federal requirements that would prohibit the use of the timber barricades or the PCTBs. However, the Federal Highway Administration, aware of the study results on I-495, contracted with the Southwest Research Institute to conduct crash tests on the timber barricade. The crash tests were conducted in November 1976 and confirmed the study results. Based on this information, the Federal Highway Administration issued FHWA Notice N 5160.27 on February 2, 1977, which states in part,

> It has been concluded that effective immediately, 'Timber Barricades' shall not be approved for use on direct federal or federal-aid projects as a positive barrier at any speed.

CONCLUSIONS

The more than doubling in the frequency of accident occurrence during the construction study period reflects a need for improved control of traffic through high-volume, high-speed roadway segments undergoing construction. The high concentration of accidents at interchanges identifies them as roadway locations where extreme care should be exercised in the selection, installation, and maintenance of traffic-control devices. Though 52.5 percent of the reported crashes for the construction study period involved vehicle contact with the timber barricades, the possible degree to which the barricades contributed to the overall increase in accidents is not known.

The timber barricades did not prove to be effective as positive barriers for the traffic conditions in the I-495 construction zone, since 73.5 percent of the vehicles impacting the barricades straddled or penetrated them. Because of the lack of information on the performance characteristics of the PCTB in construction zones, crash tests and field evaluations are needed. There is a need for a national guide to aid in the selection and use of temporary barrier systems in construction zones.

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Accident Analyses of Highway Construction Zones

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Accident analyses were conducted for 79 construction projects in seven states. Results indicate an overall increase in the accident rate of 6.8 percent. Examination of accident rate differentials reveals that 31 percent of the projects experienced decreased accident rates during construction and that 24 percent of the projects experienced rate increases of 50 percent or more. Case study analyses of three projects with rate increases of 40 percent or more indicate that construction-related accidents were responsible for the accident rate increases.

Accident analyses were conducted by Midwest Research Institute as part of a larger investigation (1) aimed at developing design and operational criteria for safe and efficient traffic operations in construction zones. The accident study portion of the research examined the accident experience of construction zone roadways before and during construction. Data from seven states were used in the analysis. Trips were made to each state to obtain data. The data were classified into two major categories—construction data and accident data. Construction data include the type of construction, length, duration, traffic volumes, and traffic controls used. Accident data were reduced into several categories, such as type, location, time of occurrence, and severity. Forms were developed for recording both types of data to ensure uniformity of the data from each state.

The data were analyzed in four stages: (a) a comparison of the number of accidents before and during construction, (b) accident rates before and during construction, (c) a regression analysis with construction-zone characteristics as independent variables and accident rates during construction as dependent variables, and (d) three construction project case studies that included determination of construction-related accidents.

DATA COLLECTION AND REDUCTION

A data collection plan was developed prior to state visits. In order to choose projects that would provide a reasonable number of accidents, project selection criteria were developed that specified a minimum product that should be obtained when the length and the duration are multiplied. These criteria, developed from typical accident rates, were presented in a previous report (2).

The collection of project data on the initial visit to a state usually requires trips to district highway department offices. In most visits, current projects were visited and photographed to obtain a perspective on the relation of controls shown on the traffic-control plans and controls that were being used in the field. The table below gives the general categories of the 79 construction-zone sites selected for analysis.

Highway	Number of Projects Urban	Number of Projects Rural	Total
Six- to eight-lane Interstate	11	0	11
Four-lane Interstate	5	19	24
Four-lane divided	6	12	18
Five-lane undivided	3	0	3
Four-lane undivided	3	1	4
Two-lane	3	16	19
Total	31	48	79

Accident data for the period of construction and the period 1 year before construction began were requested for each project. Where possible, accident reports were requested for the period during construction and computer printout line summaries were requested for the period before construction. In some states, only hard copies of construction-related accidents were available or the state could only furnish hard copies on two or three projects.

The first stage of the analysis compared the number of accidents during construction with the number of accidents during the year before construction began. Where the construction period was 1 year or less, the comparison was performed simply on a month-to-month correspondence. Where the construction period exceeded 1 year, the accident numbers before construction were expanded by the ratio of the duration of construction to the duration of the period before. One drawback to this expansion is that it ignores the effect that seasons of the year have on accident types, severity, surface condition, percentage of night accidents, and total accident numbers. However, since only 27 percent of the projects are affected by the expansion, the seasonal effects were minimal when the total accident set was analyzed.

Table 1 illustrates the total number of accidents and percent change for all projects. The table shows a 7.5 percent increase in construction accidents. Fixed-object, rear-end, head-on, and turning accidents experienced large increases; however, ran-off-road accidents declined substantially. The number of night accidents increased by 9.4 percent. However, the percentage of night accidents to total accidents remained 30 percent both before and during construction. Accident severity had similar results. Although the number of fatal and injury accidents increased by about 5 percent, the percentage of these accidents to the total number of accidents remained a constant 29 percent both before and during construction. Also, rural accidents increased slightly more than urban accidents.

The rank order of the states by the percentage increase in accidents during construction is shown below.

State	Increase in Accidents During Construction Period (%)	Rank
6	-3.4	1
2	-1.0	2
5	+9.6	3
1	+9.9	4
3	+11.6	5
4	+21.0	6
7	+37.6	7

State numbers are used instead of names to keep the state identities anonymous. Two states actually experienced slight decreases in the number of accidents during construction; however, the percentage increase in accident numbers is sensitive to the type of projects in the state and the number of accidents before construction that are considered.

The accident numbers were further analyzed by a time-trend analysis of the month-by-month accident totals. For each project, the monthly differences between accidents during construction and those in the corresponding months in the year before construction were totaled. The month-by-month accident differentials were used to determine whether there was a time-trend effect in the construction-zone accident experience. Since only 1 year of data on accidents before construction were collected, a maximum of 12 monthly differentials were analyzed. For projects that lasted more than 1 year, data after the first 12 months of construction were not considered.

In addition to the time trend, the monthly differentials were also analyzed to determine the variability of accidents in construction zones among states, areas (urban or rural), and levels of speed reduction (speed reduction or no speed reduction). Only 65 of the 79 projects studied were used in this analysis, because the before data in state 2 were not broken down on a month-by-month basis.

The natural framework for the data is the (hierarchical) analysis of variance (AOV) model. Since some cells of this framework are missing, and since the sample sizes are unbalanced throughout, the AOV required is complicated. In order to produce working estimates of variable effects with a minimum of effort, an approximate AOV was executed in phases.

The AOV considers monthly responses as replicates, i.e., independent duplicate observations of accident dif-

Table 1. Total construction-zone accidents.

Item	Before	During	Change (%)
Total accidents	8172	8785	+7.5
Night accidents[a]	2454	2685	+9.4
Severity[a]			
Property damage only	4718	5226	+10.7
Injury	2369	2488	+5.0
Fatality	62	58	-6.5
	7149	7772	
Accident class			
Right angle	720	585	-18.8
Rear end	2614	3048	+16.6
Sideswipe	939	850	-9.6
Head on	99	114	+15.2
Turning	480	552	+15.0
Ran off road	706	520	-26.3
Roll	204	225	+10.3
Animal	84	102	+21.4
Fixed object	941	1307	+38.9
Fixed object (construction equipment)	-	120	N/A
Other	1385	1362	-1.7
	8172	8785	
Surface[a]			
Dry	4190	4870	+16.2
Wet	1467	1443	-1.6
Ice or snow	706	548	-22.4
Unknown	786	911	+15.6
	7149	7772	
Area			
Urban	4873	5149	+6
Rural	3299	3636	+10
	8172	8785	

[a]Includes data from six states only.

ferential. In practice, the sequence of monthly observations within any project might be correlated to time if, for example, the effect of construction is relatively immediate but tapers off after a few months.

Therefore, prior to the AOV, an examination of the monthly accident differential versus time (in months) was undertaken. The Spearman rank correlation coefficient (r_s) was computed for the 65 projects, with the result that no significant trends were observed. Only five of the 65 r_s's were statistically significant at $\alpha = 0.05$, and, of these, three were positive and two were negative. Also, the overall incidence of positive and negative r_s's was not significantly different from an equal partition [$X^2(1) = 2.46$]. These computations indicate no general or long-term association between construction effect and time after construction. Also, a comparison of the first month's response to their expected rank under the hypothesis of no significant short-term effect yielded an insignificant test statistic ($Z = 0.57$).

The overall average accident differential of +1.60 is significantly greater than zero ($t = 4.75$, $p < 0.01$). That is to say, on the average the construction zone caused a significant increase of 1.60 accidents/month. The increase is greater in zones with a speed reduction (5.58 versus 1.11) and greater in urban locations (6.22 versus 1.19).

State 5 had the worst record (9.21), state 3 was next (3.09), and the other four states were less (0.58 to 1.37). No state exhibited a negative accident differential, although states 1 and 6 are not significantly different from zero. The average monthly accident differential was 1.60, but the average accident differential by project was 2.11. Apparently, the shorter duration construction projects caused more incremental accidents than the projects that lasted 1 year or more.

ACCIDENT RATE COMPARISONS

Although comparative analyses using accident numbers provide useful information, the change in accident rates from the period before to the period during construction is a more meaningful measure of the effects of construction. Although data were available to compute accident rates for the before period (length, duration, accident number, and traffic volumes), for only two projects were traffic volume data available for the period during construction.

Two factors are of primary concern for an estimation of construction traffic volumes based on the before data. One is the expected annual increase in average daily traffic (ADT) on the subject projects. The other is the expected decrease in traffic volumes during construction caused by a reduction in the number of lanes, by a decrease in average speed, by a general annoyance to the traveling public, or by a combination of all three.

Since most of the construction projects sampled occurred in either 1974 or 1975, the before periods were 1973 and 1974 respectively. National statistics have shown that traffic volumes for these years were quite similar due to the energy crisis. Thus, on many projects the reduction effect of construction probably outweighed the annual increase in traffic volumes, resulting in an overall drop in traffic volumes.

The two projects that had traffic volume data for the period during construction were six-lane urban freeways, where two lanes were closed in each direction. Also, several entrance ramps were closed on each project. These projects experienced traffic reductions of 60 and 35 percent. Although these projects were unique in having two lanes closed, they do indicate that on similar projects traffic volumes probably decreased significantly.

Two-lane resurfacing and rural Interstate projects were also a significant percentage of the total number of projects analyzed. These projects probably did not experience any significant drop in traffic volumes. State 6 consisted entirely of rural Interstate projects during 1972. Traffic volumes from 1971 through 1973 in this state increased 10 percent annually. For this state, the accident rate increase may be overstated.

In conclusion, the construction projects probably had lower traffic volumes than in their respective periods before construction. Thus, the increases in construction accident rates are probably somewhat greater than the results indicate.

Although the lack of traffic volume data during the construction period forced a computation of construction accident rates using traffic volumes before construction, the accident rate analysis did provide a method for comparison of accidents before and during construction by using only documented accident data, not expanded numbers. Before data used were (a) 1-year prior to construction for projects of 1 year or longer and (b) corresponding months before construction for projects shorter than 1 year. Since four of the 79 projects had no before data, only the 75 projects with before and during data were used. Table 2 ranks the states by increase in construction accident rate. This table is very similar to the listing of the increase in accident numbers in Table 1, but does show some changes in the rankings. Probably the most interesting result is the large increase in accident rate experienced by state 4.

Although Table 2 shows only a 6.8 percent overall increase in accident rates, a more interesting analysis is the distribution of accident rate increases. Figure 1 shows that 31 percent of the projects experienced decreased accident rates during construction, while 24 percent of the projects experienced rate increases of 50 percent or more.

Table 3 shows how the type of road affects accident rates. For example, six- or eight-lane divided roadways reduced to one lane in each direction experienced a rate increase of 114.6 percent, but those reduced to two lanes in each direction experienced only a 5.3 percent increase. Two-lane highways reduced to one lane had a 30.7 percent rate increase, but those shifted to a new alignment had a 14.3 percent decrease. And finally, four-lane divided Interstate highways reduced to two-lane, two-way roads experienced an increase of 147.2 percent during construction, but those in which one lane was closed in each direction experienced a 68.6 percent increase in their accident rate. Unfortunately, only two projects were reduced to two-lane, two-way, so the reliability of these data is questionable.

The table below illustrates the mean accident rates for the various work area roadway types. The mean accident rate is the number of accidents per 100 000 000 vehicle-km (1 km = 0.6 mile).

Work Area Roadway	Number of Projects	Mean Accident Rate
Lane closure	48	127.64
Crossover	4	134.55
Temporary bypass	0	–
Detour	0	–
Lane closure and crossover	5	90.18
Lane closure and temporary bypass	4	317.49
Lane closure and detour	10	179.17
Crossover and detour	3	46.3
Temporary bypass and detour	1	262.09

Lane closures with temporary bypass roadways experienced the highest accident rate followed by temporary bypass roadways with detours. However, further investigation showed that the lane closure with temporary bypass roadway had a mean accident rate before construction of 453.23/100 million vehicle-km; thus the accident rate decreased by 30 percent during construction. Also, the temporary bypass with detour work area roadway had an accident rate of 69.68/100 million vehicle km before construction; thus its construction accident rate went up substantially. However, since the work area roadway types were distributed so disproportionately (over 60 percent were lane closures), no major conclusions can be drawn from this analysis.

Table 4 illustrates the mean accident rates for the various types of construction. The construction types were distributed relatively evenly; bridge work and reconstruction of existing roadways experienced the highest percentage accident rate increases. The former had a substantial increase in raw accident rate of 61.24/100 million vehicle-km.

The table below illustrates the percentage increase in accident rates of urban and rural projects. The mean accident rate is the number of accidents per 100 000 000 vehicle-km (1 km = 0.6 mile).

Area	Mean Accident Rate: Before Construction	Mean Accident Rate: During Construction	Change (%)
Urban	170.96	190.44	+11.4
Rural	87.78	96.62	+10.1

This analysis shows that urban projects experienced a slightly higher percentage increase in accident rates. Also, their increase in accident numbers (31.16) was higher than that for rural projects (14.14).

Table 5 illustrates the severity rate experienced by state and by the total data set. States 4 and 7 experienced the largest increases in injury accident rates. Overall, the property-damage-only accident rate increased by a slightly higher percentage than the injury

Table 2. State ranking by increase in mean accident rate.

State	Number of Projects	Mean Accident Rate[a]: Before	Mean Accident Rate[a]: During	Change (%)	Rank
2	9	142.21	129.33	-9.1	1
6	15	75.13	72.95	-2.9	2
1	16	167.65	181.68	+8.4	3
3	10	178.96	143.63	+10.4	4
5	10	118.31	135.95	+28.2	5
7	5	130.49	179.61	+37.6	6
4	10	165.78	267.75	+163.16	7
Total	75	127.45	136.09	+6.8	

Note: 1 km = 0.6 mile.
[a]Number of accidents per 100 000 000 vehicle-km.

Figure 1. Project accident rate change.

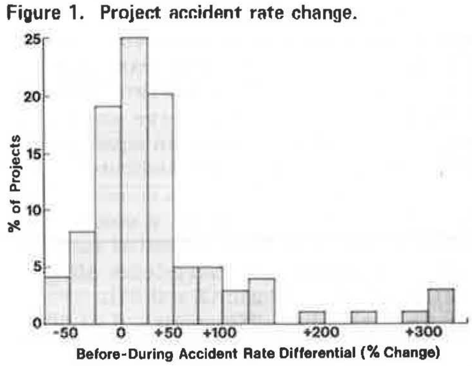

Table 3. Effect of degrading various road types.

Roadway	Number of Projects	Mean Accident Rate[a]: Before Construction	Mean Accident Rate[a]: During Construction	Change (%)
Six- or eight-lane Interstate reduced to two lanes each direction	8	121.23	127.64	+5.3
Six- or eight-lane Interstate reduced to one lane each direction	3	142.44	305.76	+114.6
Four-lane Interstate reduced to one lane each direction	22	85.10	143.47	+68.6
Four-lane Interstate reduced to two lanes, two-way	2	25.43	62.86	+147.2
Four-lane divided reduced to one lane each direction	5	196.71	225.91	+14.8
Four-lane divided reduced to two lanes, two-way	5	110.68	128.23	+15.9
Four-lane divided on new alignment	6	155.68	125.33	-19.5
Four-lane undivided reduced to two lanes	3	500.91	476.24	-4.9
Five-lane undivided with two-way left turn lane reduced to two lanes	3	305.15	485.09	+59.0
Two-lane reduced to one lane	7	227.14	297.33	+30.7
Two-lane on new alignment	11	397.98	340.96	-14.3
Total	75			

Note: 1 km = 0.6 mile.
[a]Number of accidents per 100 000 000 vehicle-km.

Table 4. Mean accident rate by type of construction.

Construction	Number of Projects	Mean Accident Rate[a] Before Construction	During Construction	Change (%)
Resurfacing, pavement patching	26	92.33	99.40	+7.7
Bridge work	5	55.17	82.79	+50.1
Median barrier work	15	116.97	127.42	+8.9
Widening of existing roadway	12	360.69	370.76	+2.8
Upgrading to Interstate standards	9	104.78	121.65	+16.1
Reconstruction of existing roadway	2	174.36	232.48	+33.3
Construction of new roadway (new alignment)	5	133.43	133.92	+0.4
Other	1	85.85	85.85	0.0

Note: 1 km = 0.6 mile.

[a]Number of accidents per 100 000 000 vehicle-km.

Table 5. Mean accident severity rates by states.

State[a]	Number of Projects	Property Damage Only[b] Before	During	Δ (%)	Injury[b] Before	During	Δ (%)	Fatal[b] Before	During	Δ (%)
1	16	133.45	146.73	+9.9	33.14	34.44	+3.9	1.05	0.51	-51.8
3	10	116.28	127.12	+9.3	59.38	65.25	+9.9	0.98	0.87	-7.9
4	10	122.35	200.29	+63.7	42.98	56.50	+33.0	0.95	0.42	-55.9
5	10	67.1	78.81	+17.4	49.79	55.43	+11.3	1.42	1.71	+20.3
6	15	50.98	49.16	-3.6	23.13	22.91	-1.0	1.03	0.89	-13.4
7	5	92.61	126.28	+36.4	37.89	53.64	+41.7	0	0	0
Total	66	76.81	80.63	+5.0	37.07	38.48	+3.8	0.99	0.90	-8.9

Note: 1 km = 0.6 mile.

[a]Data were not available for state 2.

[b]Number of accidents per 100 000 000 vehicle-km.

rate, and the fatal accident rate decreased.

Accident rate comparisons were also made between projects that had reduced lane widths and projects that maintained normal lane widths. The six projects with reduced lane widths during construction experienced a 17.6 percent increase in accident rates during construction and the 69 projects with normal lane widths experienced a 6.6 percent increase in accident rates during construction. Projects with and without speed reductions were also compared. Urban projects showed a 14.0 percent increase without speed reductions and a 6.0 percent increase with speed reductions. Rural projects, however, showed a 2.6 percent increase without speed reductions and a 16.4 percent increase with speed reductions.

REGRESSION ANALYSIS

The third stage of the analysis involved multiple regression analysis of the data using 17 independent variables and computing their relationship to 17 various accident rates during construction (dependent variables). The list of independent and dependent variables used in the multiple regressions is given below (note that Y_1, the total accident rate, was for the period during construction only).

Independent Variables	Dependent Variables
X_1 = state number (1 to 7)	Y_1 = total accident rate
X_2 = project number (1 to 79)	Y_2 = night accident rate
X_3 = project length	Y_3 = property-damage-only accident rate
X_4 = duration (days)	Y_4 = injury accident rate
X_5 = road type	Y_5 = fatal accident rate
X_6 = primary construction road type	Y_6 = nonreportable accident rate
X_7 = secondary construction road type	Y_7 = right-angle accident rate
X_8 = primary work area road type	Y_8 = rear-end accident rate
X_9 = secondary work area road type	Y_9 = sideswipe accident rate
	Y_{10} = head-on accident rate
	Y_{11} = turning accident rate
X_{10} = type of construction	Y_{12} = ran-off-road accident rate
X_{11} = area (urban, rural)	Y_{13} = overturning accident rate
X_{12} = normal speed limit	Y_{14} = animal accident rate
X_{13} = speed reduction	Y_{15} = fixed-object accident rate
X_{14} = daily traffic effect	Y_{16} = fixed-object (construction device) accident rate
X_{15} = control status	Y_{17} = other accident rate
X_{16} = lane width (normal, reduced)	
X_{17} = traffic control method	

The initial screening regression run indicated strong correlations between many of the dependent variables. For this reason, several dependent variables were eliminated from further regressions. Also, several of the independent variables were moderately correlated. This correlation of independent variables was largely due to the way the independent variables were chosen, and changes in the classification of the variables for later regressions were made based on these results.

The 17 dependent variables account for about 38 percent of the variability of the total accident rate (adjusted R^2 = 0.385) and considerably less for the other dependent variables studied.

Based on the initial regression, it was apparent that many of the dependent variables were highly correlated and, therefore, a subset of the variables could be used in further investigations. This regression also revealed some problems of moderately correlated independent variables. For these reasons, another set of regressions were run, using only total accident rate and other dependent variables that seemed to differ radically from total accident rate. The independent variables were adjusted to remove those that were significantly correlated.

Table 6 gives the general results of the second multiple regression. For the regression of total accident rate, the original 17 variables were reduced to 6. However, the adjusted R^2 value only changed from 0.385 to

0.236. The order of the independent variables indicates that normal speed limit accounts for the largest portion of the variability of total accident rate, and that construction road type (primary) accounts for the least portion of the variability of the six independent variables. The prediction of the fatal accident rate and other accident rate were both very poor, indicating the lack of relationships between the construction-zone variables and fatal accident rate. Two other accident rates in Table 6 are of particular interest: fixed-object accident rate and the construction-object accident rate. The control status variable that refers to the way the work area moves within the construction zone is an important contributor to both types of fixed-object accident rates.

Further investigations were made by conducting linear regressions of both length and duration versus the total accident rate. A regression was done on the total project set and for each road type and construction road type and also by urban and rural projects. The results of the regressions are shown in Table 7.

In general, both the length and duration regression lines had negative slopes, indicating that the long length and duration projects normally had lower accident rates. Many of the regressions broken down by type of road and construction road were hampered by small sample sizes.

Table 6. Second multiple regression.

Dependent Variables	Adjusted R^2	Independent Variables (most to least important)
Total accident rate	0.236	Normal speed limit, area type, zone type, state, project, construction road type (primary)
Fatal accident rate	0.000	State, construction road type (primary), project
Overturn accident rate	0.342	State, type of construction, project
Animal accident rate	0.214	Length, project, state
Fixed-object accident rate	0.225	Construction road type (primary), control status, type of construction, project, state
Construction-object accident rate	0.273	Control status, project, traffic control devices and methods, daily traffic effect, state
Other accident rate	0.000	Zone type, construction road type (primary), state, project

CONSTRUCTION PROJECT CASE STUDIES

Three case studies of selected construction projects were performed. Each of the case studies presented findings about an individual project. The projects were not selected randomly. Hard copy accident reports were scanned, and the projects chosen were those that demonstrated a reasonably high number of construction-related accidents. The projects were chosen this way because this stage of the analysis was aimed at getting an idea of why accidents happen in construction zones.

Table 8 gives the results of the three case studies. Each study experienced an above average increase in the number of accidents during construction. The mean accident and fatality rates are given below in accidents per 100 000 000 vehicle-km (1 km = 0.6 mile).

Table 7. Linear regression results.

Regression	b	a	r^2	n
Length versus total accident rate (all projects)	-10.87	376.20	0.06	79
Duration versus total accident rate (all projects)	-0.23	362.28	0.03	79
Length versus total accident rate				
Six- or eight-lane Interstate	12.30	241.40	0.05	12
Four-lane Interstate	-4.39	197.65	0.22	24
Four-lane divided	7.26	200.61	0.07	15
Four-lane undivided	373.37	-21.37	1.00	2[a]
Five-lane undivided with two-way left-turn lane	-148.14	1 572.50	0.84	3
Four-lane combined divided and undivided	20.13	76.81	0.33	4
Two-lane	-23.80	520.93	0.08	19
Duration versus total accident rate				
Six- or eight-lane Interstate	-0.78	460.76	0.29	12
Four-lane Interstate	-0.14	197.00	0.13	24
Four-lane divided	-0.10	280.95	0.02	15
Four-lane undivided	-49.53	14 469.0	1.00	2[a]
Five-lane undivided two-way left-turn lane	6.89	11.62	0.84	3
Four-lane combined divided and undivided	-0.07	166.14	0.73	4
Two-lane	0.10	353.80	0.01	19
Length versus total accident rate				
Two-way, two-lane reduced to one lane	-38.52	750.79	0.29	7
Four-lane divided reduced to one lane each direction	0.11	171.42	0.00	29
Four-lane divided reduced to two lanes each direction	-19.38	314.25	0.17	7
Six- or eight-lane divided reduced to two lanes each direction	-1.26	290.47	0.00	8
Six- or eight-lane divided reduced to one lane each direction	-4.00	536.77	0.04	3
Four-lane undivided reduced to two lanes	386.00	-313.71	0.55	5
Four-lane divided maintained, but on new alignment or mainline shift	-20.22	325.33	0.32	6
Two-lane highway maintained, but on new alignment or mainline shift	-20.10	425.81	0.05	12
Five-lane undivided with two-way left-turn lane reduced to two lanes	-119.57	1 335.34	1.00	2[a]
Duration versus total accident rate				
Two-way, two-lane reduced to one lane	0.48	367.51	0.02	7
Four-lane divided reduced to one lane each direction	-0.21	237.40	0.07	29
Four-lane divided reduced to two-way, two lanes	-0.15	281.10	0.14	7
Six- or eight-lane divided reduced to two lanes each direction	-0.56	388.74	0.17	8
Six- or eight-lane divided reduced to one lane each direction	-1.68	616.53	0.10	3
Four-lane undivided reduced to two lanes	-0.79	891.10	0.25	5
Four-lane divided maintained, but on new alignment or mainline shift	0.13	180.58	0.03	6
Two-lane highway maintained, but on new alignment or mainline shift	0.17	261.63	0.03	12
Five-lane undivided with two-way left-turn lane reduced to two lanes	15.89	-825.97	1.00	2[a]
Length versus total accident rate				
Urban	-10.78	485.66	0.01	31
Rural	-4.77	251.30	0.03	48
Duration versus total accident rate				
Urban	-0.25	486.75	0.02	31
Rural	-0.05	226.14	0.00	48

[a] Inadequate sample size.

Case	Mean Accident Rate Before Construction	Mean Accident Rate During Construction	Mean Fatality Rate Before Construction	Mean Fatality Rate During Construction
1	33.8	47.5	0.8	1.4
2	116	270	–	–
3	116	326	–	–

The percentage of night accidents decreased in all three cases. The percentage of the types of accidents varied between the three studies. In all of the studies the percent of property-damage-only accidents increased during construction. All of the projects studied had a large proportion of accidents that were construction related. In case 1, 36 of 102 accidents were construction related; in case 2, 78 of 103 accidents were construction related; and in case 3, 8 of 14 accidents were construction related.

The determination of construction-related accidents was a central part of the case studies. The accident was judged construction related by reading the accident report and asking, "Was the accident precipitated or affected by the construction?" Or from the opposite point of view, "Would the accident have happened and been as severe if there were no construction under way?" Although judgment was involved, the judgments were made by experienced traffic safety personnel after thorough study of the project.

In each of the projects, the number of construction-related accidents was at least equal to the increase in accidents from the period before to the period during construction. In case 2, the construction-related number is high because of a high number of rear-end accidents that occurred when queues formed during the construction. Even if the rear-end accidents had not been classified as construction related, the other 29 construction-related accidents would be near the increase in accidents comparing the before and during periods.

The general impression gained from the case studies was that the accident experience of a roadway not only increases during construction, but also the overall characteristics of the accident histories are different from those of the periods before construction.

In the first two case studies, there was a definite predominant accident type, which if remedied could have reduced the number of accidents in the zone. In the first case study, accidents involving timber barricades were prevalent throughout the construction period. In the second case study the rear-end accident was predominant. Fixed-object and head-on or sideswipe accidents were nearly the entire set of construction-related accidents in the third case study.

Table 8. Case study summaries.

Accident	Before Construction (%)	During Construction (%)	Rate of Change (%)
Case 1 accidents			
Night	50	44	-6
Rear end and sideswipe	40	21	-19
Fixed object	15	38	+23
Head on	0	2	+2
Property damage only	38	57	+19
Injury	60	40	-20
Fatality	2	3	+1
Total accident increase	-	-	+42
Case 2 accidents			
Night	43	28	-15
Rear end and sideswipe	33	50	+17
Fixed object	16	9	-7
Head on	-	-	-
Property damage only	68	79	+11
Injury	32	21	-11
Fatality	-	-	-
Total accident increase	-	-	+49
Case 3 accidents			
Night	60	50	-10
Rear end and sideswipe	60	14	-46
Fixed object	0	44	+44
Head on	0	21	+21
Property damage only	60	86	+26
Injury	40	14	-26
Fatality	-	-	-
Total accident increase	-	-	+180

SUMMARY

Accidents occurring both before and during construction were analyzed using several methods. These included analysis of the time-trend effect of monthly accident differentials, total accident number analysis, accident rate analysis, and case studies of individual projects. In addition, regression analysis was performed on the construction accident rates.

The time-trend analysis showed that construction zones caused an average increase of 1.60 accidents/month. The total number of accidents increased by 7.5 percent and the accident rate increased by 6.8 percent. Thirty-one percent of the projects studied experienced decreases in accidents during construction; 24 percent experienced rate increases of more than 50 percent. The percent differences may be understated because of the lack of data about traffic volume during construction. The analyses assumed that traffic volumes were equal before and during construction; however, for many projects, the traffic volumes during construction were probably lower than those before construction. Three case studies of zones experiencing large increases in accident rates revealed that most of the increase was due to construction-related accidents.

Both the number of accidents and accident rate analyses showed very little difference in the distribution of accident severity in the comparison. However, both analyses showed a slight shift toward property-damage-only accidents. Both analyses show a great degree of variability in the number and rate of fatal accidents. This was supported by the regression analysis, in which there was very little correlation between the construction-zone variables and the fatal accident rate.

The proportion of night accidents to the total number of accidents remained relatively constant in both the number of accidents and accident rate analyses. Again, this was supported by a relatively high degree of correlation between night accident rates and total accident rates in the regression analysis. The linear regression analysis also indicated a strong correlation between traffic-control devices and construction fixed-object accidents and a poor correlation between construction-zone variables and ran-off-road accidents. Accident number analysis showed a substantial increase in fixed-object, head-on, and rear-end accidents, but a decrease in ran-off-road and sideswipe accidents.

The time-trend analysis showed that projects where speed limits were reduced (by regulatory or advisory signs) had higher monthly accident differentials than those without speed reductions. The accident rate analysis also showed that those projects with speed reductions had a slightly higher percentage accident rate increase. According to the linear regression analysis the project speed limit, which is highly correlated with area type, accounts for the largest portion of the total accident rate variability.

Road type accounted for 4 of the 30 highest correlations between construction zone and accident variables in the linear regression analysis. Accident rate analysis resulted in some interesting results concerning road types. Six- or eight-lane Interstate projects reduced to one lane in each direction had accident rate increases of over 100 percent, but those reduced to two lanes in each direction had increases of only 5 percent. The case studies showed that the one-lane projects experience a great number of rear-end accidents. Four-lane divided Interstate projects reduced to two-lane, two-way had percentage increases more than double those in which the roadway was simply reduced to one lane in each direction. Five-lane undivided highways with two-way left-turn lanes reduced to two lanes during construction experienced the largest accident rate increase of all road types. And finally, two-lane roads reduced to one-way alternating operations experienced worse construction accident rates than those placed on new alignment during construction.

The time-trend analysis indicated a much higher monthly increase in accidents in urban areas. However, since urban areas normally have higher accident numbers, this does not necessarily mean their construction accident experience is any worse. The linear regression analysis indicated a moderately high correlation between area type and total accident rate. The accident number and accident rate analyses both showed that construction accidents went up by a similar percentage in urban and rural areas.

The time-trend analysis showed that the first month after construction begins is not significantly different than the other months of construction and that construction zones do not necessarily have better accident experiences over time. The linear regression analysis showed a negative correlation between the length and duration of projects and the accident rate; thus, the longer the duration of a project (both in time and space), the lower the accident rate.

The accident rate analysis indicated that bridge work, followed by reconstruction of existing roadway (on the same alignment), experienced the largest percentage accident rate increases. Case studies of projects with large rate increases before to during construction showed a definite predominant accident type for each of the studies.

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Computer Model for Liquefied Natural Gas and Liquefied Propane Gas Risk Simulation

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Early in 1971, the National Transportation Safety Board recommended a general framework for risk analysis of hazardous materials. The HAZ-EX computer program was developed to provide analysis of the risk to the public associated with the transportation of hazardous materials. The purpose of the program is to give project designers safety information on routes and sites during the planning stages of a project. The HAZ-EX program is a modular design whereby each module is an element of the risk analysis. The elements range from the simulation of spill dynamics to human injury criteria. The advantage of a modular approach is that updated data or alternative phenomenon descriptions can be inserted. The program capability includes material storage and ship, pipeline, truck, and rail transportation modes. Program-effects analysis capability includes prediction of injury due to toxicity, radioactivity, flammability, and explosivity. By selection of the appropriate combinations of modules, rapid comparisons can be made of site, transportation mode, transportation routes, and system alternatives. The HAZ-EX program has been applied to the storage and bulk transportation of liquefied natural gas and liquefied propane gas. The use of realistic injury and damage criteria as well as accurate physical phenomena description are extremely important. The advantage of a computerized model is speed. A few pages of computer output can apprise decision makers of the safety aspects of a proposed movement of hazardous materials. If a working definition of acceptable risks were then available, the reviewer could be easily satisfied as to the acceptability of an applicant's plans as proposed or whether modifications would be necessary. The efficacy of modifications can be evaluated by rerunning the model.

Liquefied gases will be an important source of energy in the coming decade. Liquefied natural gas (LNG) and liquefied propane gas (LPG) both offer environmentally sound response flexibility, especially since the technology has been developed to ship these products in bulk as cryogenic, or pseudo-cryogenic in the case of LPG, products rather than as liquids under pressure. However, such proposals have not been without controversy. A recent press report succinctly states the issues that must be addressed, "Critics...of the proposal...want to be certain it is as safe as possible." Hence, an important aspect of import and transshipment proposals for LNG and LPG is an understanding by project planners and systems designers of the attendant hazards and public risk of these products as they move through