Time-series models for Urban Road Traffic and Accidents in Stockholm

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1. The DRAG Model Approach

The DRAG-philosophy aims at creating an enhanced understanding of two aspects of mobility: the demand for road usage, and the complex interactions affecting road accidents. The notion is based on a three step approach, *risk exposure, accident rate and its severity*. A data base has been created for the County of Stockholm with a broad spectrum of explanatory variables, such as socio-economic factors, laws and regulations, road and public transport data, vehicle fleet data, climate data and other related information aiming at explaining the development of road traffic and road accidents *ex post*. A special statistical programme package, called TRIO[1] has been used in the analysis.

The demand model is estimated on aggregate time series data for the whole area (in this case Stockholm County). The idea is to explain both traffic volumes (vehicle kilometres, vkms) and road accidents by a wide spectrum of explanatory variables by exploiting the vast variation in the monthly data set. This technique is called DRAG and stands for: *"Demand for Road use, Accidents and their Gravity"*, and is developed by professor Marc Gaudry at the Transport Research Centre at the University of Montreal in Canada.

In our application of the DRAG approach in the Stockholm region, the following time series models have been carried out on a monthly basis for the period 1970 - 1995:

- an EXPOSURE model of total road mileage (vehicle kilometres) for petrol passenger cars
- a FREQUENCY model of total number of road accidents with personal injuries and deaths
- a SEVERITY model of the:
    - number of light injuries per road accident
    - number of severe injuries per road accident
    - number of fatal deaths per road accident.

Analogous DRAG-models have been carried out in Canada, Germany and are being developed in France and Norway[2].

2. The demand for road use in Stockholm County 1970 -1995

2.1 The model

In TRIO a demand model function is specified as follows: :

$$\frac{y_t^{l_y} - 1}{l_y} = b_0 + b_k \sum \left(\frac{x_{kt}^{l_k} - 1}{l_k} \right) + u_t$$

where

y_t = the dependent variable for month t

b_0 = the constant term

b_k = the estimated regression coefficient

x_{kt} = the independent variable x_k:s value for month t

$l_k resp\, l_y$ = the so-called lambda-parameters for the independent variable x_k and for the dependent y-variable, i.e. a scale factor also estimated on the data set and which transforms the model or to a certain mathematical form. As a special case, when lambda is = 1, you get a linear model, and if lambda is = 0, you get a logarithmic model. This transformation is called ”Box-Cox” transformation.

and

$$u_t = v_t f(Z_t)^{½},$$

$$v_t = \sum_{t=1}^{r} r_l v_{t-l} + w_t,$$

where

Z_t = a vector of heteroskedastic variables

u_t = the error term (the residual vector) depending on the heteroskedasticity

v_t = the error term (the residual vector) which is assumed to be dependent in the auto-correlation of the model

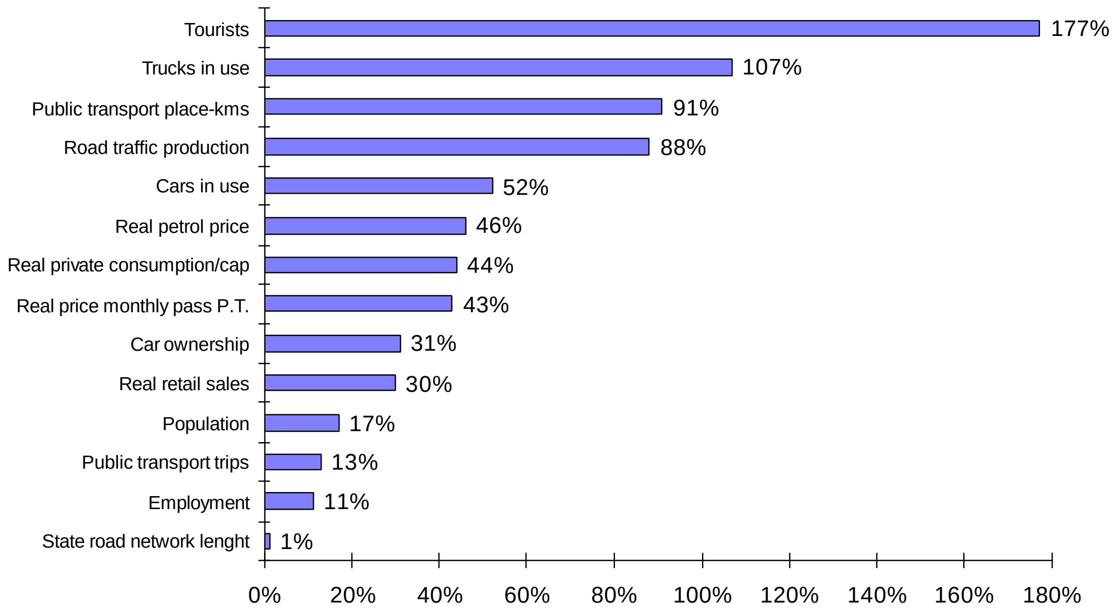
and finally

r_l = the so-called auto-regressive (time lag) parameters, which are also estimated and carries information about the time lag in the model.

ω_t = the third stage vector of residuals

2.2 Overall transport trends in Stockholm county 1970 - 1995

The rapid development of car traffic in the Stockholm County during the last 35 years can not be explained by any single factor. Rather, there is a wide range of factors, which contribute to this augmentation. Below, some key factors of importance to car traffic growth is presented in percent change between 1970 and 1995:



Public transport supply has almost doubled and increased even more than road traffic vehicle-kilometres. But public transport demand has only increased by 13 percent over the last 25 years. Real petrol prices has increased slightly more than public transport fares, 46 compared to 43 percent. The car park, measured as cars in use, is in 1995 more than 50 percent larger than in 1970.

The Stockholm county population is 16 percent larger after 25 years, i.e. some 250,000 more inhabitants; employment went up by 185,000 person from 1970 to 1990, but has declined by 115,000 persons between 1990 and 1994 due to the economic recession.

On the other side, the length of the state road network, has only expanded by one percent, i.e. it is of almost the same length as in 1970. Most new road links have replaced older ones.

In a non-linear Box-Cox regression model, some 20 explanatory factors of the model explain 96.5 percent of the total monthly variation in traffic production (vkms) during the last 25 years.

Economic activities

The "locomotive" among the explanatory variables is the *employment variable*. A 10 percent increase in the number of employed is estimated to enhance the number of vehicle-kms by 15 percent. Increased employment produces higher personal income, which in turn leads to higher car ownership and this governs much of the activities in the urban area, such as private consumption and leisure activities. A one percent population growth, without any increase in employment, on the other hand, reduces car traffic by 0,4 percent. To summarise, employed persons use the car, while others use public transport or the walk/bike mode.

The demand for transport is a derived demand. The demand for all those activities creates the demand for mobility, not income per se. That is why we have not inserted an household or personal income variable, but measured the demand via five activity variables.

As *real retail sales* increases by 10 percent, road traffic increases by 2,7 percent, according to the time-series model. This indicator measures the effect of shopping trips on total road traffic demand. The corresponding elasticity of 0,27 for Stockholm could be compared to a very similar result obtained in both Quebec and in Germany. In Quebec, Canada the corresponding elasticity has been calculated to 0,25 and in Germany to 0,24; thus, these findings are highly consistent to each other[3].

2.3 Comparison between estimated and actual road traffic demand

The overall correspondence between observed and estimated vehicle kilometres is quite good. For a single year the deviations between model and reality varies between 0 and 3 percent, with some very few exceptions:

- in 1973 the model underestimates the observed road mileage by 6,5 percent;
- in 1989 the model underestimates the observed road mileage by 5,2 percent

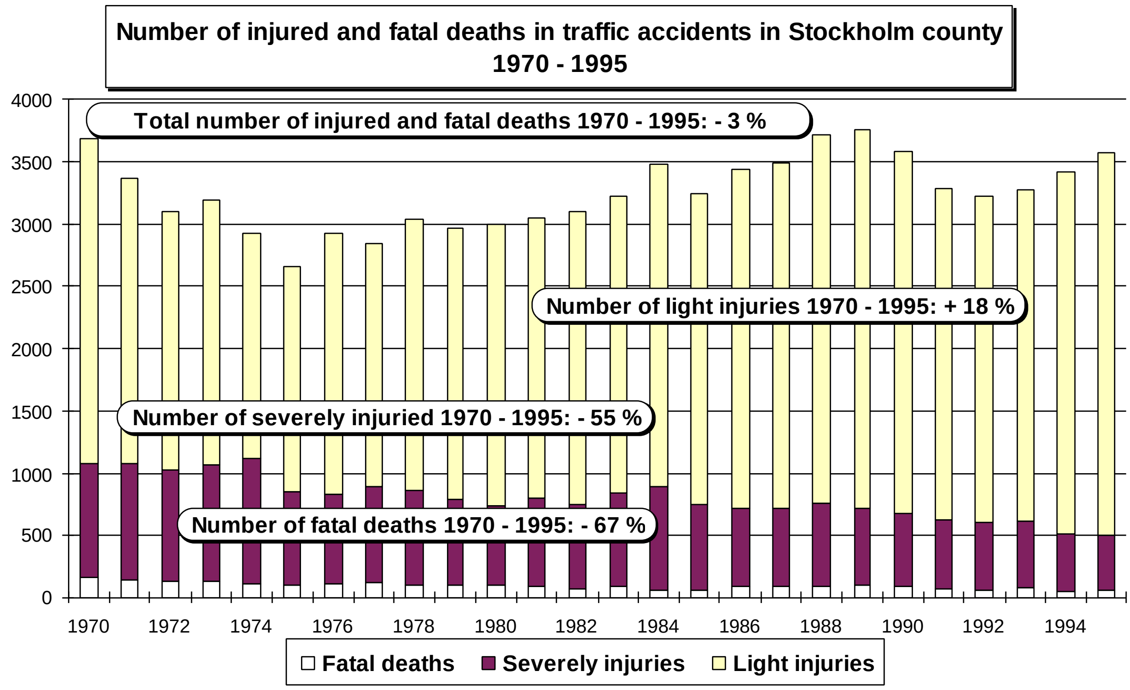
In both cases the time period could be characterised by an exceptional increase in road traffic over the past years.

3 Road Accident Exposures and Severity in Stockholm County 1970 - 1995

3.1 Accident trends in Stockholm county 1970 - 1995

The number of police-reported road traffic accidents has shown a variation around 2,000 to 2,800 accidents per annum, and the total amount has only declined by 1 percent during the last 25 year period. The number of fatal deaths and injured persons has been reduced by 3 percent in the same period. However, the severity of road traffic accidents has changed dramatically - the number of fatal deaths has gone down from some 150 persons to 50 persons, i.e. a reduction by 65 percent in 25 years.

The number of severely injured persons has changed from some 900 persons in 1970 to 450 persons in 1995. On the other side, the number of light injuries has *increased* from approximately 2,600 to 3,000 persons or by 18 percent. The overall accident pattern is shown below.



3.2 Model results - explanatory variables and elasticities

We have identified 30 various factors that contribute to explain the monthly variations in the number of road accidents with personal injuries or deaths.

Table 1: 30 factors explain the evolution of personal road accident injuries in the Stockholm County; Average elasticities for 1970-1995

Model	Road accidents with personal injuries and deaths	Light injuries per road accident	Severe injuries per road accident	Fatal deaths per road accident
Explanatory factors	**Elasticity** ***(t-value)***	**Elasticity** ***(t-value)***	**Elasticity** ***(t-value)***	**Elasticity** ***(t-value)***
Economic activities				
Vehicle kms per month	1,82	0,41	-2,03	-3,68
	(3,83)	*(1,52)*	*(-1,95)*	*(-1,31)*
Vehicle kms^2 per month	-0,70	-0,22	1,11	2,67
LAM 2	*(-1,73)*	*(-1,31)*	*(1,69)*	*(1,44)*
Employment.act./veh.km	+0,43	+0,094	-0,46	-1,29
LAM 1	*(2,05)*	*(1,08)*	*(-1,24)*	*(-1,37)*
Real retail sales/ veh.km	+0,18	-0,06	+0,09	+0,21
LAM 1	*(1,71)*	*(-0,10)*	*(0,81)*	*(0,66)*
Vacation activity/veh.km	-0,009	+0,03	-0,17	-0,47
LAM 1	*(-0,18)*	*(1,70)*	*(-1,44)*	*(-1,47)*
Vacation days ”per se”/	-0,01	+0,23	-0,90	-2,37
veh.km	*(0,03)*	*(1,83)*	*(-1,47)*	*(-1,51)*
No of tourists/veh.km	+0,18	-0,02	-0,09	-0,23
LAM 1	*(3,52)*	*(-0,49)*	*(-1,23)*	*(-1,33)*
Vehicle Fleet & Licencies				
Share of car remarks of	+0,36	+0,03	0,01	-0,01
all inspected *LAM 1*	*(2,52)*	*(0,28)*	*(0,05)*	*(-0,02)*
Registred brake errors/car	-0,29	-0,004	-0,32	-0,13
LAM 1	*(-1,83)*	*(0,03)*	*(-1,16)*	*(-0,15)*
Car occupancy/car	-2,31	-3,05	+4,68	-1,81
LAM 1	*(-1,18)*	*(-2,53)*	*(1,49)*	*(-0,22)*
Road network data				
New road links opened	+ 0,09	-0,002	-0,34	-0,35
(dummy variable)	*(0,62)*	*(-0,2)*	*(-1,40)*	*(-0,47)*
Share of motorway length	-0,03	+0,27	-0,50	+1,05
	(-0,16)	*(2,08)*	*(-1,95)*	*(1,41)*

Nota Bene: To achieve an elasticity for the *amount* of light injuries, severe injuries or fatal deaths, just sum the elasticity of the number of road accident (1st column with elasticities) with the elasticity for light, severe injury or fatal death, respectively (2nd, 3rd or 4th column, respectively); Example: Elasticity of *the number* of severe injuries with respect to new road links = 0,09 - 0,34 = -0,25.

Table 1 continued

Model	Road accidents with personal injuries and deaths	Light injuries per road accident	Severe injuries per road accident	Fatal deaths per road accident
Explanatory factors	**Elasticity** ***(t-value)***	**Elasticity** ***(t-value)***	**Elasticity** ***(t-value)***	**Elasticity** ***(t-value)***
Parking restrictions	- 0,05	0,001	+0,14	-0,16
(dummy variable) AM 1	*(1,38)*	*(0,05)*	*(2,07)*	*(-0,94)*
Park. restrictions ”per se”	-0,05	-0,05	+0,10	+0,38
(dummy variable)	*(-0,78)*	*(1,30)*	*(0,87)*	*(1,44)*
Share of no of days with	-0,035	+0,026	-0,08	+0,13
speed limit 110=>90 km/h	*(-1,30)*	*(1,31)*	*(-2,06)*	*(1,23)*
Weather data				
Average temperature/	+ 0,15	-0,02	+0,06	+0,07
month	*(5,82)*	*(-1,49)*	*(1,81)*	*(0,72)*
Rain & snowfall/month	+0,04	+0,01	-0,01	-0,02
	(3,09)	*(1,41)*	*(-0,50)*	*(-0,34)*
No of days with snow/	+0,01	+0,01	-0,02	-0,01
month	*(1,04)*	*(1,25)*	*(-1,21)*	*(-0,25)*
No of daylight hours/	- 0,32	-0,03	+0,08	-0,57
day & night per month	*(-4,61)*	*(-0,67)*	*(0,96)*	*(-2,49)*
Share of sunlight per	+0,08	+0,01	-0,04	+0,10
daytime	*(2,95)*	*(0,58)*	*(-0,89)*	*(0,92)*
Dummy for month with 1st	-0,01	+0,02	-0,03	+0,05
autumn snowfall	*(-0,41)*	*(0,90)*	*(-0,74)*	*(0,48)*
Cold winter: >40 mm	-0,02	-0,02	+0,05	-0,04
snow and temp >0 Celsius	*(-0,76)*	*(-0,83)*	*(0,97)*	*(-0,30)*
Intervention measures				
Estimat. use of safety belt	-0,50	-0,39	+1,01	-0,74
LAM 1	*(-3,32)*	*(-4,29)*	*(3,85)*	*(-1,00)*
Estimat. use of headlights	+0,11	-0,004	+0,001	-0,325
during daytime	*(2,18)*	*(-0,13)*	*(0,01)*	*(-1,69)*
Estimat. use of MC-helmet	-0,07	+0,06	-0,26	-0,05
	(-1,57)	*(1,80)*	*(-3,77)*	*(-0,21)*
Legal limit of intoxication	+0,11	+0,007	-0,05	-0,08
LAM 1	*(1,95)*	*(0,19)*	*(-0,57)*	*(-0,30)*

Table 1 continued

Model	Road accidents with personal injuries and deaths	Light injuries per road accident	Severe injuries per road accident	Fatal deaths per road accident
Explanatory factors	**Elasticity** ***(t-value)***	**Elasticity** ***(t-value)***	**Elasticity** ***(t-value)***	**Elasticity** ***(t-value)***
Calender data				
No of workdays/month	-0,18	+0,26	0,00	-0,73
	(-0,60)	*(1,92)*	*(0,00)*	*(-0,85)*
No of other days/month	-0,063	+0,10	-0,03	-0,30
	(-0,46)	*(1,78)*	*(-0,22)*	*(-0,82)*
Special events				
Kuwait war Jan-Feb 1991	+0,12	-0,02	+0,01	+0,53
(dummy variable	*(1,03)*	*(-0,54)*	*(0,06)*	*(1,55)*
Lambda 1- value for variables marked with"*LAM 1*" t-test 0;1	0,235 *(1,32/-4,30)*	0,131 *(0,47/-3,15)*	0,526 *(4,02/-3,62)*	0,569 *(6,42/-4,86)*
Lambda 2- value for variable marked with "*LAM 2*"	2,000 Set to 2	2,000 Set to 2	2,000 Set to 2	2,000 Set to 2
Explanatory power - R^2	**0,726**	**0,5732**	**0,706**	**0,422**
Log-Likelihood	**-1282,30**	**389,45**	**507,65**	**824,98**
Autoregressive term:	-0,22	+0,02	-0,08	-0,06
Rho: t-3	*(-4,12)*	*(0,25)*	*(-1,25)*	*(-0,92)*
Autoregressive term:	-0,17	+0,13	-0,05	-0,07
Rho: t-9	*(-2,76)*	*(2,29)*	*(-0,74)*	*(-1,06)*
Autoregressive term:	+0,27	-0,01	-0,03	-0,12
Rho: t-12	*(4,61)*	*(-0,18)*	*(-0,49)*	*(-1,71)*
No of observations	*288*	*288*	*288*	*288*

Economic activities

The number of personal accidents seems *not* to be proportional to the exposure in terms of vehicle kms driven. An elasticity on the number of road accidents with personal injuries of 1,8 due to the number of vehicle kms is found. However, in congested situations (late 1980's, summer months) the number of accidents tend to be reduced, probably due to lower speeds.

On the other hand, the *severity* of road accidents, seem to follow an opposite pattern - at low or modest amount of road traffic, increases of the number of vehicle kms driven, tend to lead to a reduction in the number of light and severe injuries as well as of fatal deaths, while, at least for the severe injuries and fatal deaths, they seem to increase as congestion becomes more frequent.

Employment and shopping activities increases the number of road accidents with personal injuries, while the severity of these accidents becomes less frequent when employment activities increases. Vacation activities and tourism seem to reduce both the exposure and the severity of road accidents, probably due the less time constraints and stress among drivers and pedestrians.

Vehicle fleet

Bad cars, i.e. car with a higher proportion of remarks from the annual inspections, increases the number of accidents, while the frequency of brake errors seem to lead to a more cautious driver behaviour, and thus, to a reduction in accidents and their severity. With more people in each car, the number of accidents and their severity increases substantially. Over time, however, car occupancy has fallen, which has contributed to a reduction in the number of accidents.

Road network data

New road links slightly increases the number of accidents (probably due to higher speeds), but reduces severe injuries and fatal deaths substantially. New and better roads are thus safer than other roads. Speed limits on the primary road network with a reduction from 110 to 90 km/h reduces the number of accidents and also severe injuries.

Weather data

Weather conditions do have a certain impact on the accident pattern. The number of accidents seem to *increase* as average temperature is higher than normal (more people exposed), as rain and snow limits the sigh for the drivers and also as sunlight is reducing the concentration from driving. A *decrease* in the number of accidents could be noticed as the first snow makes drivers more cautious, and as more daylight hours facilitates for the drivers to see unprotected pedestrians and cyclists. Also special cold winters reduces the number of accidents, as it slows down the vehicle speeds.

Intervention measures

An increased use of safety belts has a significant positive impact on road safety. Also the legal use of headlights during daytime, has shown to be a positive intervention measure to reduce accidents and their gravity. The same impact is found from the increased use of motor-cycle helmets.

3.3 Explanatory factors' contribution to the number of accidents

In the table below the most important factors are summarised:

Table 2. Factors with an important impact on the number of personal accidents

Factors with an important impact on the number of personal accidents	Average elasticity 1970 - 1995 with respect to the total number of accidents[4]	Average elasticity 1970 - 1995 with respect to the number of fatal death
Road traffic vehicle-kilometres	+1,8	-1,8
Use of safety belts	-0,5	-1,2
Number of employed per vehicle-km	+0,4	-0,9
Number of remarks per inspected car	+0,4	+0,4
Share of daylight hours per day	-0,3	-0,9
Medical consumption (no of recipes/person)	+0,3	+0,8
New road links	+0,1	-0,25

The elasticities indicate how much a certain accident type changes at a 1 percent change in the explanatory variable.

Our results indicate that the number of road accidents in an urbanised area like the Stockholm region increases much more than proportional to the amount of road traffic (elasticity: +1,8). Maybe it is explained by a rapid growth in the number of potential conflicts as the number of total vehicle-kilometres increases. The number of fatal deaths seems to be reduced, probably due to reduced speeds.

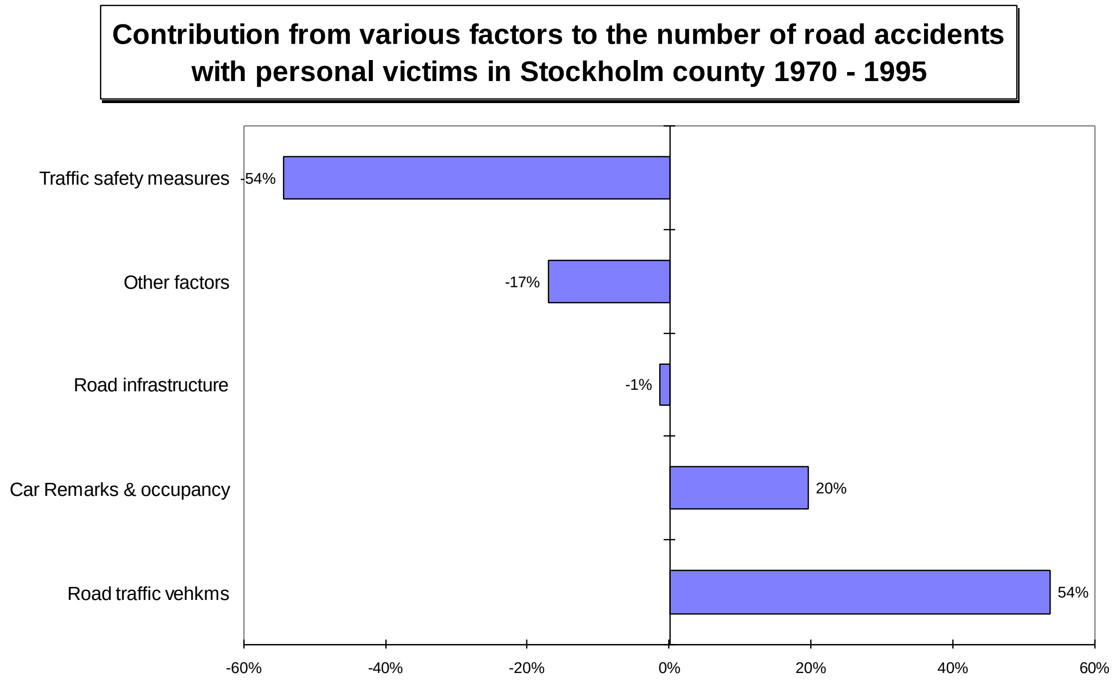
The quality of the vehicle fleet - measured here in terms of the number of remarks per inspected car - also indicate an important factor that influences both number of accidents and the severity of the accidents.

Medical consumption - measures as the number of sold recipes per person and month - seems to have a major impact on road traffic accidents, according to our findings. If supported by micro-studies, this result indicate an important factor to be dealt with in order to reduce road accidents and their severity.

An interesting result is also the impact of new road links in Stockholm county during the last 25 years. Both the number of severely injured as well as the number of fatal deaths has been reduced by 25 percent as an estimated effect of some 35 new road links during the 25 year period.

An impressive amount of various traffic safety measures have been implemented during the last 25 years in Sweden (and elsewhere). One such example is the use of traffic safety belts. A 10 percent increase in the use of safety belts is estimated to lead to a reduction in the number of road accidents with personal victims by 5 percent and a reduction in the number of fatal deaths by 12 percent, according to the time-series model for Stockholm.

A summary of the contribution from various explanatory factors to the number of road accidents with personal victims in Stockholm county 1970 - 1995 is presented below:



To sum up, one could argue that all the traffic safety measures that have been implemented during the last quarter of the century have been necessary to balance the increase in the number of accidents caused by an increase in road traffic volumes at the same time period. This is also clearly illustrated above, where the magnitude of two factors exactly even out (-54 %, +54 %). The better vehicle fleet quality has contributed to a decrease in the accident rate.

The road infrastructure is shown to have a slight positive impact, in terms of a minor accident reduction; however, the most positive impact is a substantial decrease in the number of severely injured and in the number of fatal deaths due to new and better road links in the urban area.

Notes

1 TRIO is a statistical programme package for multiple regression model estimation of dependent variables of the types: level, share and probability. TRIO has been developed by Prof. Marc Gaudry at the Centre de Recherche sur les Transports (C.R.T.) at University of Montreal in Canada.

2 Source 1: "Application of Econometric Model DRAG-2 to Road Travel Demand in Quebec" Proceedings of the Canadian Multidisciplinary Road Safety Conference VIII, June 14-16, 1993, Saskatoon, Saskatchewan. By M. Gaudry, C.R.T., Univ. of Montréal, Quebec, F.Fournier and R. Simard, Société de l' assurance automobile du Quebec; Source 2: "Aggregate Time-Series Gasoline Demand Models: Review of the Litterature and New Evidence for West Germany", by Ulrich C. H. Blum, Gertraud Foos and Marc Gaudry, Transportation Research A. Vol. 22A, No 2, pp 75-88, 1988.

3 Source: "Application of Econometric Model DRAG-2 to Road Travel Demand in Québec", M. Gaudry, F. Fornunier and R. Simard, Proceedings of the Canadian Multidisciplinary Road Safety Conference, June 14-16, 1993, Saskatoon, Saskatcehwan.

4 NB: Material damages not included

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