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Day-time Running Lights: Its Safety Evidence Revisited

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SUMMARY

Retrospective in-depth accident studies from several countries confirm that human perception errors are the main causal factor in road accidents. The share of accident types which are relevant for the effect of day-time running lights (DRL), such as overtaking and crossing accidents, in the total of daylight multiple accidents is larger than in darkness conditions. Perception research leads to the hypothesis that peripheral vision, detection and reaction time are enhanced by DRL, especially under cloudy weather and twilight conditions. Research also show that speeds of oncoming traffic with DRL are overestimated and their distances underestimated compared to non-DRL users. There are also some indications that DRL-use does not mask the perception or reduce the detection time of non-DRL users. These results points to an explanation of a DRL-effect as not only based on increased mere visibility but also based on the enhancement of timely perceptual selection of DRL-users and safer judgements, without an interactive effect on the perception of non-DRL users.
The previous evidence for increased safety by DRL comes from national evaluations of a DRL-obligation (Finland and Sweden) and fleet studies (USA and Canada). In the mid eighties less well known evidence came also from Norway (national study on voluntary DRL-use). In an earlier review we concluded that none of these single studies was convincing on its own because of methodological and statistical reasons, but we also argued that the DRL-effect of all studies together is convincing and can be combined to a statistical significant positive linear relation between the magnitude of the DRL-effect and the latitude of the study area. The hypotheses and conditions under which national and fleet studies can be combined are now reconsidered, which lead to a curvilinear relation between DRL-effect and latitude. Evidence from eight recent DRL-studies can be added now: five fleet studies (Israel (1), Austria (3), Canada (1)) and three national evaluations (one for the full DRL-obligation in Denmark, one for the later DRL-obligations for Norway and another for a winter-time DRL-campaign in Israel). Although some recent results are less positive, the mean of the recent results per country are quite well predicted by a curvilinear relation between latitude and DRL-effect obtained from the revised analysis of the older results per country. All known studies are now included in a revised analysis for an updated curvilinear relation between latitude and mean DRL-effect per country. The expected overall effect for road safety from DRL for any particular country can be deduced from that curvilinear relation, while other critical questions about the validity of the prognostic prediction of a DRL-effect and with respect to different types of accidents are discussed.

REASONS AND THEORETICAL BACKGROUND

Visual perception in traffic is not only determined by visibility, nor is it independent from cognition. Perception is closely related to the attention level, the selection and the activation of memory elements and also to the central information processing that leads to judgments and motor performances. Perception in driving generally takes place in dynamic situations and non-optimal conditions. Unfortunately theory and research for the perception of moving objects by moving perceivers under non-optimal field and perceiver conditions is hardly developed and hence the relevant knowledge about perception in traffic is very incomplete (Koornstra, 1993). Perception in traffic is activated cognitive perception and may be better described by foreseeing. Seeing elicits in the experienced road user a selection of elements which are learned to be relevant for the dynamic behaviour of himself and of others. He has to foresee the next coming conditions by a routinely prediction of the behaviour of other road users, in order to adjust his own behaviour. Incorrect seeing and incorrect selection of elements for foreseeing in traffic can be fatal. Redundancy of perceptual cues and increased conspicuity of relevant discriminative cues in general will reduce perceptual errors. Day-time running lights (in short DRL) may be such a cue which serves these purposes in traffic.

Studies of accidents by analysis of situational evidence and by interviewing involved road users have revealed that human perception and judgment errors play a dominant role in the causation of accidents. A detailed study from Japan (Nagayama, 1978), for example, specifies that perceptual errors are in about 50% of the main cause for a total of 38,625 accidents. Such findings are in accordance with many in-depth accident studies where generally the major part of road accidents are contributed to perception errors. A more recent Australian in-depth study (Cairney & Catchpole, 1990) identifies about 40% to even about 80% of certain accident types as caused by insufficient perception.

One may expect that those types of daytime multiple accidents which should benefit most from DRL, like overtaking and crossing collisions, will be relatively less frequent in darkness than in daylight. In order to investigate this hypothesis an analysis of the injury accidents of 1987 in The Netherlands, where hardly DRL was used at that time, was performed by Koornstra (1989). He compared overtaking and crossing accidents on intersections and straight road-sections in daylight and in darkness with street lighting with other multiple accidents in these conditions. Accidents in twilight were omitted, as it was not known whether the vehicle lighting is on or not. Accidents in curves or roundabouts and accidents in darkness without street lighting were also omitted, since it is known that these situations are more dangerous at night due to other perceptual road factors at night. The ratio of accidents in daylight and in darkness for the types of conflicts that benefit most from DRL turned out to be 14% higher compared to the ratio of other multiple accidents, which is a statistically very significant effect. If DRL in daylight condition would match the selective perception of traffic against their background in darkness with street lighting, one could expect a 14% reduction for these daylight multiple accidents.

Visibility as such is at daylight normally better than in darkness with street lighting. Experimental research has shown that under the usual day-time conditions in the Netherlands that cars with DRL-use are only 8% of the time better discriminated against the background of the open field (Padmos, 1988), especially under cloudy or twilight conditions. A hypothesized larger effect from DRL on multiple daylight accidents, therefore, must not only be sought in better visibility. Apart from the activation of correct attention, for example in peripheral vision (Hörberg & Rumar, 1979; Perel, 1991), and a shorter search time for the selection of relevant cues the enhanced conspicuity of the relevant dynamic elements in traffic by DRL (Rumar, 1980) may enable the road user to select better the elements for the proper judgments, like for distances, speeds and direction of correct identified vehicles. Indeed experimental research (Attwood, 1976, 1981; Hörberg, 1977; Nagayama et al. 1980; Helmers, 1988) show that distances are underestimated and speeds are overestimated under DRL conditions. DRL, therefore, may serve more than the enhancement of mere visibility and probably reduce multiple accidents, where certain types, like overtaking and crossing accidents, may benefit more than other multiple accidents.

The attention given to cars with DRL may lead to less attention to other non-DRL users or may mask their perception, which would increase the danger for non-DRL users. Since this hypothesis is also favoured by the cyclist organisations in the Netherlands and Denmark which have opposed the obligation for DRL in their countries, some Dutch research was directed to that question (Riemersma et al., 1987). It turned out that the detection time of cyclists in the neighbourhood of car with and without DRL is not different. There are also no reports on adverse effects for non-DRL users in the evaluation of countries which have introduced DRL in gradual manner over a relative long period. There are also no empirical reports on adverse effects for cars without DRL from countries where DRL-use increased partially. In fact a study from Norway (Vaaje, 1986), where the voluntary DRL-use increased from one-third to two-third, reports the one of the highest DRL-effects observed for accidents between cars as well as between cars and pedestrians if these effects are extrapolated to a 100% DRL-use. The only type of accidents which theoretically may increase by DRL are rear-end accidents, because of a possible masking of breaking lights by rear lights which are generally also switched on in daylight under the use of DRL. Perception research in experimental laboratory conditions supports this partial masking hypothesis (Akerboom et al. 1990), but evaluation of DRL-use in actual traffic are not univocal with respect to rear-end accidents. It, therefore, can be safely concluded that DRL has a potential for the reduction of day-light multiple accidents, probably without effecting other non-DRL road users or particular types of accidents negatively.

EMPERICAL EVIDENCE FOR ROAD SAFETY EFFECTS

The evidence for the effect of DRL on road safety comes from two types of studies. Studies on a national scale with changing levels of the DRL-use and studies of the effect before and after the introduction of DRL by large fleet-owners.

A national obligation for DRL was first introduced in Finland for rural roads in winter time in the early seventies and later DRL became mandatory in the late seventies in Finland and Sweden everywhere and for the whole year, while in Norway the DRL-obligation for new cars was introduced in 1985 after nearly two-third of the Norwegian drivers already used DRL voluntary and became fully mandatory in 1988. In Canada the DRL-obligation for new cars holds from december 1989 onwards and in Denmark the full

DRL-obligation was introduced in october 1990, while in march 1993 the use of DRL became obligatory in Hungary on rural roads. In Austria, the Netherlands and Israel the voluntary use of DRL is officially propagated and sustained by information campaigns by the national authorities. In Belgium and the Netherlands a national obligation was planned and is sustained by the EC in order evaluate its effect for less nordic European conditions, but the introduction is postponed because of political doubts. In Austria such a prepared national obligation is also postponed after one of three Austrian fleet studies, which were undertaken in order to convince the political authorities of the effect on road safety, turned out not to be positive. In Israel a compulsory DRL is proposed for the winter period, but its introduction is also delayed. In the USA proposals to permit the installation of DRL are issued, but not adopted at the moment.

DRL-effectiveness for multiple accidents involving motorized vehicles are reviewed by Cantelli (1970). Attwood (1981), Henderson et al. (1983), Polak (1986), Schreuder (1988), Helmers (1988) and Koornstra (1989). Special reviews with respect to DRL-effectiveness for motorcycles are given by Zador (1985) and Olson (1989). In our quantitative comparison (Koornstra, 1989) the national results from the DRL-obligations in Finland (Anderson et al., 1976) and Sweden (Anderson & Nilsson, 1981) and from the less well known evaluation of the voluntary increased DRL-use in Norway (Vaaje, 1986; Norwegian language) as well as from five fleet DRL-studies known to us up to 1988 are critically discussed and quantitatively related to the latitudes of the study areas. In that comparative review the reported DRL-effects are adjusted for the nationally different start or end levels of DRL-use in the evaluation period to a total DRL-effect {see footnote *)} in order to make their results quantitatively comparable and also with results from fleet DRL-studies.

The DRL-effect of most fleet studies are based on simple before-after comparisons or on a design with a control group without DRL-use. The DRL-effects in most national evaluations are estimated by a methodology which deduces the effect from the reduction of developments in multiple daylight accidents with respect to developments of multiple night accidents and single accidents in day-time and night. The methodology is based on the hypothesis that other things than an increased DRL-use (increased kilometrage in night or day-time, weather conditions or coinciding traffic measures) change equally for multiple and single vehicle accidents in night and daylight conditions, but that DRL only influences multiple day-time accidents. Therefore, it is a quasi-experimental control design for the deduction of a DRL-effect **).

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*) The proportion for the adjusted total DRL-effect (t) follows from its relation with the observed effect (e) for proportions of DRL-use before (ß) and after (α) by:

$$(1 - t.\alpha)/(1 - t.\beta) = 1 - e \quad \text{or} \quad t = e/[\alpha - \beta(1 - e)]$$

**) Defining: EMDa = expected multiple day-time accidents in after period,
and MDb, MDa = multiple day-time accidents in before and after period,
MNb, MNa = multiple night accidents in before and after period,
SDb, SDa = single day-time accidents in before and after period,
SNb, SNa = single night accidents in before and after period,
then EMDa = r.MNa.(SDa/SNa) where r=(MDb/SDb)/(MNb/SNb)]
and DRL-effect=1-MDa/EMDa=1-(MDa/MDb)/{(MNa/MNb).[(SDa/SDb)/(SNa/SNb)]}

Adjusted total DRL-effects on multiple daytime accidents for 100% DRL-change presented in Koornstra (1989) for the Norwegian evaluation (40%; reported 14% for a change from 35% to 65% DRL-use) and the Finnish winter-period evaluation (36.5%; reported 21% for a change from 65% to 97% DRL-use) are rather high. The Norwegian author (Vaaje, 1986) concludes: "that the increased use of daytime running lights constitutes the only explanation for this large difference, is however not likely", but he also states that other explaining factors were not discovered. The Finnish and Norwegian results were reported to be statistically significant. The Finnish results concern rural road accidents in winter day-time only. The Swedish study with an adjusted total DRL-effect of 22.5% (reported 11% for a change from 55% to 98% DRL-use) is the most detailed study. Distinctions are made in multiple day-light accidents between summer and winter, between head-on, crossing and rear-end car collisions and collisions of cars with cyclists and of cars with pedestrians. The Swedish overall results were statistically not significant. Some detailed comparisons, however, were statistically significant; especially the reduction of accidents between cars and cyclists or pedestrians. The Swedish results, however, are criticized (Theeuwes & Riemersma, 1990) for the inherent weakness of its quasi-experimental design described above. As a consequence its result for pedestrians can also be attributed to the unexplained increase of darkness accidents between cars and pedestrians, where as the overall result can be also attributed to the unexpected non-decreasing development of the single accidents. Despite such uncertainties Rumar (1981) concludes "the obtained effects on accidents coincide well with the results from the Finnish study".

Other early studies on the DRL-effect from the DRL-introduction by large fleet-owners come from the USA and Canada with DRL-effects ranging from 7% to 32%, where the 7% effect is estimated from a yellow cab-fleet comparison. In Koornstra (1989) the results, reported by Allen & Clark (1964), Cantilli (1970), Allen (1979), Attwood (1981) and Stein (1984), are summarized and used in the comparative analysis together with the above mentioned three national evaluations. The old problem of studies for DRL-effects on company fleets was the questionable interpretations of their effects of DRL, since these effects could be only due to their relative conspicuity compared with other vehicles in the absence of national DRL-use or to an increased safety awareness of drivers at the introduction of DRL in the company. The above reported adjustments of total DRL-effects of the national evaluations indicate that such interactive counter-effects or artifacts need not to be manifest since the results of fleet-owner studies seem not to contradict the national results.

THE QUANTITATIVE COMPARISON OF RESULTS

Koornstra (1989) compared the DRL-effects in a quantitative way and predicted from a relation with the degree of latitudes for the area under study the expected DRL-effects. The Swedish results indicate that no marked other DRL-effect is to be expected from better daylight conditions in the summer compared with the winter in Sweden. However, the difference between the Norwegian and the Finish winter results with respect to the Swedish may indicate less effect in better daylight conditions. Also the fleet-owner results do indicate a possible influence of the different mean daylight conditions which go along with the degree of latitude on the reduction of daylight accidents by DRL. They revealed for Canada 24% effect on mean latitude about 51°, for New York 18% effect on latitude

40° and for the mean effect of four fleets with scattered traffic over the entire USA 18% on mean latitude 39°. The effective mean latitudes are roughly taken to be there where the population and traffic is cantered. Because no interactive or counter-effects for partial use of DRL in traffic were shown (Helmers, 1988; Koornstra, 1989) it is assumed that fleet-owner effects are indicative for national total DRL-effects. Under this assumption Koornstra (1989) related DRL-effects of fleet and national studies with latitude over a broad range of latitudes by linear regression.

Although the results of eight DRL-studies from five countries yielded a statistically significant linear relation (correlation $r = 0.45$ and $p < 0.05$) with increasing DRL-effects for higher latitudes, its predictive validity has been doubted. Since mean day-time visibility is better in more southern countries on the northern hemisphere, especially due to shorter twilight periods and often less cloudy weather conditions, it will partially influence the DRL-effectiveness and, therefore, a decreasing curve for lower latitudes is to be expected. But questions about the linearity of the relation between latitude and DRL-effect as well as about its combination of fleet results and nation-wide results remained.

Firstly it can be argued that the regression must not be linear but curvilinear increasing with latitude, because mean day-time visibility reverses in a flat way around the equator with respect to northern and southern latitudes and duration of twilight periods increases quadratic with latitude, while generally also weather conditions are worsening more on higher latitudes. Therefore, a U-shaped relation between DRL-effects and latitudes with a flat minimum base level at zero latitude, based on a curvilinear regression between DRL-effects and latitudes, is more likely on prior grounds. Secondly the combinations of data from fleet owner studies and the adjusted data for national studies in one regression curve can be seen as troublesome. In national evaluations concern a comparison of a changed mix of combinations of two road-users with or without DRL-use. Here one has to distinguish three relevant multiple conflict groups: a group of two DRL-users (motorized vehicles), a group of one DRL-user and one without DRL (motorized vehicles with and without DRL as well as motorized vehicles with DRL and non-DRL using cyclist and pedestrians) and lastly a group of two non-DRL users (two motorized vehicles without DRL or one motorized vehicle without DRL and non-DRL using cyclists and pedestrians). In contrast, fleet studies exclusively concern a change from two non-DRL road users to two road users with always only one motorized DRL-user. For fleet studies the change in expected two non-DRL road users is from 100% to zero percent, but then the adjustment of the reported DRL-effect for national studies to a comparable full DRL-effect for multiple car accidents must also be based on the same change in the expected percentage of two non-DRL using cars. The adjustment for the partial change in the percentage of DRL-use itself (see footnote p. 4) as used in the discussed review of Koornstra (1989) is only correct for the change in the expected proportion of two road users with only one DRL-user and does not take into account the also increased proportion of two DRL-using road users which is only also relevant for the adjusted total DRL-effect on multiple accidents between motorized vehicles. The adjustment of observed DRL-effects for this type of multiple accident under a partial increase of DRL-use, therefore, must be corrected on the basis of the decreasing proportion in two non-DRL road users {not adjusted for the changing before/after proportions β and α of DRL-use, but for $1-(1-\beta)^2$ and $1-(1-\alpha)^2$, see footnote *) on page 7}.

We argued, because no adverse effects for non-DRL users under partial national DRL-use are reported and experimental research also does not show negative perceptual effects for non-DRL users in the presence of DRL-users, that fleet DRL-studies can be seen as indicative for comparative adjusted national total DRL-effects. The ultimate consequence of this reasoning leads to the hypothesis that the presence of at least one DRL-user in conflicting road users is sufficient for a DRL-effect in preventing partially otherwise occurring accidents. This sufficiency assumption might be quite acceptable, since it is sufficient if only one road user is more timely stimulated by DRL to accident avoidance-behaviour. The acceptance of the sufficiency assumption justifies the joint analysis of DRL-effects of fleet studies and national DRL-effects which are adjusted by the proposed revision of the adjustment, since under this sufficiency assumption the relevant matter for the study of a DRL-effect is a change in expected frequency of two non-DRL road users. It also would make the DRL-effects for accidents between motorized vehicles and between motorized vehicles and non-DRL using cyclists and pedestrians comparable. However, if a part of the multiple car accidents is only avoidable by a DRL-evoked reaction of both DRL-using car drivers, than the total DRL-effects on multiple accidents of national evaluations can be expected to be higher than fleet DRL-effects or DRL-effects on accidents with non-DRL using cyclists and pedestrians.

PREDICTION OF EFFECTS ON MULTIPLE CAR ACCIDENTS

The likely curvilinear relation between latitude and DRL-effects as well as the proposed correction for adjustment to a total DRL-effect of the reported effects in the national studies, therefore, ask for a revision our previous analysis for the relation between latitude and DRL-effect on accidents between motorized vehicles (Koornstra, 1989). Apart from the revision of the data from Stein (1984) by Stein (1985) and not contained in our review of the data before 1989, new evidence for DRL-effectiveness is now obtained from eight recent studies after 1988. It concerns again five fleet studies: one from Israel (Hakkert, 1990), three from Austria (KfV, 1989; Schützenhöfer et al. 1990; KfV, 1990) and one from Canada (Sparks et al. 1989, 1991), as well as three national evaluations: a preliminary report of the evaluation of the further increased DRL-use in Norway (Elvik, 1992) after the introduction of the DRL-obligations (for new cars in 1985 and the full DRL-use in 1988), an evaluation of a three month campaign for voluntary DRL-use in the winter time of Israel (Hocherman & Hakkert) and a national evaluation of the DRL-obligation in Denmark (Hansen, 1993). The evidence obtained after 1988 contains DRL-effects for three new countries. This enables us to analyze the fit of the hypothesized curvilinear relation between latitude and mean DRL-effect for five the countries with DRL-results before 1988 and to test the validity of the DRL-effect prediction from that

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*) The adjusted total DRL-effect (t) for accidents between two motorized vehicles is now computed from the observed effect (e) and the proportions of DRL-use before (b) and after (a) by:

$$\{1 - t.[1 - (1 - a)^2]\}/\{1 - t.[1 - (1 - b)^2]\} = 1 - e$$

or $t = e/[(2a - a^2) - (2b - b^2)(1 - e)]$.

The adjusted total DRL-effect for accidents between motorized vehicles and pedestrians or cyclists remains as described by the footnote on page 4.

curvilinear relation for the new DRL-results after 1988. For this reason and reasons discussed earlier we present in the sequel a revised analysis of Koornstra's data (Koornstra, 1989), but now with the revised results of Stein (1985). Together these data constitute all DRL-effects from studies before 1988 known to us. These data are now analyzed for a curvilinear relation between latitude and DRL-effect under the proposed new adjustments to national total DRL-effects. Table 1 gives a summary of all fleet results before 1988 known to us, while Table 2 summarizes all national evaluations up to 1988.

Source	Design	Country	Effect	Note
Allen & Clark (1964)	before/after	USA	12%	
id.	before/after	Canada	24%	
Cantelli (1965,1970)	control group	USA	18%	
Allen (1979)	control group	USA	7%	1)
Stein (1985)	control group	USA	11%	2)

Table 1. DRL-effects from Fleet Studies before 1988

Notes: 1) Checkers Cab Company compared to Yellow Cab Company.
2) Mean effect on accidents per car for three fleets compared to control group.

			DRL-Effect			Total
Source	DRL-change	Country	Obs.	Adj.1	Adj.2	Est.
Anderson et al. (1976)	50%->97%	Finland	21%	37%	52%	46%
Anderson & Nilsson (1981)	55%->98%	Sweden	11%	23%	38%	32%
Vaaje (1986)	35%->65%	Norway	14%	40%	37%	38%

Table 2. Reported and total DRL-effects from National Evaluations before 1988

The first adjustment (of footnote p.4) corrects the reported effect for the increase in the proportion of a single DRL-user in a road user encounter and the second adjustment (of footnote p.7) includes also the increase in the proportion of two jointly DRL-using road users. Since the reported DRL-effects concern all multiple daytime accidents, while in these countries about 60% consist of accidents between motorized vehicles, we estimated the total DRL-effect on multiple vehicle accidents as the weighted mean of the two adjustments (Total Estimate + .4 x (Adjustment 1) + .6 x (Adjustment 2).

In our revised analysis we use weighted regression analysis for DRL-effect and latitude per country. The regression weights are taken as the square root of a number which corresponds roughly to the number of after-period accidents for all studies per country in order to equalize the error variance in the mean effect per country. Table 3 summarizes the data per country for our revised curvilinear regression between latitude and DRL-effect. In Table 3 also more accurate mean effective latitudes for the centred traffic and population of the countries are given than the latitudes used in Koornstra (1989).

Country	DRL-effect until '88	Effective Latitude	Number Studies	Regres. Weights
Finland	46%	65	1	2.2
Norway	38%	62	1	3.5
Sweden	32%	60	1	3.0
Canada	24%	51	1	1.0
USA	12%	39	4	2.5

Table 3. DRL-effects before 1988 and Latitudes per Country.

We examined three models for a curvilinear relation. The first model describes the DRL-effect as a linear relation with latitude raised to a power. The second model specifies an exponential relation with latitude raised to a power. The last model presents the DRL-effect as a tangential function of the latitude in radians. For non-negative parameters all models predict a non-negative DRL-effect at zero latitude. The models impose no limit for the DRL-effect (can become above 100%). The tangential relation seems theoretically most interesting because the mean proportion of the twilight period increases with latitude in that way (between the tropic of Cancer and the polar circle). Tables 4a, 4b and 4c specify these models and give the main results for the analysis of Table 3 by a variety of restricted models generated from each general model. The estimation of the parameters is such that it minimizes the variance of the logarithmic DRL-effect deviations, because the logarithmic fit stabilize the expected variance of the individual proportional effects.

Model I: DRL-effect % $= a + b * (\text{Latitude}/100)^{c}$

	a	b	c	S.D.%	Dev. Var.	df
General	6.188	178.4	3.647	8.3	0.0063	2
a=0	(0)	123.2	2.49	7.4	0.0051	3
c=1	-31.090	110.2	(1)	9.8	0.0088	3
a=0,c=1	(0)	51.8	(1)	37.6	0.1021	4

Table 4a. Results of Model I for Table 3.

Model II: DRL-effect % $= \text{Exp}\{a + b * (\text{Latitude}/100)^{c}\} - 1$

	a	b	c	S.D.%	Dev. Var.	df
General	1.332	4.465	1.37	7.5	0.0053	2
a=0	(0)	5.262	0.82	6.5	0.0040	3
c=1	0.535	4.984	(1)	6.4	0.0038	3

Table 4b. Results of Model II for Table 3.

Model III: DRL-effect % = a + b * $\{TAN(Latitude/57.294)\}^c$

	a	b	c	S.D%	Dev. Var	df
General	-3.578	19.84	1.15	7.1	0.0047	2
a=0	(0)	15.96	1.35	5.9	0.0033	3
c=1	-7.284	23.77	(1)	5.9	0.0032	3
a=0,c=1	(0)	2.93	(1)	50.4	0.1665	4

Table 4c. Results of Model III for Table 3.

The general curvilinear relations have three parameters. The more specific curvilinear models with two parameters or even one parameter are derived by leaving out one or two parameter, that is by assigning a priori zero or unit values to some parameters. Also the linear and proportional relation are specifications (c=1 and a=0,c=1) of Model I. The actual fit of the general models is better than for specific models, but due to the loss of three degrees of freedom on five observations its estimated error variances are greater. The fit for the tangential two-parameter models is the best, because they yield lower estimates for the variance of logarithmic curve deviations (after correction degrees of freedom). The linear tangential model (Model III with c=1) shows a slightly better fitting curve, but it has an insignificantly negative DRL-effect at zero latitude. Therefore, we regard the other tangential two-parameter model (Model III with a=0) as the optimal model. This optimal model specifies that the DRL-effect is proportional with the tangent of the latitude raised to a power. The power parameter in the optimal model is significantly greater than unity as the comparison with proportional tangent function (Model III with a=0 and c=1) shows. The F-ratio's of the other curvilinear models, as ratio's of its deviation variance with the deviation variance of the optimal model, indicate that these other models are not fitting significantly worse. This is mainly due to the limited number of data available (5 data points and 2 or 3 parameters). Also the linear regression reaches hardly a significant difference from the optimal curvilinear model (p=.10 one sided test). However, the linear model predicts a negative DRL-effect at the latitude of zero degrees, which is unacceptable. Under the constraint of an intercept at zero latitude the deviation variance of this proportional relation (Model I with a=0 and c=1) is significantly (p <.001) larger than the optimal model. Therefore, apart from our theoretical reasoning for a curvilinear relation, a linear relation must be rejected. The variance of the curvilinear model parameters is such that a positive DRL-effect at the equator (a>0) seems insignificant and for the optimal model it is constraint to zero. The proportional standard deviation for the fit of Table 3 with the optimal model is nearly 6% of the expected value, but for the individual fleet data of Table 1 it is about 50% of the expected value. The standard deviation for the raw percentages them selves is 1.6% for the data of Table 3 and 6.2% for the individual fleet data of Table 1.

The optimal model has also some theoretical justification, since that model is based on the tangential increase of the twilight period at increasing latitudes. The fact that the power parameter is significantly greater than unity may verify that at higher latitudes the visibility is also decreased by worse weather conditions than on lower latitudes.

Figure 1 displays the data of Table 3 and the fitted curve for the optimal model.

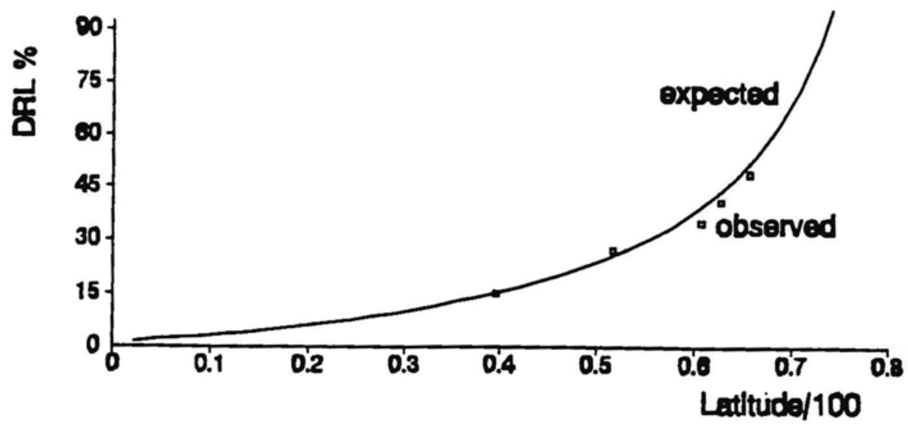

Figure 1. DRL-Curve Prediction from Latitudes and Measured DRL-effects.

This curve for the DRL-effect as a function of the latitude can be used as a prediction model for expected DRL-effects for other countries. The validity of the prognostic prediction of the positive DRL-level from this curve based on the DRL-effectiveness data before 1988 can be tested by the additional obtained DRL-effects from studies after 1988.

VALIDITY OF DRL-EFFECT PROGNOSIS

In order to investigate the validity of the model predictions for DRL-effectiveness we first review and summarize in a similar way as before the recently obtained results on DRL-effectiveness. Again the evidence after 1988 is separated in fleet studies and national evaluations, because observed national effects must be adjusted to total DRL-effects. The fleet result which appeared after 1988 are presented in Table 5 and the national evaluations since 1988 in Table 6.

Source	Design	Country	Effect	Note
KfV (1989)	before/after	Austria	2%	
Hakkert (1990)	control group	Israel	13%	
Schützenhöfer et al. (1990)	before/exp./after	Austria	21%	1)
KfV (1990)	before/after	Austria	0%	2)
Sparks et. al (1989, 1991)	control group	Canada	15%	3)

Table 5. DRL-effects from Fleet Studies after 1988

Notes: 1) One DRL-year with 21.6% and 20.9% reductions compared to years before and after without DRL.
2) Effect compared to national changes.
3) Excluding DRL-irrelevant types of accidents the effect was 28%.

Source	DRL-change	Country	DRL-Effect Obs.	Total Est.	Note
Hocherman & Hakkert (1991)	unreported	Israel	+13%	?%	1)
Elvik (1992)	50%->92%	Norway	0%/15%	31%	2)
Hansen (1993)	20%->97%	Denmark	7%/20%	28%	3)

Table 6. Reported and total DRL-effects from National Evaluations after 1988

Notes: 1) The day/night ratio of multiple accidents between motorized vehicles increased 18.5% and 8.5% compared to the first year and second year before.
2) No DRL-effect is reported for all multiple car accidents, mainly due to a 17% increase of day-time accidents in the severe winters of 1985-'87. In the summer periods daytime multiple car accidents were reduced by 15% and without rear-end accidents the reported total effect is 10%. Because of this mixed evidence the reported DRL-effect is taken to be the total 10%, excluding rear-end accidents. The adjusted total effect becomes than 31%.
3) Hansen reports a time-series effect for the DRL-intervention of 7% on multiple car accidents. However, a DRL-effect of 20% follows from the method used in other national evaluations, because the report contains for the after period for night multiples 3% increase, for day-time singles 9% increase and for night singles 13% decrease. Hence by the method of the footnote on page 4 we obtain Effect=1-.97/[1.03(1.09/.87)=-.20. The adjusted total effect then becomes 28%. and is taken as the estimated total DRL-effect for reasons of comparability of estimation methods.
4) Since these evaluations report on motorized vehicles separately only the adjustment of the footnote on page 6 applies.

Table 7 summarizes the mean observed DRL-effects and latitudes per country for the three additional countries as well as their predicted DRL-effects from figure 1. The adjusted total DRL-effect of the national DRL-campaign in Israel can not be computed. Although it must be evaluated as non-positive, we do not assume that DRL can have very negative effects. Therefore, the estimate of a DRL-effect for Israel from Table 5 and 6 is taken to be the mean of the effect in Table 5 and a zero DRL-effect for Table 6. The DRL-effect for Austria is the mean from data of Table 6. The DRL-effect for Denmark is the adjusted multiple vehicle accident percentage from Table 6.

Country	DRL-effect obs. mean	Effective Latitude	Number of Studies	Model Pred.
Denmark	28%	56	1	27.2%
Austria	8%	40	3	12.6%
Israel	6%	33	2	8.9%

Table 7. DRL-effect and Latitude of added Countries after 1988.

In our earlier review (Koornstra, 1989) we concluded that none of the single studies (up to 1988) was convincing on its own because of methodological and statistical reasons, but we also argued that the DRL-effect of all studies together is convincing and can be combined to a statistical significant positive linear relation between the magnitude of the DRL-effect and the latitude of the study area. We now note that for Tables 5 and 6 the results after 1988 contain two individual studies with a non-positive DRL-effectiveness. However, these two studies are the only non-positive ones from the total of sixteen studies. Our previous conclusion that the joint evidence of DRL-results, even if most individual studies are not statistically significant, justifies an overall prediction of an accident reduction by the use of DRL, therefore, is affirmed. A positive result for fourteen investigations out of sixteen has statistical significance (sign test $p < .01$). Moreover, the recent evidence of Table 7 confirms our now revised analysis of a curvilinear relation between DRL-effectiveness and latitude. Because of its optimal fit to the data of Table 3 and its theoretical basis, we now use Model III with a=0 for the prognostic prediction of the DRL-effect in the three added countries. These predictions are higher than observed at lower latitudes, but the obtained DRL-effects for each added country are still in the 95% range of expected deviations, if we take into account that the Austrian value is the effect of a total of three fleets. Although the observed effects are consistently somewhat lower than predicted mean effects from the optimal model and the variance of individual recent results is somewhat larger than expected, Table 7 proves the validity of the optimal model as a method for prediction of the positive safety effect of DRL-use in a particular country.

The determination of the curve and its validity for prognostic predictions, however, can be improved if we use all data available now for an updated curve fitting. Table 8 summarizes the latitude and updated mean DRL-effect per country for all previous countries with data on DRL-effectiveness, now also including the additional results after 1988 for Canada and Norway as well as the added countries with recently obtained data on DRL-effectiveness.

Country	DRL-effect until '93	Effective Latitude	Number of Studies	Regr. Weight	Note 1)
Finland	46%	65	1	2.2	
Norway	35%	62	2	4.6	2)
Sweden	32%	60	1	3.0	
Denmark	28%	56	1	2.5	3)
Canada	20%	51	2	1.4	
Austria	8%	40	3	1.7	
USA	12%	39	4	2.4	
Israel	6%	33	2	1.4	

Table 8. DRL-effects up to 1993 and Latitudes per Country.

Notes: 1) In the curve analysis the data are again weighted roughly by the square root of the number of accidents in the total of the studies per country.
2) DRL-effect of Table 3 is reduced by the effect in Elvik (1992).
3) DRL-effect of Table 3 is reduced by the effect in Sparks et al. (1991)

We use the data of Table 8 for an updated estimate of the curvilinear relation between latitude and DRL-effect. As can be seen from the comparison of Table 8 with Table 3 the new evidence after 1988 has lowered the previous obtained DRL-effectiveness for Norway and Canada. The mean DRL-effects for the added countries are overestimated somewhat by the predictions from Figure 1, while the data for the USA, Sweden and Finland remain unchanged. The updated curve, therefore, will be somewhat lowered to the equator and a bit more curved than the previous curve.

In Figure 2 we plot the mean DRL-effect per country and the updated curvilinear relation based on the best fit by the optimal model with updated parameters for the results of Table 8. The analytic results are given in the footnote *).

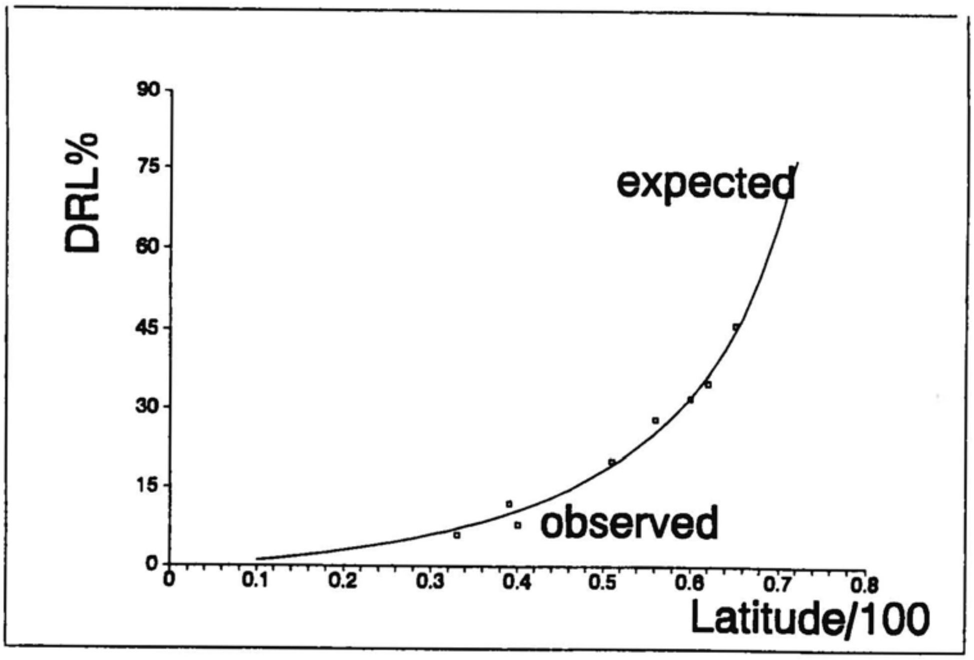

Figure 2. The updated Relation between DRL-effect and Latitude.

The updated curve presents a somewhat more curved relation which at lower and middle-range latitudes yields lower DRL-effects than the previous curve. The comparison of the previous and updated curve show that the new curve has a significantly lower multiplicative parameter and an insignificantly higher power parameter. The power of 1.525, which significantly higher than unity, probably means that also other less optimal visibility conditions on northern latitudes, due to the worsening weather conditions, play a role. The standard deviation of proportional error variance in the mid-range of the optimal curve in Figure 2 is still about a 35% of the curve value (15.5% for deviations around the

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*) The analysis with the optimal model (Model III with a=0) for Table 8 yields:
Parameter b = 13.852 with s.d.(b) = 1.056
Parameter c = 1.525 with s.d.(c) = 0.253
Variance of logarith error (log DRL %) = 0.02063
Standard deviation of error (DRL %) = 1.98%
Standard deviation of error percentage = 15.45%

curve and 6.5% for the distribution of curve uncertainty, where the latter increases to about 13.5% for higher and lower latitudes at 70° and 20°. It means that observed mean DRL-effects in the mid range of curve can vary in one out of twenty cases within a range (above and below the curve) of 43% of the curve value. For example for the Netherlands on a latitude of about 53 degrees the expected DRL-effect is a reduction of 21% for multiple daytime accidents of motorized vehicles, while on a 97.5% chance level the expected DRL-result will be more than a 12% reduction.

We conclude that predicted DRL-effects for countries with better daylight conditions on a more southern latitudes compared to the Scandinavian countries is now quite well established by the revised and updated curve for the curvilinear relation between DRL-effectiveness and latitude. Other questions of the validity of the predicted DRL-effect for other types of accidents and for countries with a relative greater part of built-up and denser populated areas than the Scandinavian countries or with larger proportions of cyclists in traffic are discussed in the sequel.

DRL-EFFECTS FOR SPECIFIC ACCIDENT TYPES

A large effect on the reduction of accidents between cyclists or pedestrians and cars was already observed in the previous Scandinavian evaluations. The adjusted total DRL-effectiveness is in the Norwegian study of Vaaje (1986) for pedestrians of 47%, in the Swedish study for cyclists of 38.5% and for pedestrians of 32.5% and in the Finnish study for pedestrians 32%. A greater effect than for multiple car accidents was explained in Koornstra (1989) by the fact that cyclists and pedestrians can nearly always avoid a collision even on short distances, once the danger of an approaching car is perceived. This would put a greater burden for the accident avoidance on the shoulders of pedestrians and cyclists and, therefore, Dutch and Danish cyclist and pedestrian organisations have objected a DRL-obligation. The recent Danish evaluation reports on the basis of day-time accident time-series that no DRL-effect for pedestrians and only a minor positive DRL-effect for cyclist is observed. However the Danish report show also that car-cyclist accidents in darkness increased by 21%, while the day-time/night ratio of single car accidents increased by a factor of 1.25. Therefore, the methodology described on page 4 and used in most other studies would say that the otherwise (without DRL) expected number of cyclist and pedestrian daytime accidents in Denmark would have increased markedly. That usual estimation method for expected DRL-effects for the Danish cyclist and pedestrian accidents yields 35% and 22% reduction and their adjusted total DRL-effects would become 41% and 27%. In contrast, the later Norwegian study on the effect of DRL-increase by additional DRL-obligations after 1984 (Elvik, 1992) did not found by the same methodology a DRL-effect for pedestrian, which Elvik attributes to an unrelated simultaneous decline over many years of night pedestrian accidents. A negative DRL-result can be found in the report of Hocherman and Hakkert (1991) in their evaluation of the Israelian DRL-winter-campaign. There the day-time/night ratio of pedestrian accidents increased by 23% and 36.5% with respect to the first and second year before, while these multiple car accident-ratio's increased by 18.5% and 8.5%. Although here the traffic increase in day-time might have been larger than at night, while also no amount of increased DRL-use is known, the result may be seen as an indication for an adverse DRL-effect on pedestrians.

In the light of the recent Israelian and Norwegian evidence we have to revise our previously stated (Koornstra, 1989) optimistic view of larger effects for pedestrians and cyclist accidents than for multiple car accidents. Nonetheless, the old evidence and the recent Danish result still justifies a marked positive DRL-effect for pedestrians and surely so to a larger extend for cyclist. In view of the earlier discussed sufficiency assumption, under which a more timely DRL-evoked accident avoidance-behaviour of only one road user is sufficient for the prevention of accidents, and the joint old and new evidence we do not expect very much reduced effects for cyclists and pedestrians compared to multiple car accidents. Since accidents with pedestrians and cyclists are concentrated in built-up areas, one might expect somewhat overall reduced effects of DRL on urban roads compared to rural roads. This seems to be the case since the DRL-effect for multiple car accidents on urban roads in the Swedish study tends to be less than on rural roads. This can also be explained by the shorter sight distances in built-up areas (also DRL can not be seen around the corner). Based on the plausible and empirically indicated effects for multiple car accidents and for cars in collision with pedestrians or cyclists on urban roads, it is expected that the total effectiveness of DRL will be somewhat larger for rural than urban roads.

Another often raised question is whether rear-end accidents are influenced negatively by DRL, since the simultaneously switched on rear lights may mask the breaking lights and DRL as front lights seem to be rather irrelevant for this type of accident. The literature of all the studies reviewed here show contradicting empirical evidence. Stein (1985) and Elvik (1991) present data with marked increases of about 20% more rear-end accidents, but the latter result may be due to the changed registering rules and insurance practices in Norway. Cantelli (1970) reports a decrease in rear-end accidents of 45%. Four other studies contain separate data for rear-end effects of DRL. Three report small rear-end accident reductions (Anderson & Nilsson, 1981; Sparks te al., 1989; Hansen, 1993) and one a small increase of rear-end accidents (Anderson et al. 1976). The mean effect of the studies with rear-end results is about zero and that is what we are inclined to conclude from the joint evidence, despite the theoretical possibility of a masking effect on break lights by the switched on rear light for DRL. A third high-mounted break light could compensate for that theoretical possibility.

The DRL-effect for multiple accidents of motorized vehicles is mainly to attribute to the reduction of front to side accidents, the only type responsible for the Danish DRL-effect (Hansen, 1993), and head-on accidents, as can also be expected from perception theory. Therefore, it seems more appropriate to investigate a DRL-effect by an extra distinction in DRL-relevant and DRL-non-relevant day-time accidents. This would also reduce the problems and weakness of the design based on night/daytime and single/multiple distinctions. Moreover, a log-linear analysis model which can account for time-series trends of non-DRL relevant accidents is recommended as a more sound analysis for the test of effects in quasi-experimental designs with a rather long before period and not too short after period. Here it is not the aim to discuss the methodological issues, but such better designs and analysis techniques for the field evaluations of DRL-effects would have made this article with a secondary analysis of the available data redundant. Apparently it is not at the moment.

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