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AN ASSESSMENT OF SEASONAL AND WEATHER EFFECTS ON THE FREQUENCY OF ROAD ACCIDENTS IN CALIFORNIA

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Abstract—The day-to-day variations in the numbers of accidents on the State Highways of California in 1970 have been studied with reference to the time of year and the weather type. The weather was found to be a major factor affecting accident numbers. The mean number per day was 353 and the overall variance 11158. The variance was reduced by over 70% when 23 wet days, Christmas Eve and Christmas Day were excluded. On very wet days the number of accidents was often double that of corresponding dry days. Single-vehicle accidents were affected more by wet weather than were most other types of accident studied.

INTRODUCTION

Road accident data for the California State Highways in 1970 have been used to study variations in accident frequency. In particular, the daily accident totals have been inspected in order to assess the extent to which the number of accidents depends on the weather and the time of year.

Little work has been done in the past on the analysis of day-to-day variations of accident numbers. The Road Research Laboratory [1960] made a study of fatal accidents in Britain at Christmas 1959, concluding that the large number of accidents then was to a great extent accounted for by a combination of bad weather and the influence of alcohol on road users. There were similar findings after later studies on the same lines [R.R.L., 1964 and 1965]. All these investigations used traffic data to determine relative accident rates, as did Tanner [1971] in a study of casualty rates at the Easter, Whitsun and August public holidays in the years 1956–65. In that report the author concluded that the unusually high number of casualties at these holiday weekends could largely be accounted for by the high volume of traffic at the time.

It is well known that weather plays a large part in the determination of accident numbers, as a result of both slippery roads and bad visibility. Codling [1974] has summarised the results of research at the Transport and Road Research Laboratory in Britain on this subject. Orne and Yang [1972] have analysed accident, traffic flow and weather data for Ingham County, Michigan and concluded that the accident rate (per million vehicle miles) was sensitive to temperature, precipitation and barometric pressure, but seasonal variation was not found to be important. Roer [1974], in a study using factor analysis to detect relationships between traffic accidents and various weather and gravitation variables, found that the frequency of accidents was affected by falling atmospheric pressure. Campbell [1971] has assessed the extent of the wet pavement accident problem in the United States.

Preliminary inspection of accident data for Great Britain and for the California State Highways indicated that it was much easier to account for the day-to-day variation in the number of accidents on the California State Highways by reference to weather differences; for Great Britain there were large fluctuations which could not be explained in this way. Therefore the California data were used for this study.

DATA

The data, which were on magnetic tapes obtained from the California Division of Highways, contained details of motor vehicle accidents on the California State Highways in 1970. The State Highway System, although comprising only about 9% of the total road mileage, carried about half the vehicle mileage of California. Over 120,000 accidents were detailed, including nearly 2,000 fatal accidents and over 40,000 other injury accidents; the remainder, about two-thirds of the total, were damage-only accidents. These accident data represented about half the fatal accidents, a quarter of the reported injury accidents and a smaller proportion of the non-injury

Table 1. California 1970—Motor vehicle accidents by month (all roads)

Month	Fatal Accidents	All Injury Accidents
January	331	13492
February	290	12522
March	352	13470
April	318	12580
May	374	13801
June	366	13669
July	387	13668
August	377	13686
September	390	13402
October	378	13741
November	362	14053
December	352	14584
Total	4277	162668

accidents in the State of California. Table 1, taken from Table J-15 of the California Statistical Abstract [1971], shows the statewide injury accident totals, month by month.

PRELIMINARY ANALYSIS

Figures 1 and 2 show the means and variances of daily accident numbers according to day of week.

The basic features of the distributions of daily accident totals are summarised in Table 2. For each extreme day any adverse weather which was prevalent is noted.

For each day of the week the maxima are listed in descending order. The starred days indicate points which must be regarded as outliers of the observed distribution; the unstarred maxima and minima are the most extreme non-outlying points. The following comments can be made concerning Table 2:

(i) Other than Christmas Day, no days had exceptionally low accident totals.

(ii) It can be seen that the peak accident totals tended to occur on wet days, some of the totals being very extreme.

(iii) After the exclusion of these exceptional (starred) days, the highest numbers of accidents usually occurred on fine summer days, when flow was no doubt high, and on wet winter days.

(iv) Days with the smallest number of accidents were often cloudy but dry, when presumably the weather was bad enough to deter travellers (i.e. decrease vehicle mileage) but not sufficiently

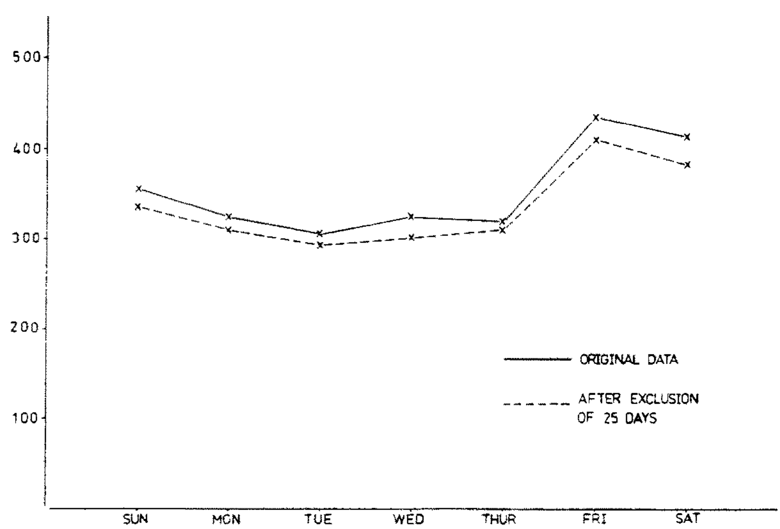

Fig. 1. California State Highways 1970—Mean accidents by day of week.

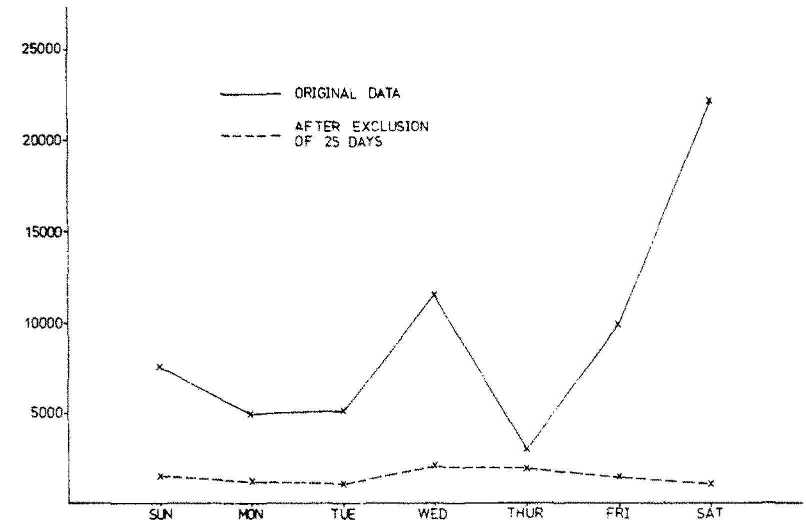

Fig. 2. California State Highways 1970—Variance of accidents by day of week.

Table 2. California State Highways 1970—Distribution of daily accident totals

	All days	Sunday	Monday	Tuesday
Mean number of accidents	353	354	324	304
Variance of number of accidents	11158	7565	4880	5069
Maxima	-	756* (29 Nov.-Rain)	652* (21 Dec.-Rain)	725* (10 Feb.-Rain)
		682* (1 March-Rain and Snow)	533* (8 June -Rain)	444* (24 Feb.-Rain and Fog)
		502* (20 Dec.-Rain and Snow)	495* (9 Feb. -Rain)	373 (30 June-Fine)
		438* (11 Jan.-Rain)	390 (30 Nov.-Rain)	
		411 (2 Aug. -Fine)		
Minima	-	230 (4 Jan.-Fine)	230 (12 Oct.-Rather Cloudy)	224 (26 May-Rather Cloudy)
Number of starred days	25	4	3	2
Mean) After) excluding	333	334	309	293
Variance) starred days	3030	1468	1199	1135

	Wednesday	Thursday	Friday	Saturday
Mean number of accidents	325	319	434	413
Variance of number of accidents	11426	2986	9847	22042
Maxima	879* (25 Nov.-Rain)	516* (Christmas Eve - Fine)	759* (9 Jan. -Rain)	1269* (28 Feb.-Rain)
	660* (4 March-Rain)	453* (26 Nov.-Rain)	732* (16 Jan.-Rain)	902* (28 Nov.-Rain)
	479* (16 Dec.-Rain	412 (17 Dec.-Rain)	731* (18 Dec.-Rain)	642* (19 Dec.-Rain)
	467* (14 Jan.-Rain)		681* (6 Nov. -Rain)	447 (16 May -Fine)
	439 (2 Dec. -Rain)		552* (23 Oct.-Rain)	
			542* (13 Feb.-Rain)	
			467 (4 Sept.-Fine)	
Minima	233 (11 March - Rather Cloudy)	236 (12 March - Rather Cloudy)	224* (Christmas Day-Rather Cloudy)	307 (12 Sept.-Rather Cloudy)
			318 (2 Jan.-Fine)	
Number of starred days	4	2	7	3
Mean) After) excluding	301	312	408	381
Variance) starred days	1953	1922	1329	1063

bad to increase the accident rate per vehicle mile. It should be noted that the driver's task would be easier on such days than on sunny days owing to less dazzle.

ANALYSIS OF SEASONAL AND WEATHER EFFECTS

Figures 3–9 present in a simple graphical form the basic data of daily accident totals, for each day of the week separately. The horizontal axis measures the week of the year, each point

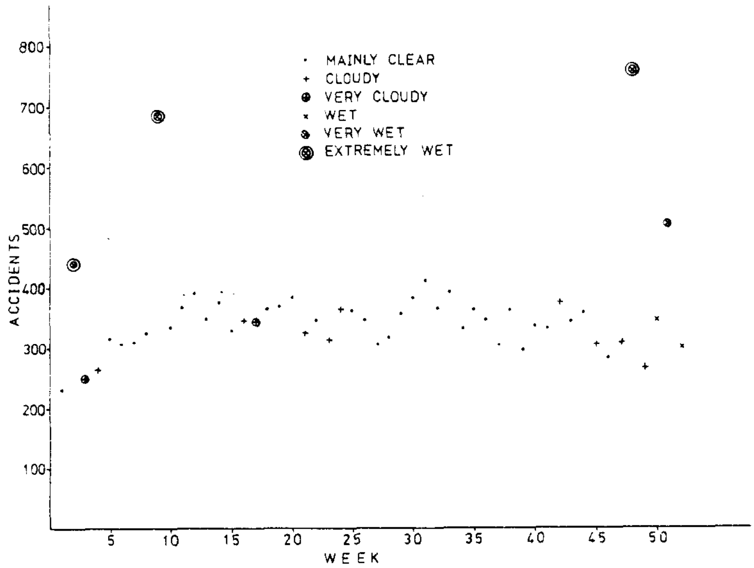

Fig. 3. California State Highways 1970—Accidents on Sundays.

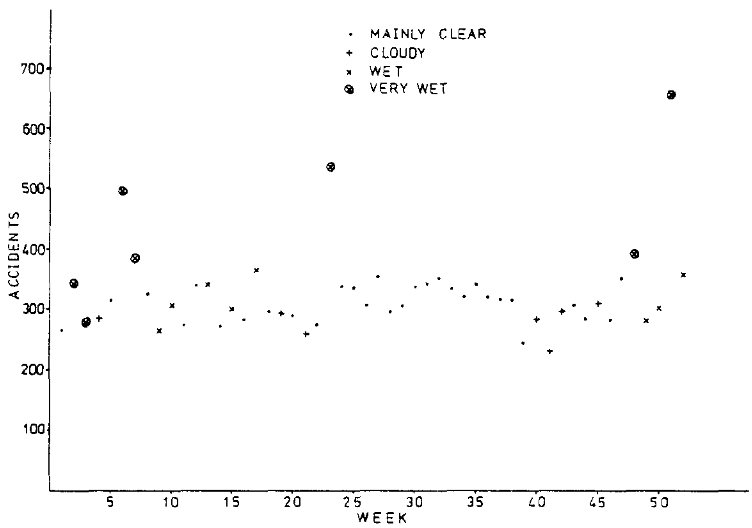

Fig. 4. California State Highways 1970—Accidents on Mondays.

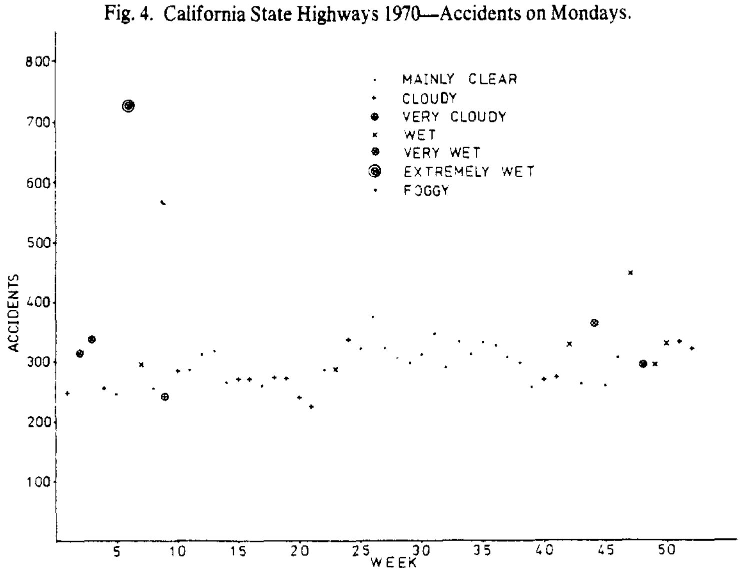

Fig. 5. California State Highways 1970—Accidents on Tuesdays.

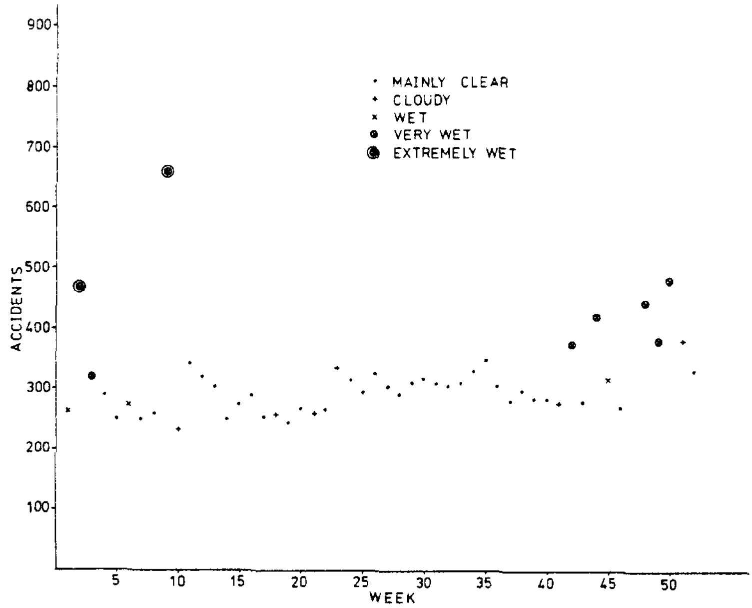

Fig. 6. California State Highways 1970—Accidents on Wednesdays.

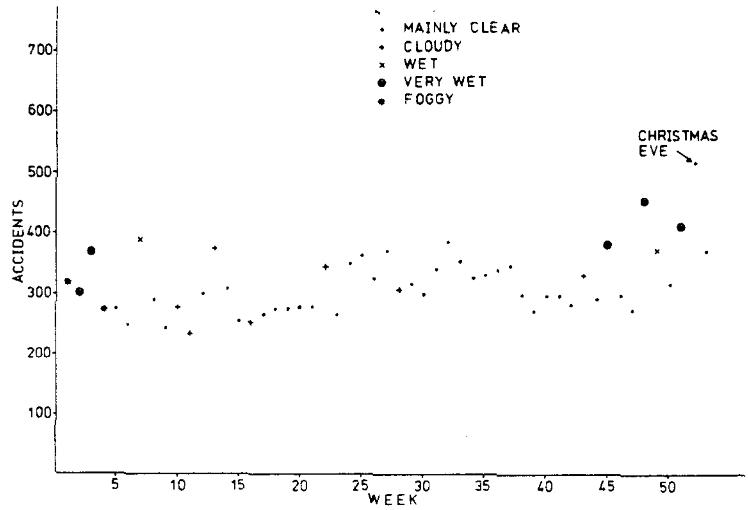

Fig. 7. California State Highways 1970—Accidents on Thursdays.

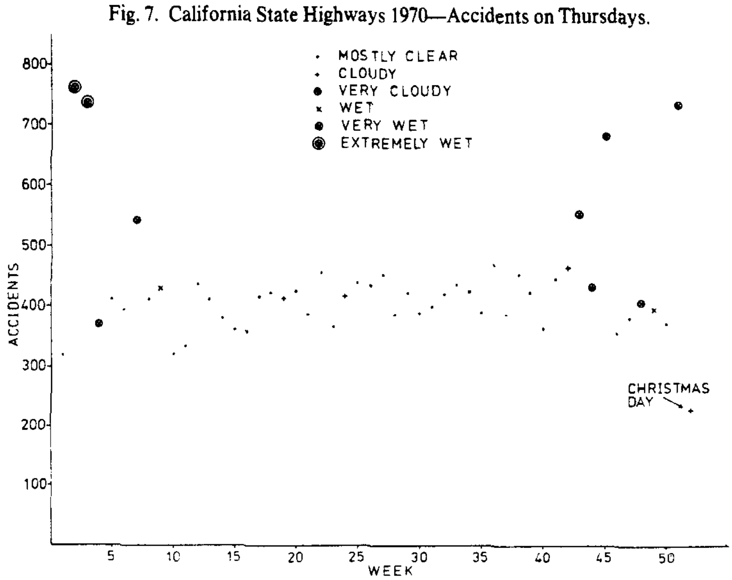

Fig. 8. California State Highways 1970—Accidents on Fridays.

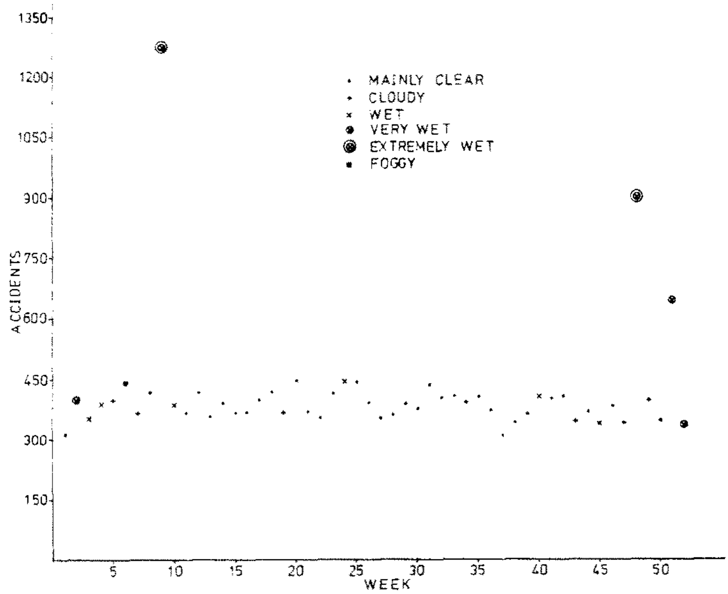

Fig. 9. California State Highways 1970—Accidents on Saturdays.

corresponding to a particular day, so that on each graph there are 52 or 53 points. In the absence of independent weather data, each day was classified according to the distribution of weather types at accident sites on that day. The types of weather specified at sites were "clear", "cloudy", "raining", "snowing", "fog", "wind", "dust", and "smoke", but the last three were coded for a negligible proportion of accidents, while there were few accidents in snow. The classification of days into the weather categories shown in the figures was made on the basis of the proportion of each day's accidents which took place in each type of weather. The details of the classification are given in Appendix 1.

General remarks on the graphs

For each day of the week it is noticeable that, if one disregards a small number of points, mostly corresponding to very wet days, the remaining points lie close to a smooth curve which represents the underlying seasonal variation of accident frequency in the absence of adverse weather.

For Sundays, having excluded the four very wet days, the pattern is particularly simple, with a strong upward trend at the beginning of the year, a strong downward trend towards the end of the year and no trend discernible in the summer months.

For days between Monday and Friday, the pattern is more interesting. Again disregarding those days with bad weather, the most remarkable feature is a conspicuous plateau stretching approximately from mid-June to mid-September, corresponding roughly to the summer holiday period. This feature is not apparent for Fridays, but for the other days its extent varies little between the four graphs. The other main feature of the graphs is an underlying upward trend on Thursdays and Fridays.

The figure for Saturdays shows three extreme days when there was widespread rain; otherwise the graph is featureless with surprisingly little seasonal variation.

EXCLUSION OF EXTREME DAYS

As noted above, it is possible to select a small number of days such that, if they are excluded from the data, the variability is much reduced. To illustrate this mathematically, a set of 25 outlying points was picked out after inspection of Figs. 3–9, so that the remaining points all lay reasonably close to smooth curves. This procedure was a subjective one and unsatisfactory for that reason; however, the selection of points was in most cases a matter of no difficulty, and it should be noted that the more objective procedure of selecting all days defined as "very wet" or "extremely wet", would have picked out all but three of the subjectively chosen set, two of the exceptions being Christmas Eve and Christmas Day. But many of the points selected by the objective method show no great departure from the underlying curves—in other words, in spite of the adverse weather on those days, there was no apparent increase in accident numbers. In view of the fact that the weather details coded in the accident data do not provide a full description, the subjective procedure was adopted for selecting days when exceptional weather conditions had a strong bearing on the accident numbers.

The days selected by the subjective method are shown in Table 2 by asterisks. On exclusion of these 25 days, the means and variances of the remaining daily accident totals are listed in Table 2 (last two rows). See Appendix 2 for consideration of how much a single outlying data point can inflate the variance.

These results are illustrated in Figs. 1 and 2. Although exclusion of the 25 points has achieved a substantial reduction of variance, for each day of the week, this is still much greater than the simple Poisson model would indicate (in that case, the mean and variance are equal). There are several reasons why this should be so, including the following:

(i) No attempt has been made to allow for seasonal factors.

(ii) The weather data used do not give a full description of the prevailing conditions.

(iii) There are many other factors (such as holidays) influencing traffic patterns and perhaps accident levels, and no account has been taken of such factors.

SOME NUMERICAL ESTIMATES OF WEATHER EFFECTS

It may be inferred from Figs. 3–9 that the effect of extreme weather is much greater than purely seasonal factors. It is therefore meaningful to aggregate days with similar weather at all times of year and compare mean accident numbers between weather classes. One must express reservations here, for all adverse weather types are more common in winter, and some inaccuracy will result, for example, from comparing wet days, predominantly in winter, with fine days, which occur mainly during the summer.

For each day of the week separately, taking the numbers of accidents on all mainly clear days, the coefficient of variation was calculated (standard deviation/mean), and, for each other class of day, the ratio (mean accidents per day on days in this weather class/mean accidents per day on mainly clear days) was found. The results are shown in Table 3, the figures in parentheses indicating the number of days in each particular weather class.

Table 3. Estimates of effects of different bad weather types on accidents for each day of the week

	Mainly Clear Days		Ratios for Bad Weather Types					
	Mean	C.V.	Wet	Very Wet	Ext. Wet	Cloudy	V.Cloudy	Foggy
Sunday	341.71 (35)	0.104	0.93 (2)	1.47 (1)	1.83 (3)	0.93 (9)	0.86 (2)	- (0)
Monday	309.80 (30)	0.093	1.01 (8)	1.42 (7)	- (0)	0.90 (7)	- (0)	- (0)
Tuesday	297.46 (26)	0.107	1.10 (6)	1.09 (4)	2.44 (1)	0.93 (13)	0.82 (1)	0.87 (1)
Wednesday	292.03 (34)	0.096	0.96 (3)	1.37 (6)	2.29 (3)	0.99 (6)	- (0)	- (0)
Thursday	310.51 (37)	0.163	1.23 (2)	1.24 (5)	- (0)	0.98 (7)	- (0)	0.96 (2)
Friday	393.05 (37)	0.182	1.11 (2)	1.41 (6)	1.90 (2)	0.96 (4)	1.09 (1)	- (0)
Saturday	382.50 (34)	0.085	1.00 (6)	1.20 (3)	2.84 (2)	0.79 (6)	- (0)	1.16 (1)
All days	336.28 (233)	0.162	1.01 (29)	1.29 (32)	2.23 (11)	0.91 (52)	0.94 (4)	0.96 (4)

It was not thought worthwhile to perform any statistical tests on the calculated ratios, for the reasons indicated above, namely that adverse weather types are not uniformly distributed through the year. However, the results are interesting, and it may be concluded that the weather effects are broadly similar on all days of the week. It seems likely, as mentioned above, that cloudy weather has a favourable effect on accident occurrence, while on days when there was widespread rain ("extremely wet"), the total number of accidents generally increased by a factor of the order of 2. It was not possible to conclude anything from the very few days with fog.

DIFFERENT TYPES OF ACCIDENT

For this section, the weather classification was coarsened, and the days were divided into two categories: those classed as either "very wet" or "extremely wet" in the previous classification, and all other days. The aim was to find some indication of which accident types were most affected by very wet weather, and, for this purpose, accidents were split into five types:

(a) Pedestrian accidents;
(b) Single-vehicle (non-pedestrian) accidents;
(c) Head-on collisions;
(d) Rear-end collisions;
(e) Other collisions.

The ratios (mean accidents on very wet days/mean accidents on all other days) were calculated for each day of the week, for each of the accident types (b), (d) and (e) and for all accidents, separately for those hours of the day which are light at all times of the year (0700–1700), those dark at all times of the year (2100–0500) and all other hours. (The reason for splitting the day in this way rather than simply into light and dark is that there are more hours of light in summer than in winter, so a much higher proportion of summer accidents occur in the light than winter accidents. Because wet days occur more frequently in winter, a simple analysis by light and dark would introduce a distortion into the weather estimates.) The results are given in Table 4. The numbers of pedestrian and head-on accidents were comparatively small, respectively 1,320 and 3,513 for the whole year, whereas there were over 30,000 of each of the other three types of accident. Therefore pedestrian and head-on accidents are not included as separate categories in Table 4. It might, however, be mentioned that the ratios for all days and all hours were calculated to be 1·59 (pedestrian accidents) and 1·80 (head-on collisions).

Table 4 confirms that the frequency of accidents of all types tended to be increased in wet weather at all times of day, both during the week and at the weekend. The highest ratios (for all days and all hours) were 1·85 (single-vehicle accidents) and 1·80 (head-on collisions), compared with only 1·34 (rear-end collisions) and 1·41 (other collisions). Thus the categories of accident apparently most affected by rain were just those which often involve skidding and loss of control by the driver; this is not at all surprising.

It is thought that the exceptionally high ratios calculated for the daylight hours on Saturday and Sunday have arisen on account of one or two days with exceptionally severe weather (notably Saturday, 28 February). Even allowing for this, the figures seem to imply that rain affects

Table 4. Estimated wet weather effects on different accident types by day of week and time of day

	Monday	Tuesday	Wednesday	Thursday	Friday	Mon - Fri	Saturday	Sunday	Sat/Sun	All Days
Single-vehicle accidents										
Day (0700-1700)	1.95	1.64	2.09	1.36	2.11	1.91	3.26	3.08	3.18	2.18
Night (2100-0500)	1.34	1.69	1.76	1.63	1.58	1.62	1.67	1.80	1.76	1.58
Other hours	1.64	2.04	2.04	1.18	1.69	1.73	1.72	1.91	1.83	1.71
All hours	1.69	1.75	1.97	1.41	1.82	1.77	2.23	2.27	2.27	1.85
Rear-end collisions										
Day (0700-1700)	1.22	1.00	1.38	1.01	1.28	1.22	1.39	1.47	1.44	1.28
Night (2100-0500)	1.31	1.48	1.77	1.33	1.50	1.53	1.37	1.46	1.44	1.40
Other hours	1.46	1.49	1.76	1.02	1.25	1.44	1.09	1.60	1.38	1.43
All hours	1.29	1.17	1.53	1.05	1.30	1.32	1.31	1.50	1.43	1.34
Other collisions										
Day (0700-1700)	1.27	1.21	1.42	1.13	1.38	1.32	1.82	1.51	1.65	1.40
Night (2100-0500)	1.27	1.01	1.68	1.22	1.42	1.40	1.55	1.49	1.53	1.35
Other hours	1.46	1.55	1.62	1.27	1.48	1.51	1.36	1.35	1.36	1.47
All hours	1.32	1.27	1.50	1.18	1.42	1.38	1.62	1.46	1.55	1.41
All accidents										
Day (0700-1700)	1.44	1.23	1.60	1.16	1.53	1.44	2.14	1.98	2.06	1.57
Night (2100-0500)	1.34	1.47	1.74	1.45	1.50	1.54	1.54	1.62	1.60	1.63
Other hours	1.53	1.69	1.83	1.19	1.45	1.56	1.40	1.65	1.55	1.55
All hours	1.44	1.38	1.68	1.23	1.50	1.49	1.76	1.78	1.79	1.54

single-vehicle accidents most adversely in daylight, whilst collisions, especially rear-end ones, seem to be worse affected at night than in the day. The latter is plausible, as the combination of darkness and rain produces bad visual conditions very likely to result in rear-end accidents, but the explanation of the greater effect on single-vehicle accidents during the day is hard to find.

CONCLUSIONS

The results have illustrated the large effect which wet weather had on accidents on the State Highways of California in 1970. Multiplying factors of 2 and more have been quoted above. It should be emphasised that this is probably an underestimate of the true effect of wet weather, because even those days classified as "extremely wet" were not entirely rainy, and, if it had been possible to study days 100% wet, the accident figures may well have been much higher.

After removing these very wet days, it has been illustrated how little variance remains and how smoothly accident numbers vary with season for each day of the week if a few bad days are excluded. It is easy to pick out an underlying seasonal pattern.

One clear result to emerge is that the accidents affected most by rain are single-vehicle and head-on accidents, while most other types of collisions are affected much less.

The special nature of the California State Highway system precludes generalisation of the results to networks of more traditional roads. Another point to bear in mind is the predominantly fine and dry climate, not typical of the United States in general and unlike that of European countries. It is illuminating that in such an environment the weather is a most important factor in determining road accident numbers.

Acknowledgement—I am very grateful to the Division of Highways in the State of California for the use of their accident data.

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APPENDIX 1

Weather criteria for classification of days

Suppose that on a particular day there were N accidents, of which N_i were in a weather category i. Let $p_i = N_i/N$ for each i. Thus p_i is the proportion of the day's accidents which occurred in weather category i. For most of the weather types specified in the data, $p_i < 0{\cdot}1$ for all days. The exceptions were clear weather, cloudy weather, rain and fog ($i = 1, 2, 3, 4$ respectively).

The classification of days into weather types was done as follows:

(1) If $p_4 \geq 0{\cdot}1$, the day was classified as "foggy". (In fact $p_4 < 0{\cdot}3$ for all days of 1970.)

(2) If $p_4 < 0{\cdot}1$ but $p_3 \geq 0{\cdot}1$, the day was classified as "wet", "very wet" or "extremely wet" according to whether p_3 lay in the intervals $[0{\cdot}1, 0{\cdot}3)$, $[0{\cdot}3, 0{\cdot}6)$ or $[0{\cdot}6, 1{\cdot}0]$.

(3) If both $p_4 < 0{\cdot}1$ and $p_3 < 0{\cdot}1$ but $p_2 \geq 0{\cdot}1$, the day was classified as "cloudy" or "very cloudy" according to whether p_2 lay in the intervals $[0{\cdot}1, 0{\cdot}3)$ or $[0{\cdot}3, 0{\cdot}6)$. (In fact $p_2 < 0{\cdot}6$ for all the days of 1970.)

(4) Otherwise the day was classified as "mainly clear".

The simplicity of this classification owed much to the fact that there were no days when more than one type of adverse weather was widespread: in particular, on all the "foggy" days ($p_4 \geq 0{\cdot}1$), there was little rain ($p_3 < 0{\cdot}1$).

APPENDIX 2

The effect of an outlying point on a sample variance

For simplicity, suppose there is just one outlying point $Y_0 = y$, and that the remaining observations Y_i $(i = 1, \ldots n)$ are independent random variables following a Poisson distribution of mean μ. $Y_0 = y$ is assumed fixed. Denote the sample mean and sample variance of $Y_0, \ldots Y_n$ by m, s^2, and the sample mean and sample variance of $Y_1, \ldots Y_n$ by m_0, s_0^2 (i.e. omitting the outlier).

Then

$$Em_0 = Es_0^2 = \mu.$$

Also

$$m = \frac{1}{(n+1)}\left\{\sum_{i=1}^{n} Y_i + y\right\},$$

so that

$$Em = \mu + \frac{y-\mu}{(n+1)}$$

Now

$$\begin{aligned} s^2 &= \frac{1}{n}\sum_{i=0}^{n}\{y_i - m\}^2 \\ &= \frac{1}{n}\left\{y^2 + \sum_{i=1}^{n} Y_i^2 - nm^2 - m^2\right\} \\ &= \frac{n-1}{n} s_0^2 + \frac{1}{n}(y^2 + m^2) + (m_0^2 - m^2) \end{aligned}$$

Thus

$$Es^2 = \frac{n-1}{n}\mu + \frac{1}{n}y^2 + Em_0^2 - \frac{(n+1)}{n}Em^2$$

It is easily shown that

$$Em_0^2 = \frac{\mu}{n} + \mu^2$$

and

$$Em^2 = \frac{1}{(n+1)^2}\{n\mu + (y + n\mu)^2\}$$

Hence

$$Es^2 = \frac{1}{(n+1)}\{n\mu + (y-\mu)^2\}$$

For example, if there are 50 observations drawn from a Poisson distribution of mean 300, and one outlier $y = 600$, then

$$\begin{aligned} Es^2 &= \frac{1}{51}\{50 \times 300 + (600 - 300)^2\} \\ &\simeq 300 + 6 \times 300 = 2100 \\ Es_0^2 &= 300 \end{aligned}$$

Thus in this simple case the existence of just one outlier is sufficient to multiply the expected value of the sample variance by nearly 7.