of alcohol (beer, wine, spirits) can have separate effects on the dependent variables. Given these limits of the constructed variable, results should be carefully interpreted.

The significant effects of an increase in pure alcohol consumption are an increase in accidents with property damage and a decrease in mortality. There is a small decrease in the distance travelled by diesel-powered vehicles, in the number of bodily injury and fatal accidents and in the number of victims killed. Also there is a small increase in morbidity and little effect on the number of victims injured.

RETAIL SALES

Retail sales are used in constant dollars weighted by an index to translate the number of trips per dollar spent, converted to an employment basis. The purpose of the variable is threefold.

1. To assess the prevalence of shopping as the reason for travel in the distance travelled by gas-powered vehicles.
2. To estimate the proportion home deliveries by truck as the reason for travel in the distance travelled by diesel-powered vehicles.
3. To determine the effect of shopping as the reason for travel in total distance travelled on the number of accidents and victims.

An increase in retail sales results in a significant increase in the distance travelled by gas-powered vehicles and in the number of bodily-injury accidents. Furthermore, there is a small increase in the distance travelled by diesel-powered vehicles and a small decrease in the number of accidents with property damage only. Also an average decrease in morbidity is noted, and an average increase in mortality, the number of fatal accidents, the number of victims injured and the number of victims killed.

Next, the results are presented for six other variables. These variables pertain to vehicle maintenance costs, the number of motorcycles and mopeds on the road, the new Highway Safety Code, the proportion of young drivers aged 16 to 24, unemployment and the introduction of Bill "C-19". The principal characteristics are described for each variable, and the results are summarized in the table below. The same conventions are used as in the previous table to depict the results and to indicate the level of statistical significance.

10 % increase in …→	Vehicle maintenance costs	Motor cycles and mopeds per adult	Highway Safety Code	Proportion of drivers aged 16 - 24	Unemployed per driver's license	Criminal Code C-19
Distance travelled by gas vehicles	↓ *	↓ **	↑ *		↓ ***	
Distance travelled by diesel vehicles			↑ *			
Property damage only accidents	↓ ***	↑ **	↓ ***	↑ *	↓ ***	↓ *
Bodily-injury accidents	↓ ***	↑ ***	↓ ***	↑ **	↓ **	↓ ***
Fatal accidents	↓ **	↑ ***	↓ **	↑ ***	↓ **	↓ ***
Morbidity	↓ **	↓ **	↓ *	↓ **	↓ **	↓ *
Mortality	↓ **	↑ **	↑ *	↓ *	- *	↑ *
Victims injured	↓ ***	↑ ***	↓ ***	↑ **	↓ ***	↓ ***
Victims killed	↓ **	↑ ***	↓ **	↑ **	↓ **	↓ ***

Table 3: Drag 2 – Results for Six Other Variables

VEHICLE MAINTENANCE COSTS

This variable is an index of maintenance cost for vehicles expressed in constant dollars. An increase in vehicle maintenance costs would result in a decrease in distance travelled by gas-powered vehicles. Looking at the influence of an increase in this factor on the number of road accidents, a decline is noted.

NUMBER OF MOTORCYCLES AND MOPEDS PER ADULT

The construction of this variable is based on the number of motorcycles and mopeds registered for road use, computed on a per adult basis and corrected for no use during the winter, partial use in spring and fall and maximum use in summer. An increase in the number of motorcycles and mopeds per adult has a small but average statistical significant effect (decline) on the distance travelled by gas-powered vehicles. It would also cause an increase in the number of road accidents, a drop in morbidity and an increase in mortality and the number of victims.

THE NEW HIGHWAY SAFETY CODE

This intervention variable was included to determine the effect of introducing the new Highway Safety Code in 1982, and its amendments in 1987 and 1991. The Safety Code had very little effect on total distances travelled, but resulted in a significant drop in the number of road accidents. The impact on morbidity and mortality is not statistically significant. The number of victims significantly declined both for injuries and for deaths.

THE PROPORTION OF DRIVERS AGE 16 TO 24

This variable is used to determine the effect of a change in the proportion of young drivers age 16 to 24 compared to the total number of drivers on the number of road accidents. An increase in the number of young drivers results in a rise in the number of road accidents and a decline in the morbidity and mortality (although the statistical significance is low for mortality). The number of injuries would increase for injuries and for deaths.

THE NUMBER OF UNEMPLOYED PER DRIVER'S LICENSE

The number of unemployed per driver's license is included as an indicator of economic conditions. It is the ratio of the number of unemployed compared to the number of people with driver's licenses. An increase in this variable would result in a decline in the distance travelled by gas-powered vehicles. Also, an increase in the ratio would result in a decline in accidents, but in an increase in morbidity. For mortality, the effect is almost zero. The number of victims would decline both for injuries and for deaths.

CRIMINAL CODE C-19

The Criminal Code C-19 imposes harsher penalties for driving under the influence of alcohol. This legislation had a significant effect on the number of road accidents. The significance of the effect on morbidity and mortality is statistically very small. The number of victims injured and killed declined significantly with the new penalties.

5.4 Forecasting step

As mentioned in the introduction to the DRAG-2 model, the second objective was to forecast changes in distances travelled, the number of accidents and victims over the coming years. To obtain forecasts from an econometric model, several steps should be followed (Fournier and Simard 2000). First of all, parameter values are estimated for the model. In the case of the DRAG-2 model, parameter estimates are obtained from the model specification for the period of December 1956 to December 1993. Next, data for the independent variables should be available for the forecasting period. Reference sources are consulted and estimation techniques applied to obtain monthly figures on the independent variables up to a certain period. In a third step, data on the independent variables for the future were applied to the parameters of the model specification. This results in an initial forecast. Next, it is crucial to verify the obtained outcomes. More specifically, one should look for unlikely outcomes, and unstable results (like sudden or unexpected jumps) should be identified. If necessary, the model should be re-specified, and parameters of the model's equation re-estimated, using more recent or other data. As an example, it might be necessary to free some Box-Cox parameters in the model in order to obtain a better fit and more reliable forecasts. With the newly specified model, new forecasts can be obtained and, again, verified. This process eventually results in a final forecast for the dependent variables in the model. For more details on the forecasting step and the results for the DRAG-2 model, the reader is referred to Fournier and Simard (2000).

6. OTHER MODELS IN THE DRAG FAMILY

Over the years, a larger family of models emerged, all explaining the Demand for Road use, Accidents and their Gravity, and all inspired by the DRAG model for Quebec. An account of all of these models is presented in Gaudry and Lassarre (2000). The common feature of all members of the DRAG family is an at least three-layer recursive structure of explanation, including road use, accident frequency and severity as separate equations. Road use (traffic volume) is not considered an exogenous factor, but explained by a number of socio-economic, physical and political variables. Accident frequency is modeled depending on road use, the presumably single most important causal factor. Accident severity is modeled as the number of severe injuries or fatalities per accident, that is, as the conditional probability of sustaining severe injury given that an accident takes place. The decomposition of the absolute number of fatalities or severe injuries into these two multiplicative parts allows for interesting substantive interpretations.

The following models, inspired by the DRAG framework discussed earlier, are summarized in the subsequent sections (Chambron 2000; Fridstrom 1999).

1. **SNUS** (Straßenverkehrs-Nachfrage, Unfälle und ihre Schwere), authored by Gaudry and Blum (1993 and 1998), covering Germany. The study uses monthly data from 1968 to 1989, and covers whole West Germany. Specific for this model is the inclusion of material damage accidents, the distinction between light and material damages and the separate modelling of fuel and diesel vehicles.
2. **TRULS** (TRafikk, Ulykker og deres Skadegrad), by Fridstrom, covering Norway, appeared in a first version in 1991. This model estimates the traffic from the fuel sales, including the evolution of the fuel consumption of the vehicles according to different categories, meteorological conditions… Two econometric equations, explaining the seat belt rate and the car fleet are included. The results are disaggregated by road users categories (pedestrians, cyclists, car drivers…).
3. **DRAG-Stockholm** (Demand for Road use, Accidents and their Gravity in Stockholm), authored by Tegnér and Loncar-Lucassi (1996), covering the Stockholm county of Sweden.
4. **TAG** (Transports routiers, Accidents et Gravité), authored by Jaeger and Lassarre (1997), covering France. Specific features include modeling of the average speed and estimation of monthly mileage.
5. **TRACS-CA** (Traffic Risk And Crash Severity - California), authored by McCarthy and covering California, delivered its first results in 1998. In this model, material damage accidents are included. For the severity of accidents, the death and injury rates are used. Elasticities have been recalculated.

6.1 Germany: the SNUS-2.5 model

In Germany, an improved version (SNUS-2.5) of the SNUS-1 model (Gaudry and Blum 1993) was developed. The main difficulties faced by the authors have to do with the specification of the employment activity variable and with the role of vehicle stocks in road demand models. Further, several specific aspects characterize the German situation, namely the absence of general speed limits on motorways, the large size of the country, with high car ownership and an important car industry, and the poly-central infrastructure and structural breaks in the data series caused by the unification of the country.

The diagram below (Jaeger 1998) summarizes the model structure in the German context. The dependent variables are shown in the categories "Demand for road use", "Accident frequency" and "Accident severity".

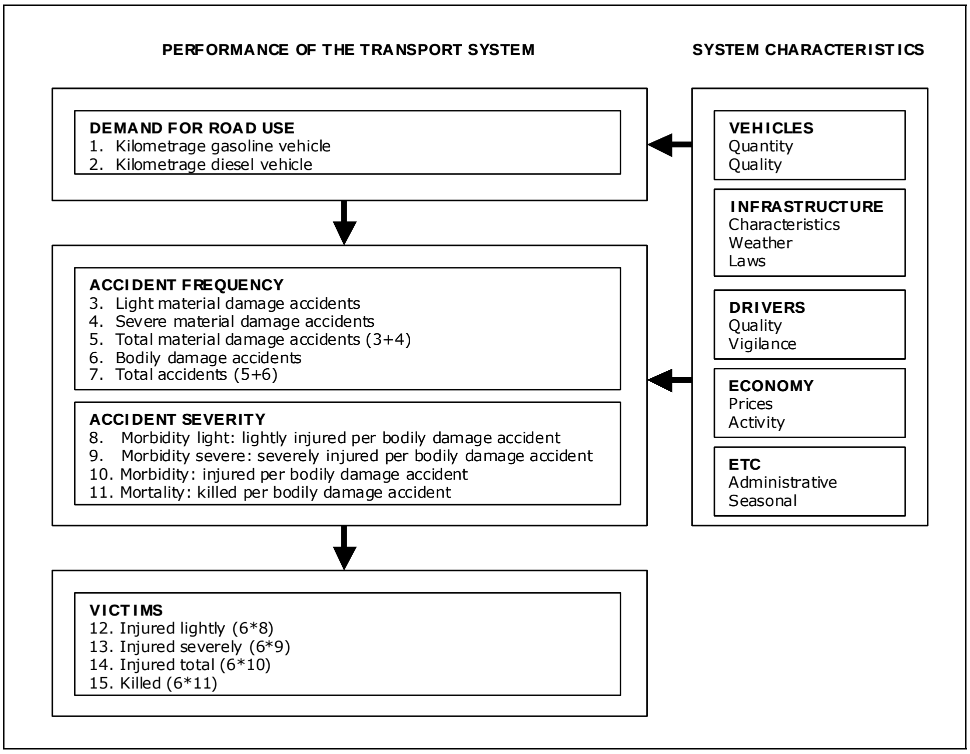

Figure 3: Diagram for the SNUS-2.5 Model (Blum and Gaudry 2000, inspired by Jaeger 1998)

Some results, reported by the authors Blum and Gaudry (2000), are summarized.

- The exposure has differentiated impacts. There is an increase in the number of severe material damage, and a higher severity.
- A higher fuel price leads to lower risk taking, although the elasticities for the demand for road use are relatively low.
- An increase in temperature implies a strong decrease in material damage accidents and an increase in the number of bodily injury accidents and in morbidity and mortality rates. It also strongly increases the road demand.
- Seat belt use reduces both the frequency and the severity of bodily injury accidents, but increases the frequency of material damage accidents.
- The social aspect of beer consumption increases road demand. Beer consumption increases the number of bodily injury accidents, mortality and, consequently, the number of fatalities. In the same context, the blood alcohol concentration limit reduced driving, accidents and their severity.
- Shopping (for food and clothing) increases the frequency of bodily injury accidents and, to a lesser extend, the number of material damage accidents. The reduction in mortality is not large enough to offset the negative influences of shopping.
- Concerning the weather variables, there are strong effects of sunshine on the frequency and severity of accidents, and the presence of rain has larger proportionate impacts than the amount of rain.
- The introduction of speed limits has beneficial effects on all dependent variables.

6.2 The TRULS-1 model for Norway

Fridstrom developed the TRULS-1 model in Norway as part of his PhD thesis. It is the successor of the generalised Poisson regression models estimated in Fridstrom and

Ingebrigtsen (1991) and in Fridstrom et al. (1995). In the TRULS-1 model, the assumption is made that casualty counts follow a generalised Poisson distribution. The main attempt of the model is to explain exposure.

The model includes an additional layer of car ownership, which is a dynamic, partial adjustment structure. A vehicle pool has high rates of turnover and a short life expectancy. The stock of cars changes with new car acquisition, used car sales and scrapping. The model further includes an additional layer for the decomposition between light and heavy vehicle road use. The light and heavy vehicle exposure measures are based on a sub-model designed to "purge" the fuel sales figures of nuisance factors affecting the number of vehicle kilometres driven per unit of fuel sold. This sub model is an auxiliary relation (a measurement model), which is not part of the model's recursive causal structure. The TRULS-1 model also includes a sub-model of seat belt use, and separate equations are estimated for various subsets of casualties (car occupants, seat belt non-users etc.), in order to shed a light on the causal mechanism governing accidents and severity. Given the assumption of Poisson distributed casualty counts, the accident equations are specified with a disturbance variance assumption approximately consistent with the Poisson law. As far as the data are concerned, the TRULS-1 model is based on pooled cross-section / time-series data.

The structure and the interdependencies between the dependent variables are shown in the diagram below. Single lines indicate use as explanatory variables, while double lines are used for certain dependent variable relations that are derived from a combination of other relations. The full model consists of 13 dependent variables.

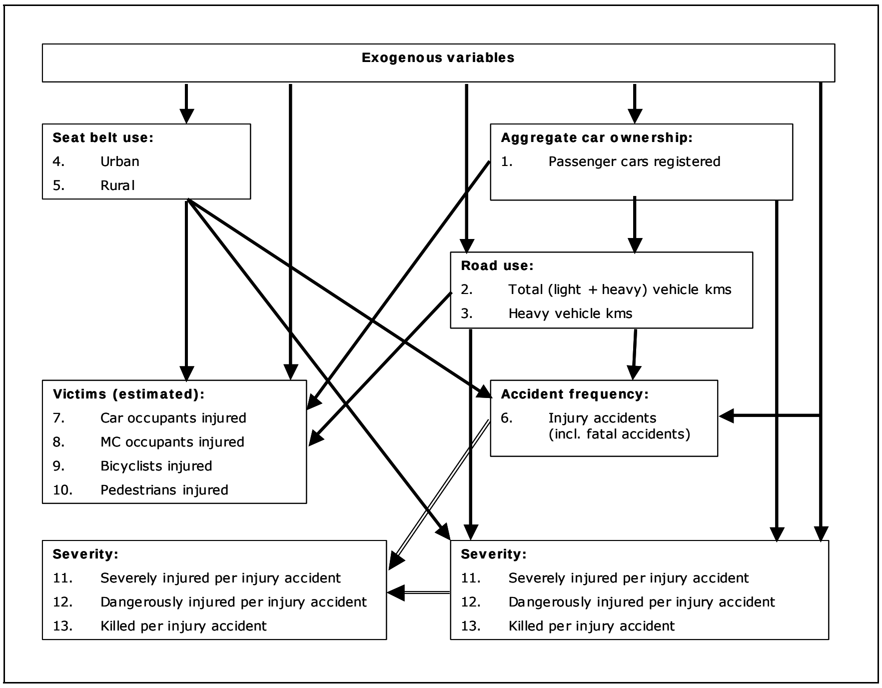

Figure 4: Recursive Structure of the model TRULS-1 (Fridstrom 2000)

Some results are summarized below.

- Injury accidents increase almost in proportion to the traffic volume, other things being equal. This applies, however, on the condition that the ratio of vehicle kilometres to road kilometres remains constant. An increase in traffic density tends to dampen the effect of larger traffic volumes (measured in vehicle kilometres).
- Heavy vehicles are more dangerous than private cars. The larger the heavy vehicles share of the traffic volume, the higher the injury accident frequency. The number of

car occupants injured does not increase with the heavy vehicle share. Also, heavy vehicles appear to be particularly dangerous to two-wheelers.

- In the long run, an increase in income results in an increase in vehicle ownership, in road use demand and in injury accidents. The number of pedestrian injuries is relatively insensitive to income.
- The current rate of interest is a price variable that affects car ownership, road use, accidents and victims.
- In Norway, injury accidents become less frequent when the ground is covered by snow. The risk reduction is larger the deeper the snow is. This "snowdrift effect" reduces the frequency of single vehicle injury accidents, but increases the risk of head-on collisions. The number of injury accidents goes up during days with snowfall, but at the same time the severity is reduced. This is a "risk compensation effect".
- The monthly number of days with temperatures dropping below zero has a favourable effect on the number of accidents, especially on the most severe injuries. This effect is much stronger for bicyclists and motorcyclists than for pedestrians, suggesting a reduction in the two-wheeler exposure.
- The favourable effect of rainfall on the injury accident count is partly explained by the reduced exposure among unprotected road users.
- Lack of daylight during the traffic peak hour period and dark evenings has a significant effect on risk, especially for pedestrians.
- An increase in the number of car drivers not wearing a seat belt increases the number of injuries and fatalities. Seat belts are more effective in preventing less severe injuries than in saving lives, and they do not trigger a car driver behavioural adaptation. The model also allows estimating the effect of increasing the fine for not wearing a safety belt.
- For each severity, a higher level of alcohol results in more accidents. The restrictive Norwegian alcohol policy has helped preventing road accidents and fatalities.
- Car ownership and road use increase, ceteris paribus, almost proportionately with the size of the population. The first quarter pregnancy rate has a significant unfavourable effect on the injury accident frequency, but not on the number of fatal injuries.

6.3 The DRAG-Stockholm-2 Model

In this study, the traffic safety in the Stockholm Region has been investigated (Tegnér et al. 2000). The model of traffic demand for Stockholm is estimated on aggregate time-series data for the Stockholm County. The objective is to explain traffic volumes (in vehicle-kilometres) and road accidents, using a spectrum of monthly explanatory variables. The following time-series models have been estimated:

- An exposure model for the total road mileage (vehicle-kilometres) for gasoline driven passenger cars;
- A frequency model for the total number of injury and fatal road accidents;
- A severity model for the number of persons lightly, severely and fatally injured per road accident.

The demand for road use is mainly influenced by the following variables.

- A first group of variables depict the economic activities. Employment seems to be a key variable. An increase in the number of employed people increases the number of vehicle-kilometres. Increased employment leads to a higher rate of car ownership, because of a higher personal income.
  Another economic factor is retail sales. Road traffic increases when retail sales rise.

This includes the effect of shopping trips on total road traffic demand, which is consistent with findings in Canada, Germany and Sweden (Gaudry et. al, 1995).

- The growth in car park in Stockholm has contributed to an increase in road traffic volume. However, given the small elasticities, the authors conclude that congestion may cause a negative effect on road traffic usage, and that the increase in car park should mainly be found in the second, third… car per household, which is less used than the first. Similar results are found in Germany.
- The road network and the traffic system may affect road traffic in different ways. Connecting new residential or commercial areas by new roads or improvement in the quality of existing roads result in an increase in road traffic. On the other hand, when new road links replace congested bottlenecks, they may reduce total vehicle mileage.
- Car drivers drive more kilometers in order to avoid high parking fees and penalties.
- Gasoline prices affect the demand for road traffic. When gasoline prices increase, car traffic is reduced.

The impact of the most important factors influencing the number of accidents and fatalities are shown in the following table, by the sign of their average elasticities. These indicate in which direction the dependent variable changes as a result of a one-percent change in the factor.

	Dependent variable	
Factor	**Total number of accidents**	**Number of fatalities**
Road traffic vehicle-kilometers	↑	↓
Use of seat-belts	↓	↓
Number of employed per vehicle-km	↑	↓
Number of remarks per inspected car	↑	↑
Share of daylight hours per day	↓	↓
Medical consumption (nr. of recipes per person	↑	↑
New road links	↑	↓

Table 4: Effects of the factors on the dependent variables (Tegnér et al. 2000)

After this first model, a new one has been developed. The new model includes also diesel vehicles, tests some new explanatory variables and a new specification of the frequency and severity model. The new frequency model is specified in terms of three sub-models: lightly injured persons per bodily-injured accidents, severely injured persons per severe and fatal accidents and fatalities per fatal accidents. For the second frequency model, the new specification leads to an improvement of overall performance. The new severity model resulted in the correct inverted U-shaped relationship between total vehicle-kilometres and the dependent variables. At a low traffic level, accident severity increases as traffic grows. But at a certain level, when congestion occurs, the severity of accidents declines, together with speed drops. Overall, however, the old specification of the model is superior.

Some results of the new specification are the following. A greater share of heavy vehicles (diesel share) reduces accident risks. Also, more motorways contribute to fewer accidents. While the number of light injury accidents is higher, the number of severe injury accidents is reduced. Next, new urban road links lead to fewer fatalities. Last, traffic intervention measures have a positive impact on traffic safety. Seat belt usage reduces the number injury accidents, and the impact of the use of headlight during daytime has a positive impact on the number of fatalities (including, however, a risk compensation effect).

A special model variant was used to test the influence of alcohol and medicine consumption on the number of injuries and fatalities. Low consumption levels of alcohol reduce the number of light and severe injuries. At higher levels of consumption, accident risk augments rapidly. The use of medicine (drugs sold on prescription) has a devastating influence on accidents with injuries and fatalities. However, measuring the effect of drug consumption using aggregated time-series data is an indirect way of looking for cause-effect relations. It is not sure whether an increase in overall drug consumption is identically reflected in the group of car drivers.

In various DRAG-type models, the number of pregnant women seems to influence road traffic accidents. An increase in the number of pregnancies leads to an increase in the number of accidents and fatalities. This could possibly be due to substantial hormonal changes during the first three months of pregnancy. However, pregnancy is an unexplored accident risk factor, which should be verified in a more elaborate study.

6.4 The TAG-1 Model for France

The TAG econometric model of road safety in France (Jaeger 1998; Jaeger and Lassarre 2000) is a system of seven simultaneous, recursive equations pertaining to four types of risk: exposure risk (measured by the number of vehicle-kilometres), risk-taking behaviour (average speed on the intercity road network), accident frequency and the severity of accidents interpreted as the light injury and severe injury morbidity rates, as well as the mortality rate, of bodily damage accidents. The development of the TAG-1 model started from the DRAG model in Quebec. The structure of the model is adapted in order to reflect specific conditions of traffic risk in France, and speed is included as an indicator of driver behaviour. A new aspect of the model is the inclusion of a fourth dimension related to behavioural risk, made possible by the availability of a series on speeds driven. TAG-1 is structured to explain the damage (victims of road accidents) as a function of exposure to risk, risky behaviour, the risk of an injury accident and the risk of injury (Jaeger and Lassarre, 1998).

Data is used on the period 1957-1993. About fifty factors are used as explanatory variables in the model. Accident frequencies and severity rates depend on two endogenous variables of the system, vehicle-kilometrage and (average highway) speed. The effect of changes in explanatory variables on risk indicators is measured by direct and indirect elasticities of their impact on kilometrage and speed. The TAG-1 structure allows, on the one hand, the identification of direct and indirect effects of explanatory variables on road accident toll (risk exposure and average speed), and, on the other hand, the analysis of substitution or compensation effects between the different categories of accidents, and the different levels of gravity.

The structure of the TAG-1 model is determined by the characteristics, the environment and the performance of the road transport system. Road safety problems are considered as the result of malfunctions in the components of the road transport system: vehicle, driver and infrastructure. These factors are internal to the system, meaning that they are measured and quantified within the road system. The road transport system should be seen in a broader environment, where governmental, economic, demographic and climatic elements have a direct or indirect impact on the performance of the road traffic system. These are external factors. Indicators of traffic system performance are those that reflect the functioning of the system (total mileage driven, speed practised, …) and the malfunctions (personal injury accidents and severity). The main explanatory factors for road transport demand, average speed, the incidence of road accidents and their degree of gravity are classified into the following categories.

CHARACTERISTICS ↓ Internal factors	Vehicles	**Stock**
	Drivers	**Characteristics** **Behaviour variables**
	Infrastructure	**Networks**
ENVIRONMENT ↓ External factors	Demographic system	**Population**
	Economic system	**Price** **Unemployment** **Reasons for journeys** **Reasons for goods transport**
	Governmental system	**Road safety laws**
	Climatic system	**Climatic variables**

Table 5: Classification of Explanatory Variables in the TAG Model (Jaeger and Lassarre 2000)

Taken all together, the model consists of four layers related to four risk dimensions, namely the risk exposure (number of kilometres travelled), the risk behaviour (average speed driven), injury accident frequency (divided in fatal and non-fatal) and accident gravity (rate of fatalities, minor injuries and serious injuries per injury accident).

At the level of road transport demand, the following major results are obtained. On the one hand, a rise in the employment index (a proxy for home-to-workplace journeys), the stock of private cars, the wine consumption per adult, the average national temperature or the proportion of diesel-engine cars results, ceteris paribus, in an increase in kilometres travelled. On the other hand, the introduction of technical inspections (with the disappearance of old and unsafe cars), the increase in the price of fuel per kilometre or the increase in the share of small cars have, ceteris paribus, the effect of reducing the number of kilometres driven.

In the model of risk behaviour, an increase in the motor vehicle price index, the proportion of motorway traffic or the percentage of private motor cars (≥ 11 fiscal horsepower) have a positive impact on the average speed driven. The same is true for the seat belt use, which underlines the existence of a risk compensating effect. Average speed is significantly reduced by the laws and enforcement measures relating to speed limits. Also a higher price of fuel per kilometre reduces the average speed, indicating the growing awareness of drivers about the positive relation between speed and fuel consumption.

As far as the injury accident frequency is concerned, the average speed, the number of motorised two-wheelers, the total mileage and the industrial activity have a significant positive impact. Conversely, only some temporary events (like the Gulf war) and various road safety measures (breathalyser tests and the rate of seat belt wearing) seem to result in a reduction of fatal and non-fatal injury accidents. The conclusions regarding victims are similar to those relating to accidents.

In relation with accident toll (injury accident frequency and accident gravity), the following effects of the explanatory variables have been noted.

- In accordance with Hakim et al. and with the results of the DRAG-2 model in Quebec, exposure to risk in terms of kilometres travelled is positively correlated with the number of accidents and deaths. The increase in mileage increases the risk of fatal accidents more than the risk of non-fatal injury accidents.
- Speed limits on the road network have significant effects, and are due more to a reduction in the dispersion of speeds than to a drop in average speed. The impact of speed on fatal accidents is much larger than the impact on non-fatal injury accidents.
- Although the fact of wearing a seat belt reduces traffic risk, there is a (smaller) contrary compensating effect, since wearing a seat belt also leads to an increase in speed.
- An increase in wine consumption per adult increases the number of fatal accidents, minor and serious injuries and fatalities. However, wine consumption is only an imperfect reflection of total alcohol consumption.

- An increase in the number of heavy goods vehicles increases traffic risk, mainly the number of accidents whose degree of gravity is limited. At a given mileage, the share of small cars and an increase in the number of motorized two-wheelers brings an increase in accident toll.
- An increase in the proportion of motorway traffic leads, with average significance, to a decrease in personal injury accidents and in the number of serious injuries, but at the same time it increases the number of fatal accidents and deaths. An increase in traffic on main roads leads to a substantial increase in traffic accidents.
- The effects of the real price of fuel per kilometre and the unemployment rate come with a very low significance level. An increase in the real price of petrol results in a reduction in traffic risk. A rise in unemployment increases traffic risk to a negligible extend. These results conflict with the DRAG-2 model for Quebec and various other studies.

6.5 The TRACS-CA Model for California

TRACS-CA involves the development and the estimation of a structural aggregate model of highway safety, based upon historical time series data (1981 - 1989) from California. The model is consistent with Gaudry's DRAG multi-equation approach. McCarthy (2000) generalizes a previous version of the model by refining empirical specifications in traffic exposure and crash frequency, and by including additional models for crash mortality and morbidity.

With the TRACS-CA study, the authors want to progress in their understanding of the relations between highway risk, crash frequency and crash severity. In addition, they want to provide policy makers with information on the impact of traffic enforcement, alcohol-related and highway safety policies on road safety.

The three main components of the model are risk exposure, crash frequency and crash severity. The dependent variable in the risk exposure model is total vehicle miles travelled (VMT) on state highways. The crash frequency is disaggregated by severity, and splits up into three sub-models: fatal, non-fatal injury and material damage only crash frequency. The crash severity is disaggregated into fatal and non-fatal crashes, with sub-models for the mortality and the morbidity rate. The dependent variables are supposed to be influenced by three sets of explanatory variables: socio-economic, transport system and environmental factors. The table below summarizes the direct effects of the independent (explanatory) factors on the dependent variables.

INDEPENDENT VARIABLE	Demand for Road Space	Fatal Crashes	Injury Crashes	Material Crashes	Mortality	Morbidity
Socio-economic Factors						
Index of per capita expenditures	√					
Real gasoline price	√	√	√	√		√
Unemployed per 1000 drivers	√					
Unemployed per VMT					√	
Alcohol licenses per capita			√	√		
Alcohol consumption per capita	√	√	√	√	√	√
Monthly population	√					
Weekends	√	√	√	√	√	√
Transport system factors						
Exposure		√	√	√	√	√
Traffic arrests per capita		√	√	√	√	√
Motorcycle density		√	√	√		√
Seat belt law		√	√	√	√	√
Relaxed speed limit law	√	√	√	√	√	√
Environmental factors						
Average rainfall	√	√	√	√	√	√

Table 6: TRACS-CA Explanatory Variables According to the Dependent Variable (McCarthy 2000)

The index of per capita expenditures is a proxy for income in the model. To accommodate differences in driver preferences for travel and risk taking, alcohol consumption per capita and weekends travel are included. The latter is defined as the number of weekend days per month, and is meant as a surrogate for changes in the distribution of trip purposes and trip timing.

Some results of the TRACS-CA model are summarized below.

- A rise in risk exposure increases fatal and material only crashes and, less strongly, non-fatal injury crashes. Apart from the frequency, also the mortality and morbidity rise with higher exposure.
- The real gasoline price has no impact upon the demand for travel. Further, the primary effect of an increase in this variable is a decrease in non-fatal and material only crashes and in morbidity.
- An increase in per capita beer consumption increased the demand for travel. A rise in the consumption of distilled spirits has a significant impact on fatalities. A higher consumption results in more fatal crashes. A higher total consumption of wine per capita has a considerable increasing impact on injury and material only crashes. The number of non-fatal crashes is also influenced by the availability of alcohol.
- Average rainfall significantly affects the frequency and severity of crashes, but the direction of the effect is negative for fatal crashes and mortality and positive for non-fatal crashes and morbidity.
- Increased enforcement significantly reduces fatal crashes, but results in a rise in the frequency of property damage only crashes. The reason for this effect needs further investigation.
- Mandatory seat belt use has no effect on the frequency of fatal crashes, but when a fatal crash occurs, more persons are killed. It also increases the incidence of non-fatal injury and material only crashes, but when an injury crash occurs, fewer people suffer an injury. This underlines the risk substitution effect.
- Increased speed limit slightly reduce risk exposure. Higher speeds have no effect on the number of fatal crashes but a positive impact on the frequency of non-fatal injury crashes.

7. CONCLUSION

In this text, an overview is given of the use of macro models in general and DRAG models in particular in the field of traffic safety. After a short description of different types of traffic safety models, the specific characteristics of macro models were discussed. Then attention was given to the development and the results of the DRAG-2 model and other members of the DRAG family. As already mentioned, the DRAG model philosophy belongs to the group of analytic macro models. The model allows the study of the demand for road use, the accidents and their severity. The DRAG framework provides a rigorous and advanced analytical framework to study the impact of several explaining variables on road safety. The effect of both controllable and uncontrollable variables is modelled, and allows the determination of effective road safety countermeasures.

The DRAG model, as any other predictive model, attempts to relate the independent variables of interest to accidents using a mathematical equation. The key issue of predictive modelling in econometrics is the combination of a subject-matter theory, mathematical statistics, and empirical data. The presence of a subject-matter theory is a big difference between econometrics (as an approach to empirical analysis) and mathematical statistics.

The use of econometric models in traffic safety goes with some difficulties and disadvantages. First, the use of aggregated data makes it impossible to fine-tune the results on an individual level. This structure makes it difficult to capture every kind of effect in the model. This analysis should therefore be performed in separate models or in an adapted version of a time series model, and strongly depends upon the availability of individual data. Second, it is difficult to cover the complete field of explanatory risk factors by means of the available data (Jaeger and Lassarre 2000). For several factors, there is no chronological series available. For others, the data may be only accessible on a yearly instead of a monthly basis. If exact data is not available (like for speed, seat belt use, alcohol consumption, …), good proxy variables should be developed and used. Third, the complexity is often quite high, because of the statistical properties that should be taken into account. Decisions about the functional form, the choice of variables and the probability distributions are not always straightforward, and typical time-series analysis problems like autoregression and autocorrelation should be given careful thought. However, specialised statistical techniques are available in state-of-the-art software packages, and should allow a correct treatment of the time-series.

On the other hand, the use of DRAG-like models in traffic safety offers several opportunities. First of all, they offer a valuable alternative in situations where the design of a perfect experimental setting is impossible. It would indeed be very difficult to control for the large number of factors that may affect traffic safety through experimental design. Moreover, accidents are unwanted events, which precludes the use of perfectly controlled experiments to gain insights into the causal relationships governing the accident generating process. Accident data therefore are, as a rule, eminently non-experimental. The many confounding effects commonly present in non-experimental situations can be avoided by including the relevant explanatory factors in the model, as is common practice in econometric modelling. Second, accidents appear to be random phenomena. Apart from allowing for the analyst's imperfect insight, a probabilistic approach is a highly realistic representation of the accident process itself. Third, econometric modelling techniques allow to highlight not only the effect of certain accident countermeasures, but also the contribution of factors which are not usually thought of as elements in the accident causation process. It further allows to evaluate the effects of road safety measures at a national level and to base the interpretation of traffic risk on mobility and economy factors (Jaeger and Lassarre, 2000). Fourth, road accidents can be seen as causally determined, random events, occurring as the outcome of multivariate probabilistic processes, containing systematic and stochastic variation (OCDE 1997).

Moreover, accidents and traffic safety typically have a time-related factor. Therefore, the use of econometric time series models is justified as a way to gain insight in the traffic safety process and to determine fruitful actions to influence it.

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