VTI RAPPORT

Nr 208A · 1981
ISSN 0347-6030

Statens väg- och trafikinstitut (VTI) · 581 01 Linköping
National Road & Traffic Research Institute · S-581 01 Linköping · Sweden

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INNEHÅLLSFÖRTECKNING

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ABSTRACT

The report is an attempt to describe the effects on accidents of compulsory use of running lights – low beam or special lamps – during daylight in Sweden.

The study is carried out on police reported traffic accidents with personal injury in Sweden. The before and after periods are two years before and two years after the operative day of the law, October 1st 1977.

The use of running lights in the before-period was roughly speaking 50 % and in the after-period over 95 %.

The basic assumption is that the use of running lights in daylight influences multiple accidents in daylight and only those. The method used is to study the relation of daylight to darkness numbers of multiple accidents. The corresponding relation for single vehicle accidents is taken as control.

The estimated total effect depends both on the subdivision of accident data and the method used for accidents with unprotected road users. The estimates vary from 6 to 13 % reduction – from the before-period to the after period – of multiple accidents during daylight or 450 to 1100 less police reported accidents with personal injury per year. The estimated effects are not significant on a 5 % level.

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SUMMARY

The report is an attempt to describe the effects on accidents of compulsory use of running lights – low beam or special lamps – during daylight in Sweden.

The study is carried out on traffic accidents with personal injury in Sweden. The before and after periods are two years before and two years after the operative day of the law, October 1st 1977.

The use of running lights in the before-period was roughly speaking 50 % and in the after-period over 95 %.

The basic assumption is that the use of running lights in daylight influences multiple accidents in daylight and only those. The method used is to study the relation of daylight to darkness numbers of multiple accidents. The corresponding relation for single vehicle accidents is taken as control.

Multiple accidents during daylight are estimated to decrease by 11 % or 900 accidents per year from before to after. This change is not significant on the 5 % level.

A subdivision into accident types, where the first three groups are accidents between motor vehicles, gives the following results

10 % reduction for accidents where the vehicles have opposing directions
9 % reduction for accidents where the vehicles have crossing directions
2 % reduction for coincident directions accidents
21 % reduction for accidents between motor vehicles and cycles or mopeds
17 % reduction for accidents between motor vehicles and pedestrians

The greatest reductions are found for accidents between motor vehicles and unprotected road users. Alternative methods for the latter accident types, without use of single accidents distribution on daylight and darkness as control, gives a 5 to 13 % reduction for cycle and moped accidents and 1 to 5 % reduction for pedestrian accidents. These effects are not significant on the 5 % level.

The estimated total effect depends on how accident data are subdivided and what method is used for accidents with unprotected road users. The estimates vary from 6 to 13 % reduction – from the before-period to the after period – of multiple accidents during daylight or 450 to 1100 less police reported accidents with personal injury per year. The estimated effects are not significant on a 5 % level.

A subdivision according to weather gives no obvious dependence. This might be a result from the fact that in the before-period, the use of running lights was highest when the external light was poorest i.e. when the effect of running lights was expected to be highest.

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1. BACKGROUND

Effective October 1st, 1977 all cars and motorcycles are to be driven with their lights on, low beams or special lights, during daylight.

Before the law came into effect, the Swedish Road Safety Office and National Swedish Road and Traffic Research Institute was given the task of investigating what effect the law had on the use of vehicle lights during daylight and on traffic accidents. In a previous joint Nordic project an investigation was made in Finland regarding the effect of recommended and compulsory use of vehicle lights during daylight in winter outside built-up areas.[1)]

Unlike the Finnish law, which was in effect only during the winter and outside built-up areas, the Swedish law has no time or area limits.

In relation to single accidents and multiple accidents in darkness, the number of multiple accidents in daylight outside built-up areas in Finland decreased by 20 % during the winter from periods without the law or the recommendation up to periods when the law came into effect. However, through the Finnish study it was not possible to estimate the effectiveness of a law which would include built-up areas and would be in effect during summer periods.

The climate and light conditions in Sweden and Finland are very similar. Before the recommendation or the law came into effect in Finland, the use of vehicle lights during the winter periods was the same or somewhat lower than it was in Sweden before the Swedish law came into effect. The

1) The effect of recommended and compulsory use of running lights on traffic accidents in Finland. Report no 102. 1977. National Swedish Road and Traffic Research Institute. Linköping. Sweden.

Finnish experiences also showed that the law was followed by most drivers, i.e. the use of lights was over 95 %.

The Finnish study stated that the largest effects were related to head-on collisions and accidents between vehicles and pedestrians.

When the Swedish study was planned the experiences of the Finnish study were of great significance and the methodology used for the present analysis is very similar.

2. THE USE OF VEHICLE LIGHTS IN DAYLIGHT BEFORE AND AFTER THE LAW

The use of vehicle lights in daylight – running lights (RL) – has increased remarkably since the end of the 1960's up to October 1st, 1977, when the law came into effect. When the first measurements were made in the spring of 1967, 1 to 2 percent of the cars used some kind of light in daylight.

Since then, the frequency of use of lights in daylight has been recorded on different occasions simultaneously at up to 18 places in Sweden during two-hour periods.The most extensive measurements have been done by the Swedish Road Safety Office and these comprise 12 measurement periods (Thursdays-Sundays) from June 1974 to May 1978. The National Swedish Road and Traffic Research Institute has also recorded the use of running lights during daylight both in the winter of 1975/76 and in 1977 before the law came into effect and on two occasions in 1978. This was done in the counties of Östergötland and Södermanland and on national roads only.

The observations made by the Swedish Road Safety Office are compiled in Figure 1. This figure also contains information collected by the National Swedish Road and Traffic Research Institute. The figure is to a certain extent adjusted to the accident analysis, and the purpose is to give a rough picture of the changes which occurred when the law was introduced. The striped areas show the variation in the use of running lights between different environments during summer and winter.

The biggest changes occurred during the summer and especially during clear and cloudy weather. Before the law came into effect, 50-60 % of the vehicles had their lights on during clear weather in the winter periods. In the summer , 25-30 % of the vehicles had their lights on during clear weather.

The classification of the different types of weather, i.e. clear, cloudy and precipitation, is in itself, less than reliable. In the measurements made by the National Swedish Road and Traffic Research Institute, the intensity of the ambient light was measured every 15th minute. The relative frequency of use of running lights as a function of the ambient light

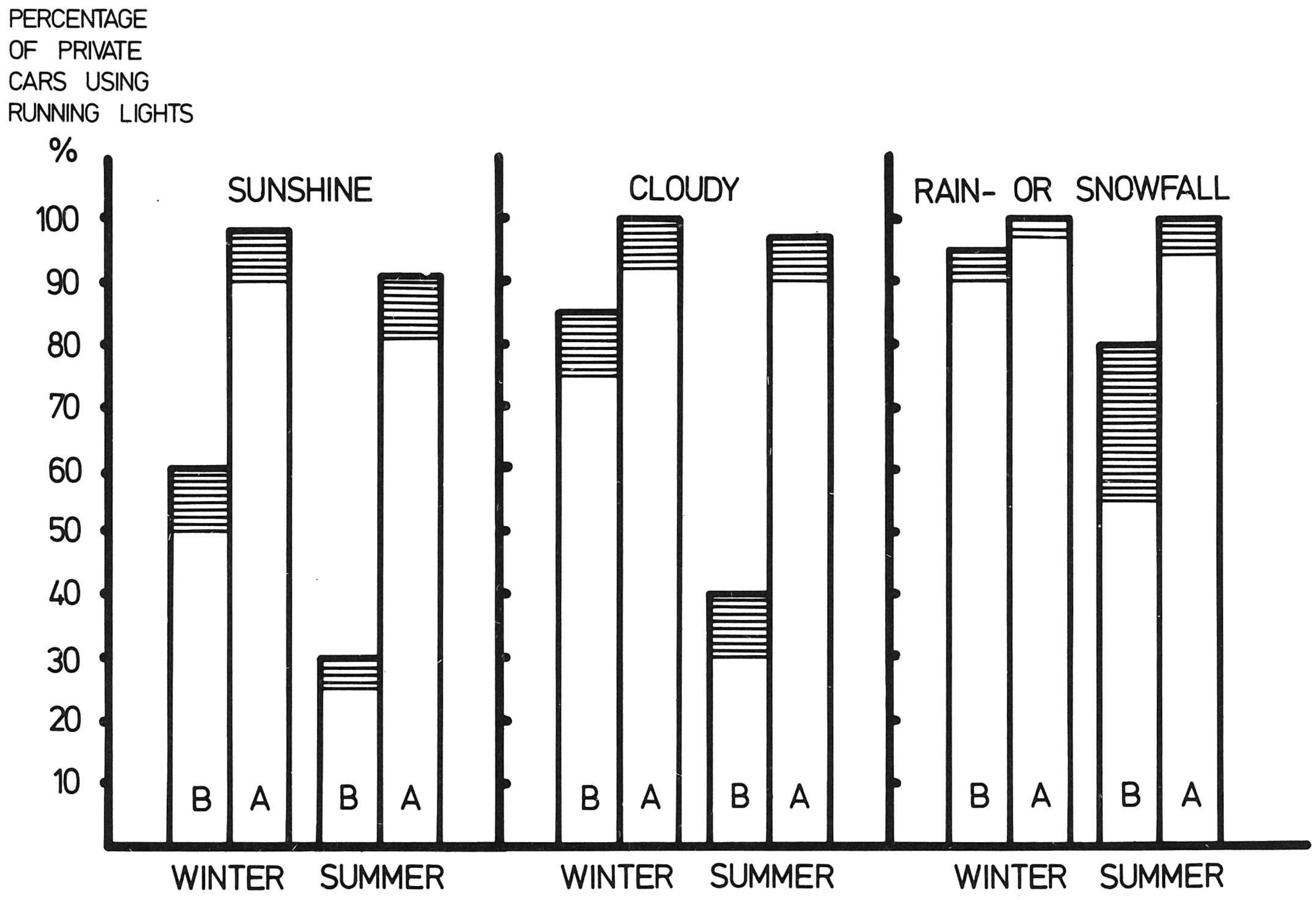


Figure 1. The use of before (B) and after (A) in different weather conditions.

sity of the ambient light was measured every 15th minute. The relative frequency of use of running lights as a function of the ambient light during different types of weather is outlined in Figure 2. The observations were made in the winter of 1975/76 and during different types of weather outside built-up areas in the counties of Östergötland and Södermanland (in 10 different locations).

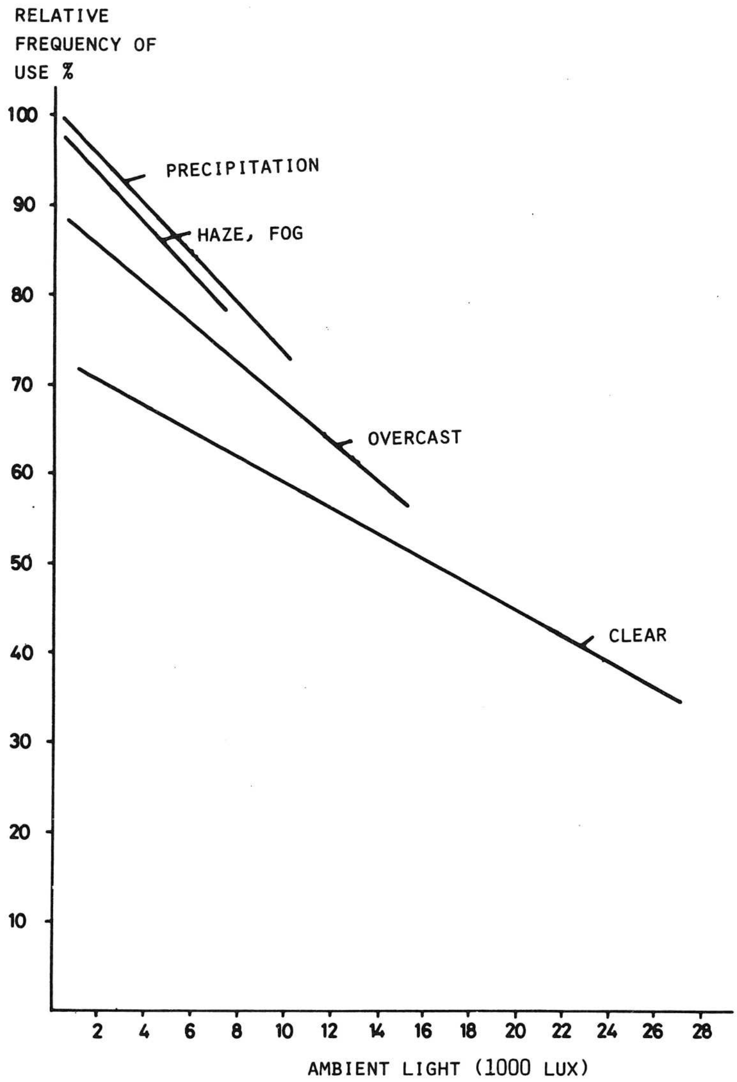


Figure 2. Relative frequency of use of running lights as a function of ambient light during daylight for different types of weather conditions in 1975/76.

In some of these locations passenger cars and trucks were dealt with separately.

In Figure 3, the use of running lights by passenger cars and trucks is shown as it was before and after the law in relation to the intensity of the ambient light.

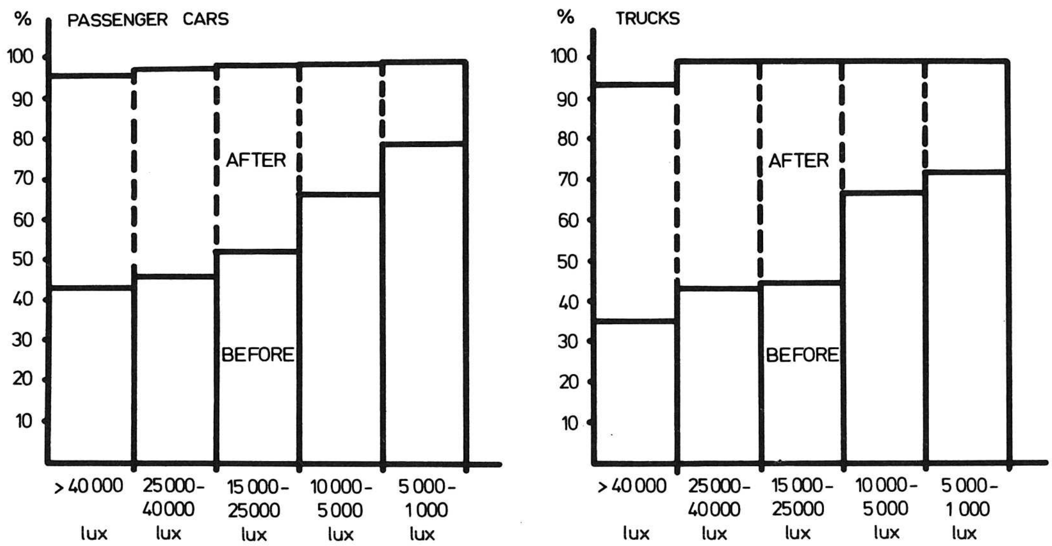


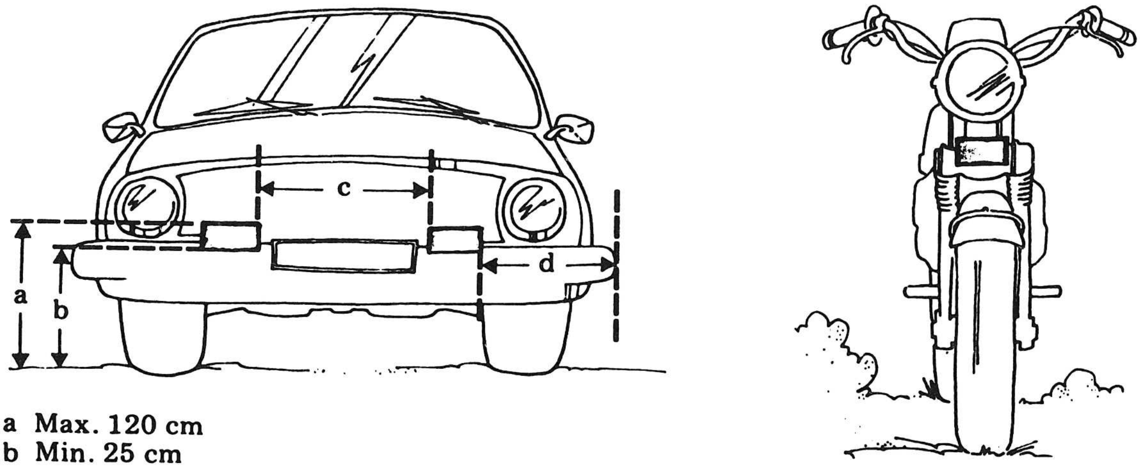
Figure 3. The use of running lights on E4 (European highway No. 4) in relation to ambient lighting in D-county before and after the law came into effect.

Unfortunately, the number of comparative measurements between years is rather limited (i.e. the same place, the same season and the same weather conditions) and it is therefore difficult to find a clear explanation for the variations in the use of running lights during daylight. However, the following can be verified:

- The use increases with increased cloudiness
- The use is greatest during precipitation
- The use is greater outside built-up areas
- The use is greater in the afternoon than before noon
- The use increases when the length of daylight period decrease
- As soon as the law was in effect, October 1st, 1977, the use was close to "total"
- An increase in the use before the law, i.e. the summer of 1977, was not noticed. It was first during the days close to the law that a noticeable increase occurred

In connection with the Swedish Road Safety Office's measurements, the use of special running lamps was also recorded.

These special running lamps are of two kinds, additional equipment as in Figure 4 or standard equipment as in Figure 5 (shows the installation on passenger cars Volvo and Saab).



a Max. 120 cm
b Min. 25 cm
c Min. 60 cm
d Max. 40 cm

Figure 4: Rules for installation of special running lamps additional equipment on cars and motorcycles.

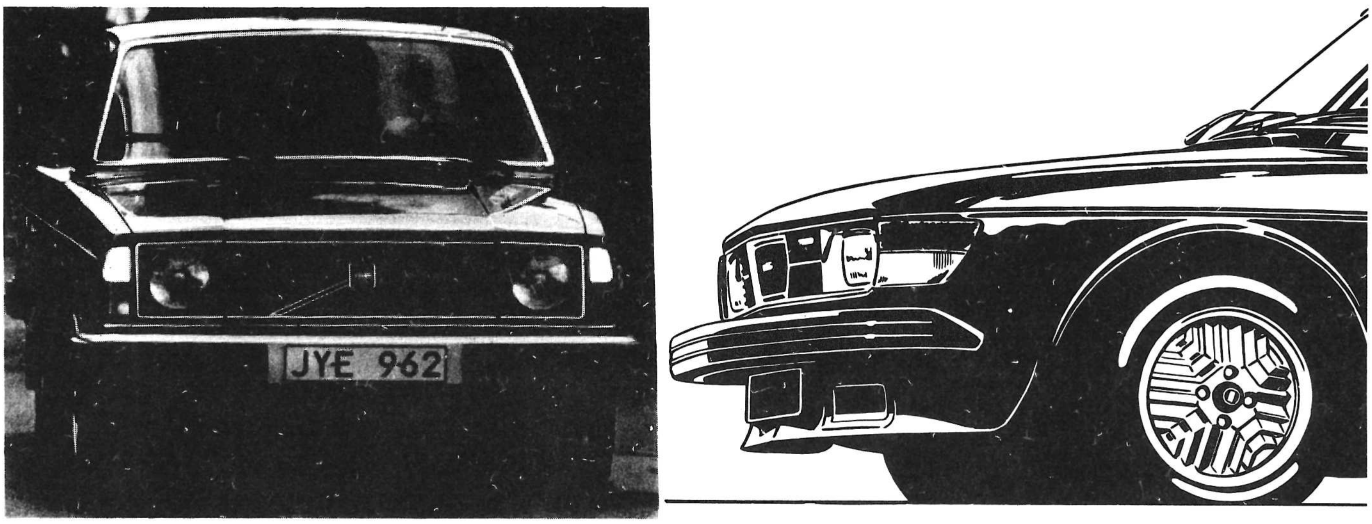


Figure 5: Passenger cars of Volvo and Saab standard equipped with special running lamps.

Point in Time	Percentage of the number of cars with special running lamps
June 1974	0,4
September 1975	3,9
Week 16, 1977	6,7
Week 22, 1977	7,6
Week 29, 1977	9,5
Week 34, 1977	7,6
Week 37, 1977	9,5
Week 39, 1977	13,3
Week 42, 1977	15,6

Volvo's and Saab's passenger cars, which are "standard equipped" are not included in the above tableau. During the first year of the law, these standard equipped passenger cars accounted for approximately 10 % of the registered passenger cars, which means that close to 30 % of all passenger cars had some kind of special running lamps during the first year of the law.

As mentioned earlier, it is very difficult to make a comparison between the use of running lights before and after the law came into effect. A simple analysis of the Swedish Road Safety Office's measurements is shown in Table 1. The results include all observations within the same two-hour period made in the same places and during the same type of weather. The range of variation between different places and two hour periods is shown within brackets.

Table 1 refers predominantly to summer conditions. The range of variation reflects both the observed environment and the increase in use which occurred during the days before the law came into effect. The tables, however, reflect the conditions during the summer periods before the law, whereas the after-the-law results mainly come from measurements during the winter periods.

However, Table 1 clearly underlines the effect of the law itself, and also reflects the influence that information and weather conditions had before the law came into effect.

In Table 2 and Table 3, an attempt has been made to divide the National Road Safety Office's observation locations into "outside built-up areas" and "inside built-up areas". As is indicated by the tables, the difference between the two settings during various weather conditions is small.

Table 1. Percentage passenger cars with vehicle lights in use during daylight and different weather conditions before and after the law during different weather conditions.

	No Precipitation		Intermittent Rain		Rain	
	Before	After	Before	After	Before	After
Clear	33 (13-85)	93 (68-100)	-	-	-	-
Partially Cloudy	39 (22-74)	94 (88-98)	48 (23-83)	89 (85-95)	-	-
Overcast	48 (25-88)	97 (83-100)	51 (34-91)	96 (91-100)	64 (35-96)	94 (87-100)
Haze/Fog	53 (35-71)	96 (86-100)	76 (60-89)	96 (95-98)	74 (48-96)	97 (97)

Table 2. Percentage passenger cars with vehicle lights in use during daylight before and after the law during different weather conditions and outside densely populated areas.

	No Precipitation		Intermittent Rain		Rain	
	Before	After	Before	After	Before	After
Clear	34 (16-85)	94 (70-100)	-	-	-	-
Partially Cloudy	37 (22-69)	97 (96-98)	51 (34-83)	-	-	-
Overcast	51 (25-84)	97 (96-99)	54 (47-61)	94 (94)	69 (38-96)	96 (87-100)
Haze/Fog	-	98 (96-99)	60 (60)	97 (96-98)	70 (98-83)	-

Table 3. Percentage passenger cars with vehicle lights in use during daylight, before and after the law, during different weather conditions within densely populated areas.

	No Precipitation		Intermittent Rain		Rain	
	Before	After	Before	After	Before	After
Clear	32 (13-74)	92 (68-150)	-	-	-	-
Partially Cloudy	41 (23-74)	91 (88-93)	46 (23-80)	89 (85-95)	-	-
Overcast	47 (27-88)	97 (83-100)	51 (34-91)	97 (91-100)	61 (35-86)	92 (88-96)
Haze/Fog	53 (35-71)	96 (88-93)	84 (79-89)	96 (95-98)	79 (66-98)	97 (97)

3. DATA ON ACCIDENTS

The data on accidents are based on police-reported personal injury accidents during the period from October 1975 to September 1979. This means that the periods before and after the law are both two years.

The data on accidents have been divided into accidents outside built-up areas and accidents inside built-up areas and according to month and day.

The accidents were classified according to the region in which they occurred: southern, central or northern Sweden.

The accident type categories are as follows:

Group 1
- single motor vehicle accidents
- multiple vehicle accidents, opposing directions (i.e. head-on collisions)
- multiple vehicle accidents, crossing directions
- multiple vehicle accidents, coinciding directions
- motor vehicle/pedestrian
- motor vehicle/bicycle, moped

Group 2
- other single vehicle accidents
- other multiple vehicle accidents
- motor vehicle/animal

Only accidents from Group 1 are analysed. The accidents have also been divided according to whether they occurred in daylight or in darkness. Accidents in twilight or when the light conditions are unknown, are not included in the analysis which is based on monthly results.

When the analysis was based on a 24-hour period, accidents in twilight and unknown light conditions were included in darkness accidents. In this case the accidents were recorded according to whether the period was sunny, normal or cloudy. The following geographical places were chosen from the Swedish Meteorological and Hydrological Institute's (SMHI) monthly reports: Sundsvall, Karlstad, Bromma, Norrköping, Jönköping, Landvetter, Svalöv.

If the number of sunny hours during a 24-hour period for the above seven places averaged out to be more than 57 % of the daylight hours, the period was classified as "sunny". If the average was less than 29 %, it was classified as "cloudy". The intervening periods were termed "normal". The reason for this classification is to be able to examine the effect of running lights during different existing ambient light conditions. Furthermore, this classification increases the possibilities of a comparison between different years, as the use of running lights before the law was influenced by the existing light conditions.

Table 4 shows the number of accidents during the four investigated one-year periods.

Table 4 Number of police-reported personal injury accidents inside built-up areas and outside built-up areas during the different time periods before and after the law.

	Number of personal injury accidents			
	BEFORE		AFTER	
	Oct 75-Sept 76	Oct 76-Sept 77	Oct 77-Sept 78	Oct 78-Sept 79
Inside built-up areas	7 320	6 849	6 942	6 320
Outside built-up areas	9 860	9 521	9 380	9 044
Total	17 180	16 370	16 272	15 364

The reason behind the compulsory use of vehicle lights in daylight was that vehicles will be noticed earlier when their lights are on.

This implies that of all accidents, the multiple accidents during daylight are the ones which will be influenced by the law.

All in all, this type of accident constitutes more than 50 % of all police-reported personal injury accidents. Table 5 shows the percentage distribution of accidents according to inside built-up areas versus outside built-up areas, single versus multiple accidents, and daylight versus darkness during the four-year period (October 1975-September 1979).

The circled numbers indicate those groups which can be affected by the use of the law. As shown in the table, 2/3 of these accidents occur inside built-up areas and 1/3 outside built-up areas.

Table 5 The percentage distribution of the police-reported personal injury accidents in relation to environment, light conditions and single (S) versus multiple (M) accidents during the period of October 1975–September 1979.

Environment	Light conditions	Oct. 75 - Sept. 79	
		S	M
Inside built-up area	Daylight	3,7	37,2
	Darkness	4,0	14,6
Outside built-up area	Daylight	9,4	18,6
	Darkness	7,2	5,8
	Total	100%	

If the effect of the use of vehicle lights during daylight is different for different types of multiple accidents, the rates of different types of multiple accidents will vary between inside built-up areas and outside build-up areas. Therefore, the rate of multiple accidents inside built-up areas versus outside built-up areas might be affected differently by the use of vehicle lights during daylights. In Table 6, the percentage distribution is shown for the five different types of multiple accidents, i.e. multiple accidents - opposite directions, multiple accidents – crossing directions, multiple accidents - coinciding direction, motor vehicles - bicycles or mopeds, motor vehicles – pedestrians.

Table 6 Multiple accidents during daylight according to type of accident and environment. Percentage distribution (1975/79).

Accident types	Inside built-up area	Outside built-up area	Total
Multiple accidents-Opposite directions	7.0	11.9	18.9
Multiple accidents-crossing directions	17.3	5.2	22.5
Multiple accidents-coinciding directions	7.8	8.5	15.2
Motor vehicle/ Bicycle or Moped	23.1	5.6	28.7
Motor vehicle/ Pedestrian	12.0	1.7	13.7
Total	67.2	32.8	100.0

More than 1/2 of the multiple accidents inside built-up areas occur between motor vehicles and the combined group of pedestrians, bicyclists and mopedists.

4. CHANGES IN THE RATE OF ACCIDENTS DURING THE YEARS STUDIED

The data in this section are compiled from official accident statistics. They show the changes in the rate of single and multiple accidents with personal injuries during daylight and darkness on a monthly basis.

SINGLE VEHICLE ACCIDENTS

Period	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total
1975/76	348	394	442	297	261	322	283	345	370	375	332	279	4048
1976/77	320	443	266	151	130	198	323	279	366	373	349	248	3446
1977/78	300	430	326	362	199	245	261	280	337	349	323	296	3708
1978/79	382	422	282	115	102	230	257	294	366	319	310	233	3307

MULTIPLE VEHICLE ACCIDENTS

Period	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1975/76	1019	972	1001	868	674	717	702	981	1031	948	1170	1002	11085
1976/77	981	1058	995	739	789	732	657	890	1045	911	1051	1008	10856
1977/78	889	1059	883	797	676	638	615	899	995	943	1049	946	10389
1978/79	852	937	783	719	742	543	608	908	970	874	1028	888	9809

Since the analysis is simultaneously based on the number of single and multiple accidents during daylight and darkness, these figures are also shown.

SINGLE VEHICLE ACCIDENTS, DAYLIGHT

Period	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1975/76	150	138	164	125	109	180	158	248	295	290	210	146	2213
1976/77	138	176	90	61	63	110	198	200	292	291	214	143	1976
1977/78	131	198	131	160	119	134	158	210	276	276	217	155	2165
1978/79	198	180	119	57	60	100	151	203	300	238	204	137	1947

SINGLE VEHICLE ACCIDENTS, DARKNESS

Period	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1975/76	198	256	278	172	152	142	125	97	75	85	122	133	1825
1976/77	182	267	176	90	67	88	125	79	74	82	135	105	1470
1977/78	131	198	198	202	80	111	103	70	61	73	106	141	1543
1978/79	184	242	163	58	42	130	106	91	66	76	106	96	1360

MULTIPLE VEHICLE ACCIDENTS, DAYLIGHT

Period	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total
1975/76	633	423	406	484	424	574	609	898	970	881	1001	801	8104
1976/77	593	457	420	384	528	566	558	807	985	823	924	816	7861
1977/78	551	490	358	369	489	484	530	818	924	862	918	745	7538
1978/79	539	433	364	401	535	404	507	812	908	721	889	686	7249

MULTIPLE VEHICLE ACCIDENTS, DARKNESS

Period	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total
1975/76	386	549	595	384	250	143	93	83	61	67	169	201	2981
1976/77	388	601	575	355	261	166	99	83	60	88	127	192	2995
1977/78	338	569	525	428	187	154	85	81	71	81	131	201	2851
1978/79	263	504	419	318	207	139	101	96	62	103	139	202	2553

5. ACCIDENT ANALYSIS

5.1 Some general remarks

The basic assumption behind the analysis is that the use of running lights (RL) only affects the number of multiple[1)] accidents in daylight conditions. Thus the number of single-car accidents as well as the number of accidents in darkness are supposed to be unaffected by the change in use of RL.

Obviously, several other factors affect the number of accidents, both single and multiple and in daylight as well as darkness. Those factors, their changes and effects are essentially unknown.

However, the effect of unknown factors can be controlled to some extent. Consider the following four groups of accidents:

SD = number of single accidents in daylight (D=day)
MD = number of multiple accidents in daylight
SN = number of single accidents in darkness (N=night)
MN = number of multiple accidents in darkness

If we study the quotient

(MD/SD)/(MN/SN)

the general effects of other factors are eliminated. By general effect we mean

- changes that are equal for single and multiple accidents in daylight
- changes in the relation between the number of single and multiple accidents,that are equal for daylight and darkness.

Effects that only change one group of accidents are called selective. The quotient above expresses the selective effects. One cannot draw the conclusion that the selective effect is caused by the law (i.e. the changed

1) accidents primarily involving two or more road users

use of RL). There are two reasons for this. First, other factors with selective effect may have changed. Second, if a factor (e.g. speeds) is supposed to affect all groups of accidents it is by no means clear that all groups are affected equal. As is shown later, a given effect can be divided into (or considered as a mixture of) general and selective effects.

Thus, we are led to study the quotient MD·SN/SD·MN and ask ourselves: Are there other factors that have changed and can be expected to have selective effects on accidents.

If selective effects of other factors are disregarded, the change of the quotient can be taken as a measure of the effect of the RL-law.

The following tables are based on road traffic accidents in Sweden with personal injury two years before and after the introduction of the RL-law October 1st 1977. Collisions with animals, accidents without motor vehicles involved and other unclassified accidents are excluded.

Darkness includes dusk and unknown light conditions.

Table 7 Number of road traffic accidents with personal injury in Sweden

	BEFORE	AFTER	CHANGE
Single, daylight (SD)	4 189	4 112	- 2 %
Single, darkness (SN)	3 304	2 893	- 12 %
Multiple, daylight (MD)	15 965	14 867	- 7 %
Multiple, darkness (MN)	5 976	5 379	- 10 %

The number of accidents has thus decreased in all groups. The next table shows the quotient of multiple accidents to single accidents.

Table 8 q_1 = (number of multiple accidents)/(number of single accidents)

	BEFORE	AFTER	CHANGE
Daylight (D)	3.81	3.62	- 5 %
Darkness (N)	1.81	1.86	+ 3 %

Finally, the quotient between daylight and darkness gives the desired selective change.

Table 9 $q_2 = q_1(D)/q_1(N) = (MD/SD)/(MN/SN)$

	BEFORE	AFTER	CHANGE
q_2	2.11	1.95	- 8 %

Let us again point out that one cannot draw the conclusion that this is the effect of the RL-law. The only thing done so far is to eliminate (some of the) effects that obviously not can be a result of the RL-law. Other selective effects may have contributed to the change.

If the 8 % decrease of q_2 is supposed to be a result of a selective change of the number of multiple accidents in daylight the absolute value of this change would be 1240 accidents or 620 accidents per year. In the following detailed analysis the estimate of the selective change varies between - 460 and – 1100 accidents per year (- 6 to - 13 percent) depending on method.

The mathematical model for the statistical analysis (a multiplicative poisson model) is discussed in the next chapter.

Later the analysis is differentiated for the following basic factors

- summer/winter
- urban/rural areas
- types of accidents
- weather conditions

There are several reasons for such a differentiation

- The model for the analysis assumes that accidents come from a population that is in some sense homogenous.
- Differentiated results are more informative (for a comparison, the Finnish RL-law applies only in urban areas wintertime).
- Stronger conclusions can be drawn if the variation of differentiated results follows an expected pattern.
- The method can be modified in some cases e.g. for accidents with unprotected road users.

5.2 The model

Accidents are supposed to be poisson distributed, i.e.

$P(X=k) = p(m,k) = m^k e^{-m}/k!$, k=0, 1, . . .

where m is the expected value of the number of accidents X. Usually m is written as a product of risk λ and exposure T, $m = \lambda T$, but in the absence of traffic data we have to work with induced exposures.

Consider the following two-by-two-table of accidents

	SINGLE(S)	MULTIPLE(M)
DAYLIGHT (D)	X(S,D)	X(M,D)
DARKNESS (N)	X(S,N)	X(M,N)

And the corrresponding expectations (when vehicle mileage is taken as exposure):

	SINGLE	MULTIPLE
DAYLIGHT	$\lambda_{S,D}\ T_D$	$\lambda_{M,D}\ T_D$
DARKNESS	$\lambda_{S,N}\ T_M$	$\lambda_{M,N}\ T_N$

The risks $\lambda_{S,D},\ldots, \lambda_{MN}$ are assumed to follow the multiplicative structure

	SINGLE	MULTIPLE
DAYLIGHT	$\lambda_{SD} = \lambda$	$\lambda_{MD} = \lambda\beta\delta$
DARKNESS	$\lambda_{SN} = \lambda\alpha$	$\lambda_{MN} = \lambda\alpha\beta$

(1)

If we assume that all λ:s are >0 this model lays no other restrictions on them since we have expressed four variables with four new ones. The factors λ, α, β can be considered as <u>general</u> factors since they influence at least two groups each. The interaction factor δ is called <u>selective</u> since it only affects one group of accidents: multiple accidents in daylight (X_{MD}).

The transformation $\gamma = 1/\delta$, $\beta' = \beta\delta$ gives

	SINGLE	MULTIPLE
DAYLIGHT	λ	$\lambda\beta'$
DARKNESS	$\lambda\alpha$	$\lambda\alpha\beta'\gamma$

(2)

which shows that the selective interaction factor can be placed anywhere in the two-by-two table. (1) is preferred for interpretation and (2) for symmetry. We show both to emphasize that the interaction factor is not tied to multiple accidents in daylight.

Next, consider (1) for four different years. The expected numbers of accidents year i, i=1,...4, are given by

	SINGLE	MULTIPLE
DAYLIGHT	$E(X_{SDi}) = \lambda_i T_{Di}$	$E(X_{MDi}) = \lambda_i\beta_i\delta_i T_{Di}$
DARKNESS	$E(X_{SNi}) = \lambda_i\alpha_i T_{Ni}$	$E(X_{MNi}) = \lambda_i\alpha_i\beta_i\ T_{Ni}$

If we let

$$\lambda_i' = \lambda_i T_{Di}$$

$$\alpha_i' = \alpha_i T_{Ni}/T_{Di}$$

we finally arrive at the following induced exposures model for expected numbers of accidents:

	SINGLE	MULTIPLE
DAYLIGHT	λ_i'	$\lambda_i'\beta_i\delta_i$
DARKNESS	$\lambda_i'\alpha_i'$	$\lambda_i'\alpha_i'\beta_i$

The values of α_i' , β_i and λ_i' are of little interest and will not be given. The aim of the analysis is to make inference about $\delta_1,\dots,\delta_4$

The maximum-likelihood estimate of δ_i is

$$\Delta_i = \frac{X_{MDi}\, X_{SNi}}{X_{SDi}\, X_{MNi}}$$

and in the case of two years the relative change δ_2/δ_1 is estimated by Δ_2/Δ_1. The corresponding percentual change is (Δ_2/Δ_1-1) 100%. This is the estimate of the change in expected number of multiple accidents in daylight due to a change in δ, i.e compared to what could be expected if δ had remained unchanged but α, β, λ had changed as they did. The ML-estimate in the case of four years is a bit more complicated.

5.3 Analysis

The numbers of accidents year i, are supposed to be poisson distributed according to a multiplicative model for expectations

	SINGLE	MULTIPLE
DAYLIGHT	λ_i	$\lambda_i\beta_i\delta_i$
DARKNESS	$\lambda_i\alpha_i$	$\lambda_i\alpha_i\beta_i$

In search for selective changes of the number of multiple accidents in daylight from before (years 1 and 2) to after (years 3 and 4) we formulate the following hypothesis

$$H_o = \delta_1 = \delta_2 = \delta_3 = \delta_4 \quad (=\delta_0)$$

and the alternative

$$H_1 = \delta_1 = \delta_2 \neq \delta_3 = \delta_4$$

In both cases the parameters $\alpha_i, \beta_i, \lambda_i$ are supposed to be > 0.

We use the likelihood-ratio (L-test) to test H_0 against H_1. H_0 is rejected when $\eta = -2\ \ln(L_0/L_1)$ is too great, where L_0 and L_1 are the likelihood functions under H_0 and H_1.

For reasons of symmetry we prefer to work with the transformed model

	SINGLE	MULTIPLE
DAYLIGHT	λ_i	$\lambda_i\beta_i$
DARKNESS	$\lambda_i\alpha_i$	$\lambda_i\alpha_i\beta_i\gamma_i$

The hypotheses

$H_0: \gamma_1 = \gamma_2 = \gamma_3 = \gamma_4$

$H_1: \gamma_1 = \gamma_2 \neq \gamma_3 = \gamma_4$

are equivalent to the old ones since the $\alpha_i, \beta_i, \lambda_i$ are unrestricted but >0.

The ML-estimates are in the H_0 case solutions to

$$X_{SDi}+X_{MDi}+X_{SNi}+X_{MNi} = \lambda_i(1+\alpha_i+\beta_i+\alpha_i\beta_i\gamma) \qquad i=1,\ldots,4$$

$$X_{MDi}+X_{MNi} = \lambda_i\beta_i(1+\alpha_i\gamma) \qquad i = 1,\ldots,4 \qquad (3)$$

$$X_{SNi}+X_{MNi} = \lambda_i\alpha_i(1+\beta_i\gamma) \qquad i = 1,\ldots,4$$

$$\sum_{i=1}^{4}(X_{SDi}+X_{MDi}+X_{SNi}+X_{MNi}) = \gamma\sum_{i=1}^{4}\lambda_i\alpha_i\beta_i$$

In the H_1 case the ML-estimates are solutions to two independent systems of the form (3) but with two years each (i = 1,2 and i = 3,4 respectively)

In order to simplyfy formulas the accidents are written with double index

	SINGLE	MULTIPLE
DAYLIGHT	X_{i1}	X_{i2}
DARKNESS	X_{i3}	X_{i4}

Let m_{ij} be the expected value of X_{ij}, e.g. $m_{i4}=\lambda_i\alpha_i\beta_i\gamma_i$. Let $\hat{m}_{ijo}$ be the value of m_{ij} when the H_o-estimates of $\lambda_i, \alpha_i, \beta_i, \gamma_i$ are used and let $\hat{m}_{ij1}$ be the corresponding H_1-estimate.

With the notions introduced above, the likelihood-ratio test is to reject H_o when

$$\eta = \sum_{i,j} 2\, N_{ij} \ln (\hat{m}_{ij1}/\hat{m}_{ijo})$$

is too large. When H_o is true, η has approximative χ^2-distribution with df=1.

When H_o is rejected the conclusion is that there has been a significant change in the parameter γ or equivalently its inverse δ. The effect on accidents is estimated by

$$R = (\hat{\delta}_3/\hat{\delta}_1 - 1) \cdot 100\ \%.$$

The goodness-of-fit χ^2 is in the usual way given by $\chi^2 = (X_{ij}-\hat{m}_{ij})^2/\hat{m}_{ij}$.

5.4 Results

The L-test

The induced exposure technique requires that accident data come from a homogenous population. Consequently, the material is first divided into built-up and non built-up areas for summer and winter, (table 10). Accidents in dusk or unknown light conditions are included in darkness.

Table 10. The L-test and estimated effects.

Subgroup	χ^2-goodness of fit		$\eta =$ $-2\ln\Lambda$	$q =$ δ_3/δ_1	effect	
	before	after			%	accidents 2 years
summer						
buil-up	0.14	1.77	3.08	0.85	- 15	- 1166
non built-up	0.62	1.00	0.26	0.95	- 5	- 142
winter						
built-up	1.27	4.31	0.59	0.93	- 7	- 278
non built-up	0.57	1.83	2.58	0.89	- 11	- 255
Sum	2.60	8.91	6.51	-	- 11	- 1841

The first two columns in table 10 shows the χ^2 for goodness-of-fit of the H_1 model before and after. Each of them have one degree of freedom (df=1). According to the χ^2-criteria, the model is accepted. It should, however, be noted that the agreement is much better for the before-period than for the after-period, χ^2-sums are 2.60 and 8.91 respectively (df=4).

The third column shows the values of the test variable $\eta = -2\ln(L_0/L_1)$ where L_0 and L_1 are the likelihood functions under H_0 and H_1. If H_0 is true, η has χ^2-distribution with df=1. None of the η-values in table 10 is greater than the critical value 3.84 (on 5% level). The sum of the η-values is smaller than 9.49 which is the critical value for df = 4. Thus the null hypothesis can not be rejected or, in other words, the estimated effects are not significant. The fourth column shows the quotient $Q = \hat{\delta}_3/\hat{\delta}_1 = \hat{\delta}_{after}/\hat{\delta}_{before}$ which expresses the selective change. $Q<1$ means reduction of the number of multiple accidents in daylight. The estimated change is transformed into percentual effect in column 5. All effects are reductions between 5 and 15 %. None of them is significantly different from zero since no η-value is greater than 3.84.

The fact that all effects are negative makes the indication stronger that there is an effect. In fact, if H_0 is true, the probability that all effects are negative is only $2^{-4}=0.0625$. If the sign of the effect and η-values are assumed to be independent, the probability of the event that all effects are negative and the η-sum is greater than 6 is only $2^{-4} \cdot 0.20=0.01$. This calculation can not be taken as a fair test since the critical event (all signs negative and the η-sum greater than a critical value) not was formulated beforehand.

The expected effects in number of accidents during the after-period (two years) are given in the last column. The greatest contribution comes from built-up areas, summer. The total estimated effect is a reduction of 920 accidents per year. As before, this effect is not significant.

The conclusions of this section are:

- the estimated selective change is an 11 % decrease of all multiple accidents.
- the decrease is not statistically significant
- the estimated change is of expected magnitude – insignificancy can be a consequence of insufficient data.
- a combined sign- and L-test gives stronger indication that the estimated effects are real.

We proceed to see what information a further subdivision will bring.

Accident types

In the previous analyses the population was divided into disjoint subsets. When we turn to subdivision according to type of multiple accidents, it should be observed that all types are compared to the same set of single accidents. Therefore, the different accident-type estimations are dependent.

Accidents are classifed according to primary conflict. The following types are considered:

- opposing – conflict between motor vehicles from opposing directions.
- crossing – conflict between motor vehicles from crossing directions.
- coincident – conflict between motor vehicles from coincident directions.
- cycle – conflict between motor vehicle and bicycle or moped.
- pedestrian – conflict between motor vehicle and bicycle or moped.

The total sum of estimated effects in this analysis (-13 %) differs from the total sum in the previos subdivision. This is a consequense of the non-linear model.

Table 11 Percentual effects by accident type.

	SUMMER		WINTER		SUM
	built-up	non built-up	built-up	non built-up	
Opposing	- 13	- 8	- 8	- 11*	- 10
Crossing	- 12	+ 25	- 13	- 15	- 9
Coincident	- 2	+ 4	+ 6	- 16	- 2
Cyclists	- 25*	- 19	- 10	- 18	- 21
Pedestrians	- 27*	+ 7	- 7*	- 9	- 17
SUM	- 19	- 3	- 8	- 13	- 13

*) Significant on the 5 % level.

The corresponding effects in absolute figures are given in the next table.

Table 12 Estimated absolute effects, number of accidents per two years.

	SUMMER		WINTER		SUM
		non		non	
	built-up	built-up	built up	built-up	
Opposing	- 84	- 66	- 37	- 117	- 304
Crossing	- 199	+ 90	- 153	- 51	- 313
Coincident	- 14	+ 30	+ 27	- 93	- 50
Cyclists	- 864	- 153	- 90	- 32	- 1139
Pedestrians	- 363	+ 11	- 62	- 10	- 424
SUM	- 1524	- 88	- 315	- 303	- 2230

If running lights have any effect,greatest effect is expected for accidents with opposing directions and smallest (no decrease or increase) for coincident directions. The effect on accidents with crossing directions can be expected to be somewhere in between. Accidents with cyclists and pedestrians can also be expected to decrease with the use of running lights.

The pattern in tables 11 and 12 support this expectation:

- Opposing direction accidents show a 10 % decrease.
- Crossing direction accidents decrease 9 % with some variation.
- Coincident direction accidents decrease 2 %.
- Accidents with mopeds and cycles involved decrease 21 %. This is the greatest reduction and most of it is due to the decrease in built-up areas, summer.
- Accidents with pedestrians decrease 17 %, also in this case a major contribution comes from built-up areas in summer (-27 %).

Since the pattern of effects agrees with expectations the results support the hypothesis that the decrease is connected with the increased use of running lights.

The strong effect for accidents with unprotected road users (mopeds, cycles and pedestrians) can be questionned. The fact that accidents with unprotected road users decrease more than accidents involving two vehicles from opposing directions is fully acceptable on the hypothesis that peripheral vision plays an important role for unprotected road users and that running lights are important for peripheral perception.

However, the use of single car accidents as an induced measure of exposure can be questionned. The exposure for accidents involving unprotected road users is a function of both vehicle traffic and unprotected road users traffic. Since single accidents for unprotected road users not are regarded, there is no induced estimate of unprotected road users traffic.

An alternative method for analysis of accidents with unprotected road users is to make a simple two by two comparison with all accidents that are assumed to be unaffected by running lights, i.e. the sum of all accidents involving unprotected road users in darkness and single vehicle accidents in daylight and darkness.

Table 13. Accidents involving unprotected road users in daylight. Control group is the same type of accidents in darkness plus single vehicle accidents.

GROUP	ACCIDENTS				χ^2	EFFECT	
	Daylight collisions		Control			%	accidents, 2 years
	before	after	before	after			
CYCLE							
summer							
built-up	2788	2588	1495	1459	1.19	- 5	- 133
non-built-up	777	649	2991	2768	2.98	- 10	- 70
winter							
built-up	915	845	1793	1736	0.66	- 5	- 41
non built-up	150	146	2771	2578	0.14	+ 5	+ 6
SUM						- 5	- 238
PEDESTRIAN							
summer							
built-up	1014	996	1464	1450	0.02	- 1	- 8
non built-up	162	157	3012	2776	0.19	+ 5	+ 8
winter							
built-up	878	816	2313	2184	0.08	- 2	- 13
non built-up	108	100	2796	2584	0.00	0	0
SUM						- 1	- 13

The results from this approach are given in table 13. According to the χ^2-values there is no reason to reject the null hypothesis that there is no effect.

It is also possible to compare accidents involving unprotected road users in daylight with the same group in darkness. In this analysis accidents in built-up and non built-up areas are added.

Table 14. Accidents involving unprotected road users in daylight and darkness.

GROUP	ACCIDENTS				χ^2	EFFECT	
	Daylight		Darkness			%	accidents 2 years
	before	after	before	after			
CYCLE							
summer	3565	3237	355	391	6.27	- 18*	- 690*
winter	1065	991	899	803	0.39	+ 4	+ 40
SUM						- 13*	- 650*
PEDESTRIAN							
summer	1176	1153	345	390	2.82	- 13	- 176
winter	986	916	1444	1257	1.18	+ 7	+ 58
SUM						- 5	- 118

The four groups in table 14 are disjoint so they can be considered as independent. In only one case, accidents involving bicycles and mopeds in summer, the change is statistically significant.

Thus, there are three possible quotients to study in order to estimate the change of accidents involving unprotected road users.

I. the quotient δ in the original model (i.e. to compare the daylight to darkness ratio of studied group of accidents with the corresponding ratio for single vehicle accidents).

II. the ratio of collisions in daylight to the sum of collisions in darkness and single vehicle accidents.

III. the ratio of collisions in daylight to darkness.

The estimated effects of the three methods are – 1563 accidents per 2 year for the first method, – 211 for the second and – 768 for the third method.

It is satisfactory to observe that the simplest method (nr 3) gives a result between the results of the two more sofisticated methods.

The estimated effect per year for unprotected road users thus varies between – 100 and – 800 accidents. Apart from this uncertainty, which is due to different methods, there is the ordinary statistical uncertainty. Only a few of the terms in the sum of accident reductions are statistically significant from zero. It follows that the statistical uncertainty is at least as great as the estimated effects.

To summarize, the estimates for different accident types and, in the case of unprotected road users, for different methods are listed in table 15.

Table 15. Effects on accident types, accidents per year and percent.

		SUMMER	WINTER	SUM	
Opposing		- 75	- 77	- 152	(- 10 %)
Crossing		- 55	-102	- 157	(- 9 %)
Coinciding		+ 8	- 33	- 25	(- 2 %)
Cycles	I	-508	- 61	- 569	(- 21 %)
	II	-101	- 18	- 119	(- 5 %)
	III	-345	+ 20	- 325	(- 13 %)
Pedestrian	I	-176	- 36	- 212	(- 17 %)
	II	0	- 6	- 6	(- 1 %)
	III	- 88	+ 29	- 59	(- 5 %)
SUM	I	-806	-309	-1115	(- 13 %)
	II	-223	-236	- 459	(- 6 %)
	III	-555	-163	- 718	(- 9 %)

Numbers that are significantly different from zero when individually tested are asterisked. It is clear that the total effect is not significantly different from zero.

Weather-light conditions

A subdivision according to the weather gives the following percentual effects

Table 16 Percentual changes by weather

	SUMMER		WINTER		SUM
	built-up	non built-up	built-up	non built-up	
sunny	- 24	+ 1	- 1	- 10	-15
normal	- 3	- 25-	16	+ 3	-11
cloudy	- 9	+ 25-	5	- 14	- 5
Sum	- 13	- 7-	8	- 10	-10

None of the figures in table 16 are significantly different from zero.

The pattern in table 16 is quite random. The sum-column indicates a weaker effect for cloudy days than for sunny and normal days. This is not surprising if the effect per vehicle is assumed to be weakest for sunny days. Because of this expectation, the use of running lights before the law was highest when the expected effect was highest i.e. on cloudy days. And in the after period, the use was near 100 % in all cases. So the increase in use is reciprocal to expected effect per vehicle, and thus it is not possible to say which weather condition should present the greatest reduction. However the tendency in the sum column indicates that the average driver underestimated the effect of running lights in good weather conditions.The fluctuations in table 16 demonstrate the uncertainty of the method when the material is small.