Effect of Pavement and Shoulder Condition on Highway Accidents

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The effect of pavement surface condition on traffic accidents was investigated as part of an Israeli Public Works Department survey of the feasibility of investing in the maintenance of the interurban road network in Israel. An analysis of this problem for the whole network attempted to correlate the state of the pavement surface with conditions of safety. The results of the investigation did not indicate any unilateral correlation between these two parameters. In contrast, similar tests that concentrated on specific road sections indicated that an increase in pavement surface grading might improve or worsen traffic safety, depending on the geometric and traffic characteristics of the section under investigation. Additional tests conducted in the context of this survey concerned the state of the pavement shoulders and the slipperiness of the pavement. According to the Israeli data, it is possible to decrease the total number of accidents (nonintersection accidents) on the interurban road network by approximately 7.5 percent if the skid coefficient of the pavement surface, as measured by the Mu-Meter, is greater than 37. Similarly, it is possible to diminish the number of such accidents by about 8 percent if the shoulder's surface is in good condition and the width of the shoulders is no less than 2 m. The findings of this investigation indicate that black spots or black section analyses are required rather than an analysis of the whole network to determine the pavement and shoulder condition on highway accidents. An application of the black spots or black sections concept facilitates the achievement of an optimal level of economic feasibility. Thus, for example, antiskid treatments provided at those sections where there is a high rate of accidents of this type, or treatment of the pavement shoulders and their widening at those sections where there is a high rate of accidents caused by a state of disrepair, can lead to high benefit-cost values.

One of the issues investigated as part of an Israeli Public Works Department survey (*1*) of the feasibility of investing in the maintenance of interurban roads was the influence of the state of the pavement surface and shoulders on the rate of accidents. Obviously, any decrease in the rate of accidents constitutes part of the benefits obtained by investing in routine or major maintenance of the road network.

Naturally, the existence of such a correlation between the state of the pavement surface and traffic safety seems reasonable. Improving the pavement surface condition by overlaying its surface is conducive to a decrease in the number of accidents. As reported by TRB (*2*), an overlay on two-lane roads leads to a decrease of 12 percent in the number of accidents, most of them being wet accidents. Additionally, some American sources, cited by Hakkert (*3*), report that resurfacing reduces wet accidents by 12 to 33 percent. According to one source (*4*), the cost of accidents increases by 10 percent for pavements in a deteriorated condition. Haas and Hudson (*5*) state that the cost of accidents varies according to the type of road and the state of the pavement. For example, for two-lane roads the cost difference in accidents between a good pavement with a present serviceability index (PSI) equal to 4 and a bad pavement with a PSI equal to 2.5 is 13 percent. In the last two references (*4,5*), no emphasis is given to accidents on wet pavements. In contrast to these sources, others point out that a decrease in the number of accidents on dry pavement as a result of an improvement in the pavement state is balanced by accidents caused as a consequence of increased speeds. For example, TRB (*6*) states that overlaying activity increases the initial accident rate on a dry road by 10 percent and decreases the initial rate of accidents on wet roads by 15 percent. Thus, summation of these two rates eventually cancels out the effect of overlaying on the change in the total rate of accidents, when the total initial increase is about 5 percent.

As a result of these findings, an investigation was conducted to attempt to determine whether there is a decrease in the number of dry-road accidents in the interurban road network in Israel as a result of improved pavement surfaces and to present specific examples of the possible rate of change in such accidents for some specific cases. Furthermore, the investigation was required to estimate the extent of the decrease in wet-road accidents after proper antiskid overlaying and to estimate the rate of the decrease in road-shoulder accidents after improvement.

Itemization of the issues connected with these tasks is presented in the following sections.

GENERAL CASE

To examine the influence of pavement state on the incidence of accidents, the Israeli roads network was classified into five pavement state groups according to the Washington State Department of Transportation criteria (*7*), as presented in Table 1. A rating of 100 in this table signifies a pavement in excellent state (pavement immediately after paving or over-

TABLE 1 CLASSIFICATION OF ROADS NETWORK ACCORDING TO PAVEMENT SURFACE CONDITION

Group No.	Range of Pavement Rating (PR) Values
1	90-100
2	70-90
3	50-70
4	30-50
5	0-30

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laying), whereas a rating of 0 signifies the worst state of pavement surface (a totally deteriorated pavement).

The average accident rate per vehicle-kilometer was computed for each group (1983 data). These data are shown in Figure 1. No visible influence of the pavement state on the rate of accidents is indicated.

Additionally, the Kruskal-Wallis H test has been used to test whether the accident rates of the five groups are from the same populations. In this test the H value is calculated according to the following equation:

$$H = \frac{12}{N(N + 1)} \left(\sum_{i=1}^{5} \frac{R_i^2}{N_i} \right) - 3(N + 1) \quad (1)$$

where

N = number in all groups combined,
N_i = number in i groups, and
R_i = sum of ranks in the ith group.

To rank the accident rates shown in Figure 1, these rates should be normalized for an average traffic volume (AADT). This procedure is done using the following regression lines (shown in Figure 1):

Single Carriageway

$$A = 0.454 - (0.016/1{,}000) \times \text{AADT}$$
$$R^2 = 0.233$$
$$N = 20 \quad (2)$$

Dual Carriageway

$$A = 0.128 - (0.001/1{,}000) \times \text{AADT}$$
$$R^2 = 0.154$$
$$N = 10 \quad (3)$$

Single and Dual Carriageway

$$A = 0.404 - (0.010/1{,}000) \times \text{AADT}$$
$$R^2 = 0.438$$
$$N = 30 \quad (4)$$

The normalized values obtained by the three regression lines (mean and standard deviation only) are presented in Table 2.

For the detailed normalized values of the single-carriage way accident rates, $H = 5.257$. This value of H is interpreted as chi-square with the number of samples minus 1 degree of freedom. For the given problem $d_f = 4$ and the tabulated value of chi-square, is 9.488 when $\alpha = 0.05$. Because $9.488 > 5.257$, H is not significant; that is, all the values of accident rates for the five groups of single carriageway are from the same population. For the dual-carriageway roads, a similar calculation indicates that the calculated value of H is 3.055, which is not significant ($9.488 > 3.055$). The same conclusion applies to both single- and dual-carriageway roads for which the calculated value of H is 2.70 ($9.488 > 2.70$).

The conclusion that pavement state does not influence the rate of accidents is only applicable in the general case of the whole network. However, it cannot be established that the improvement in pavement state does not decrease (or even increase) the rate of accidents in specific cases. This issue is discussed in the following section. The data in Figure 1 also indicate that, for a certain intermediate range of AADT (between 10,000 and 20,000 AADT), single-carriageway roads do not necessarily have higher accident rates than dual-carriageway roads, as indicated by the scatter of points in that region.

Similar conclusions were reached in Israel by other investigators (*8*). Figure 2 shows accident rates on single carriageways with high volumes (more than 10,000 AADT). Although

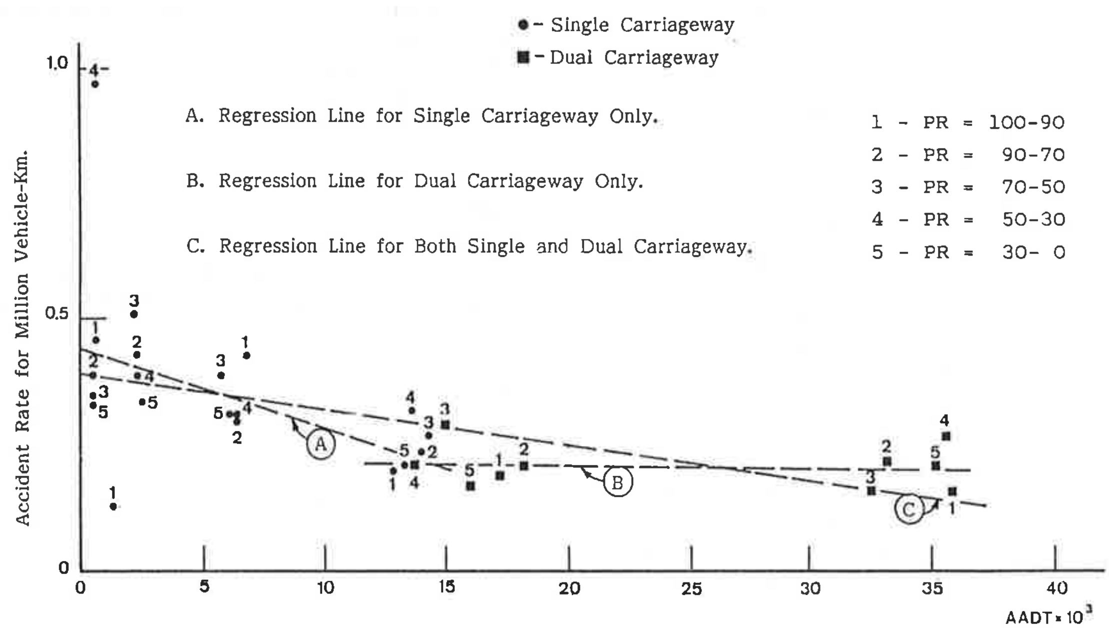


FIGURE 1 Relationship between yearly accident rates per million vehicle-kilometers and AADT values as a function of the pavement surface state (*1*).

TABLE 2 NORMALIZED ACCIDENT RATES PER 10^6 vehicle-km FOR THE FIVE GROUPS OF PAVEMENTS

Range of PR	Single Carriageway corrected for mean AADT of 5685		Dual Carriageway corrected for mean AADT of 24660		Single & Dual Way corrected for mean AADT of 12010	
	Mean	st. dev.	Mean	st. dev.	Mean	st. dev.
90-100	0.302	0.160	0.090	0.001	0.237	0.134
70- 90	0.304	0.099	0.108	0.011	0.266	0.060
50- 70	0.382	0.078	0.112	0.035	0.289	0.079
30- 50	0.498	0.260	0.118	0.032	0.371	0.246
0- 30	0.295	0.037	0.115	0.004	0.230	0.079

rates are scattered over a wide range, an average value of 0.5 accident per million vehicle-kilometers can be observed. Figure 3 shows values of accident rates on dual-carriageway roads. Rates vary from a high value of 1.0 accident per million vehicle-kilometers to a low value of 0.1 accident per million vehicle-kilometers, according to the specific conditions of the roads. This finding confirms the previous conclusion that dual-carriageway roads do not necessarily have lower accident rates.

SPECIFIC CASES

In contrast to the general investigation presented in the preceding section, this section illustrates a specific investigation for two practical examples. The first site examined is Road 4, located between the 131st and 148th kilometers (Ra'anana intersection to the Hasharon intersection). This site is a four-lane road with a dual carriageway. A 40 percent decrease in the total rate of nonintersection accidents has been reported as a consequence of pavement surface overlaying (see Table 3). Most of the accidents in this section are dry-road accidents. There was a similar rate of decrease (38 percent) in intersection accidents. However, this decrease must be ascribed to the changes in traffic arrangements that resulted in some of the intersections, especially at the Hasharon intersection, rather than to the overlaying work itself.

Similarly, another road section can be examined in which overlaying might increase the rate of accidents as a consequence of improving the riding conditions of a road with low geometric standards. The road examined is the 13.7-km-long Road 806 (Ma'ar-Elaboon). This road is situated in a mountainous region with low geometric standards, and its surface is extremely deteriorated. The rate of accidents on this road from 1982 through 1987 is an average of approximately 0.3 accident per million vehicle-kilometers of travel, with an average traffic volume of 2,000 vehicles per day. This accident rate is low and corresponds to that of a road with high standards. This rate exists in the road section under consideration solely because of bad travel conditions. Any improvement of these conditions through overlaying that is not accompanied by geometric improvements will increase the rate of dry-road accidents. Various authors have presented estimations of the increase in the number of accidents as a consequence of pavement resurfacing without improving the geometry of the road. On the one hand, the improvement in pavement surface invites speeding; on the other hand, a low geometric standard contributes to an increase in the number of accidents under

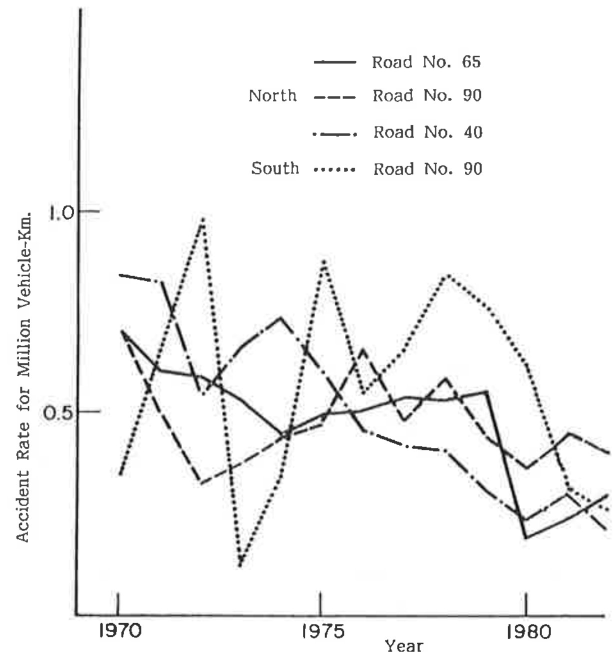


FIGURE 2 Accident rates per million vehicle-kilometers on major interurban roads in Israel (1970–1982): single carriageway (*8*).

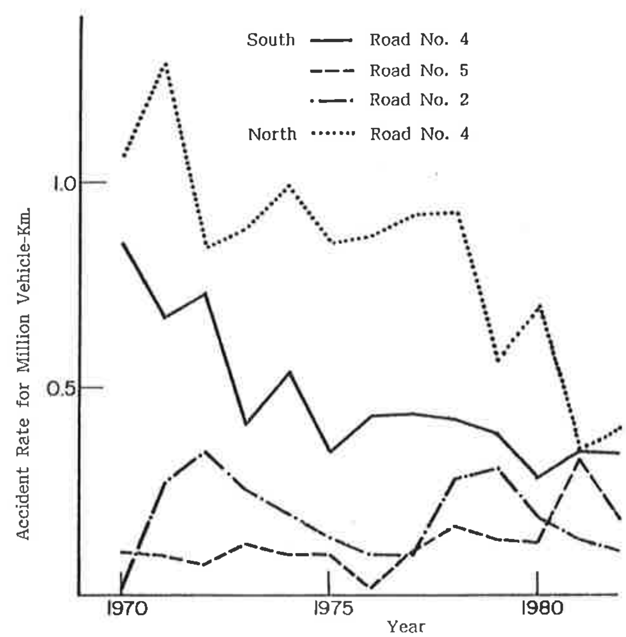


FIGURE 3 Accident rates per million vehicle-kilometers on major interurban roads in Israel (1970–1982): dual carriageway (*8*).

TABLE 3 COMPARISON OF ACCIDENTS BEFORE AND AFTER OVERLAYING ON ROAD 4 BETWEEN THE RA'ANANA AND HASHARON INTERSECTIONS

Place	After overlaying	Before overlaying	
	Year 1986	Year 1983	Year 1982
Raanana intersection North	5	11	5
Basra intersection	1	--	1
Dror intersection	8	5	2
Even Yehuda intersection	1	--	1
Pardesia intersection	1	1	1
Hasharon intersection	2	12	13
Total intersection	18	29	23
Total elsewhere	15	25	23
Total accidents	33	54	46

conditions of increased speed. On the basis of before and after studies conducted by the Transport and Road Research Laboratory (TRRL) (*9*) on English roads, it is estimated that this increase in the accident rate could amount to 65 percent. It has also been stated that "pavement resurfacing without other highway improvements will have a small negative effect on safety on most roads" (*6*).

These two examples present opposing phenomena, yet each example has its own unique explanation. On the dual-carriageway road, most of the traffic concentrated in the left lane before overlaying because of deterring aberrations in the surface of the right lane. Obviously, such a state could encourage dangerous driving maneuvers, which in turn could engender the proliferation of accidents. After overlaying of the pavement, the traffic resumed its use of both lanes of travel with a natural distribution, and the redundant and dangerous driving maneuvers disappeared.

For the road with low geometric standards, the pavement surface that is subject to improvement causes drivers to increase their speeds and drive less cautiously after overlaying than they would on a road with low standards. This behavior could increase the number of dangerous maneuvers and thus, of course, the rate of accidents. Before overlaying, the deteriorated pavement surface increases the caution of the drivers and thus led to a lower rate of accidents.

These two examples illustrate that the effect of the pavement state on traffic safety is correlated with the unique characteristics of the case under investigation and cannot be established for the whole network.

WET ACCIDENTS

In rainy weather, road accidents can be engendered by the following causes:

- Accidents stemming from the same causes that generate accidents on dry pavements,
- Accidents stemming from low visibility in rainy weather, and
- Accidents stemming from skidding on a wet pavement.

Obviously, antiskid overlaying of the pavement surface can only decrease the rate of skid accidents. To calculate the extent of this accident rate, the following expression should be applied:

$$A_{sw} = m \left(A_w - \frac{A_w}{n + 1} \right) \times 100 \qquad (5)$$

where

A_{sw} = proportion of skid accidents out of the total of all accidents on the road,
A_w = proportion of wet-pavement accidents out of the total of all accidents on both wet and dry pavements,
n = relative frequency of accidents on a wet pavement compared with accidents on a dry pavement, and
m = proportion of skid accidents out of the total of wet-pavement accidents.

The value of n can be calculated from the following facts. First, according to Nedavia (*10*), the time during which the pavement is wet is estimated to be 3 percent of the total year. This estimation is based on data obtained from the meteorological service to which were added the number of hours that the roads remain wet after the rain. Because of the lack of precise data on actual traffic volumes during wet periods, it was assumed that the traffic volume is proportional to the condition of the pavement, that is, that 97 percent of the traffic takes place on dry pavement surfaces and that 3 percent takes place on wet pavement surfaces. Second, Table 4 indicates that the percentage of accidents on a wet pavement out of the total number of accidents is 12 percent. Thus, the relative frequency (n) of accidents on wet pavement compared with accidents on dry pavement that are caused by traffic throughout the network is

$$n = \frac{n_w}{n_d} = \frac{12/0.03}{88/0.97} = 4.4 \qquad (6)$$

where

n_w = frequency of accidents on wet pavement (in the preceding case the rate of accidents is 12 percent and the traffic volume is 3 percent of the total traffic passing through the network in vehicle-kilometers); and

TABLE 4 STATE OF ACCIDENTS ON ISRAELI ROAD SECTIONS DURING 1983–1986

Type of Road	1986		1985		1984		1983	
	Total Accd.	Wet Accd.	Total Accd.	Wet Accd.	Total Accd.	Wet Accd.	Total Accd.	Wet Accd.
Dual carriageway	672	81	554	55	546	66	645	82
Main road	928	126	811	87	842	98	830	102
Regional road	332	43	311	38	282	28	311	39
Local road	84	10	57	0	59	3	63	6
Undefined road	18	2	9	0	11	0	21	0
Total	2034	262	1742	180	1740	195	1870	229

n_d = frequency of accidents on dry pavement (the frequency of accidents is 88 percent, and the traffic volume is 97 percent of the total traffic passing through the network in vehicle-kilometers).

The result obtained is that the frequency of accidents on wet pavement is 4.4 times that of accidents on dry pavement (1.26 wet accidents per million vehicle-kilometers in 1983 compared with 0.28 dry accident per million vehicle-kilometers in that year). This finding indicates the high frequency of accidents on wet pavement. In other countries, such as France, this frequency is less than 2, which indicates that the pavement surface resistance to skid is at a lower standard in Israel.

This finding leads to the estimation that the percentage of skid accidents in Israel out of the total accidents on wet pavement (m) is 80 percent, in contrast to lower values in other countries (such as 55 percent for England). Hence, the percentage of skid accidents out of the total number of road accidents that can be prevented through proper overlaying is

$$A_{sw} = 0.8\left(0.12 - \frac{0.12}{5.4}\right) \times 100 = 7.5 \text{ percent} \qquad (7)$$

Another method of estimating the rate is based on the data in Figure 4. This figure shows the percentage of wet-pavement accidents compared with the total number of accidents, depending on the relationship between the length of those sections in which the friction value SN on the Mu-Meter is less than 37 (sections with low skid resistance) and the total length of the sections. According to this figure, the percentage of accidents is 9 percent when all the sections examined have an appropriate skid coefficient and 16 percent when they do not. Hence, increasing the skid coefficient decreases the rate of wet accidents from 16 to 9 percent. Thus,

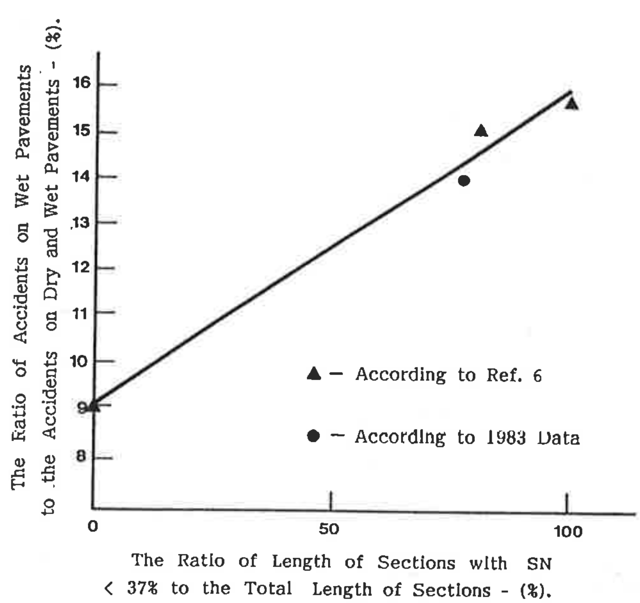


FIGURE 4 Relationships between the relative length of a section with low SN value and wet accident rates (*1*).

$$\frac{W}{W + D} = 0.16 \qquad (8)$$

$$\frac{W - dW}{W - dW + D} = 0.09 \qquad (9)$$

where

W = number of accidents on wet pavement,
D = number of accidents on dry pavement, and
dW = decrease in number of accidents on wet pavement as a result of raising the skid coefficient from an SN value lower than 37 to one higher than 37.

Equations 8 and 9 give D/W equals 5.25, dW/W equals 0.48, and dW/(W + D)), that is, A_{sw} equals 7.7 percent. This result is practically identical to that presented at the beginning of this section (7.5 percent) and constitutes proof that the percentage of skid accidents out of the total number of accidents on wet pavement is 80 percent.

SOUNDNESS OF ROAD SHOULDERS

In considering the effect of the shoulders on traffic safety, it is appropriate to quote the following excerpt (*6*):

> Wide lanes and shoulders provide motorists with increased opportunity for safe recovery when their vehicles run off the road (an important factor in single vehicle accidents) and increased lateral separation between overtaking and meeting vehicles (an important factor in sideswipe and head-on accidents). Additional safety benefits include reduced interruption from both emergency stopping and road maintenance activities, less wear at the lane edge, improved sight distance at critical horizontal curves, and improved roadway surface drainage.

To learn the influence of shoulder state and width on the rate of accidents in Israel, 1983 data pertaining to nonintersection accidents on interurban roads in Israel are presented in Table 5. Both the total number of accidents and only single-vehicle accidents are examined according to sound and unsound shoulders (as determined by the police examiner's classification), where the width of the shoulders is < 2 m and where it is ≥ 2 m.

On the basis of the many local observations and studies, it has been found that the rate of single-vehicle accidents increases in segments with unsound shoulders (narrow shoulders, shoulders in a deteriorated state, soft shoulders, etc.). When a single vehicle veers off the road onto an unsound shoulder, it is difficult for the driver to safely return to the road. There is often a loss of steering control, which can lead to a single-vehicle accident. This trend can also be observed in Table 5.

According to the quotation, the ratio between the number of single-vehicle accidents and the total number of accidents can be viewed as an indication of the extent of the shoulders' efficiency. Obviously, as this ratio increases, it can be assumed that the efficiency of the shoulders decreases, when the efficiency itself is correlated with the soundness and width of the shoulders. Indeed, for the entire network the relationship for unsound shoulders is 66 percent. This relationship is smaller

TABLE 5 NONINTERSECTION ACCIDENTS ON INTERURBAN ROADS IN 1983

State and Width Of Shoulders	Length in km	Number of Accidents		% Single Vehicle Accidents
		Total	Single Vehicle	
General Total				
Bad	325	50	33	66.0
Medium and Good	3555	1694	584	34.5
Total	3880	1744	617	35.4
Less Than 2 m.				
Bad	217	26	20	76.9
Medium and Good	1182	247	91	36.8
Total	1399	273	111	40.7
2 m. and more				
Bad	108	24	13	54.2
Medium and Good	2370	1447	493	34.1
Total	2478	1471	506	34.4

by almost half (34 percent) for sound shoulders. Figure 5 and Table 5 both indicate that the width of the shoulders is also an important factor in the issue of travel safety. The ratio between the number of single-vehicle accidents and the total number of accidents increases to 77 percent for unsound shoulders less than 2 m wide and to 54 percent for unsound shoulders 2 m wide or more.

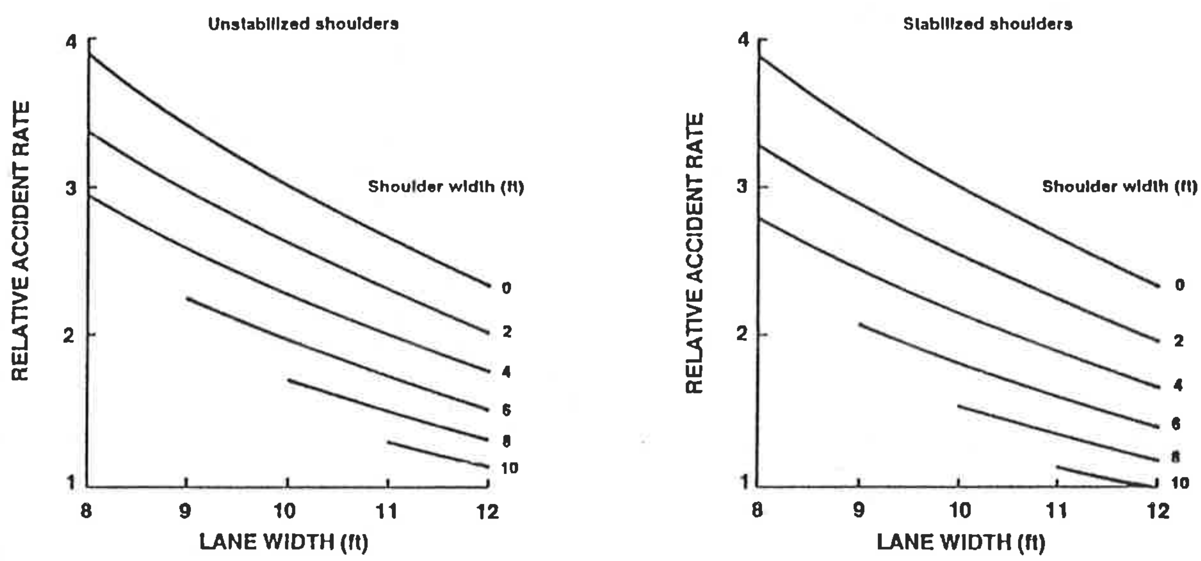
According to the data in Table 5, it is possible to compute the percentage of accidents out of the total number of accidents (A_s) that can be prevented if all the shoulders are sound and of a width of 2 m. This calculation is as follows:

$$\frac{0.354 - A_s}{1 - A_s} = 0.341 \qquad (10)$$

This calculation leads to an A_s value equal to 2 percent. It should be assumed that the actual value would have been higher if the classification of the shoulder had been conducted to study their effect on riding safety rather than to fill out an accident report. Thus, for example, if the real ratio between single-vehicle accidents and the total number of accidents in a road section of sound shoulders with a width of ≥ 2 m is 30 percent (rather than 34.1 percent), the value of A_s increases to 8 percent. This latter value seems more realistic in light of the data shown in Figure 5.

SUMMARY AND CONCLUSIONS

The data presented lead to the conclusion that the issue of road safety should be viewed not in general terms (i.e., systems concepts) but in the specific terms of black spots or black sections. Upgrading the state of the pavement surface does not always decrease the rate of accidents; therefore, each case must be examined separately. General terms that would aspire to be identically pertinent to every section of the network cannot be used. Even the question of widening a single-carriageway road into a dual-carriageway road cannot be assessed using uniform, generalized concepts. There are dual-carriageway roads where the accident rate is far lower than that on single-carriageway roads, but there are also dual-carriageway roads with a far higher accident rate. Hence, it is concluded that additional factors, such as geometric and environmental elements dictate the possible change that can be effected in the accident rate through widening the road to a dual-carriageway one. This question, too, must be specifically examined in each particular case (*8*).



NOTES: Accident relationship covers single-vehicle, sideswipe, and opposite-direction accidents on two-lane rural highways. Relative accident rate is defined as a multiple of the accidents per million vehicle miles for 12-ft lanes and 10-ft stabilized shoulders.

FIGURE 5 Normalized relationship between accidents and lane and shoulder conditions (*6*).

Increasing the skid coefficient of the pavement surface reduces the wet-accident rate. Here, a general decrease rate can be established for the whole network (7.5 percent of all accidents in road sections). However, from the point of view of economic feasibility, discussion should obviously refer only to black spots or black sections. There is no doubt that high economic feasibility can be achieved only when those sections in which there is a high incidence of skid accidents are treated. Hence, in Israel the following rule serves as the minimal criterion required for justifying the application of an antiskid asphalt layer: An application of asphalt layer is recommended if there have been at least 6 accidents during the preceding 3 years on a road where the percentage of wet-accidents out of the total number of accidents is greater than 30 percent or if there have been at least 12 accidents during the preceding 3 years on a road where the percentage is 25 percent.

Increasing the soundness of the shoulders decreases the incidence of accidents in which the shoulders are involved. Here, too, treatment is only worthwhile on those sections with a high incidence of accidents.

In summary, the influence of the state of the pavement surface and shoulders on riding safety has been addressed. According to the Israeli data, the total number of accidents (nonintersection accidents) on the interurban roads network can be decreased by approximately 7.5 percent if the skid coefficient of the pavement surface, as measured by the Mu-Meter, is ≥ 37. Similarly, it is possible to diminish the number of such accidents by approximately 8 percent if the perfect soundness of the shoulders is ensured and their width is increased to 2 m or more.

The value of 8 percent has been chosen as more realistic than the calculated value of 2 percent. The latter value is extremely conservative, stemming from the routine police examiner's classification method for the state of the shoulders. A combination of the two activities might annually prevent 250 to 300 accidents in Israel.

ACKNOWLEDGMENT

This paper is based partly on data obtained from work carried out for the Israeli Public Works Department.

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Publication of this paper sponsored by Committee on Traffic Records and Accident Analysis.