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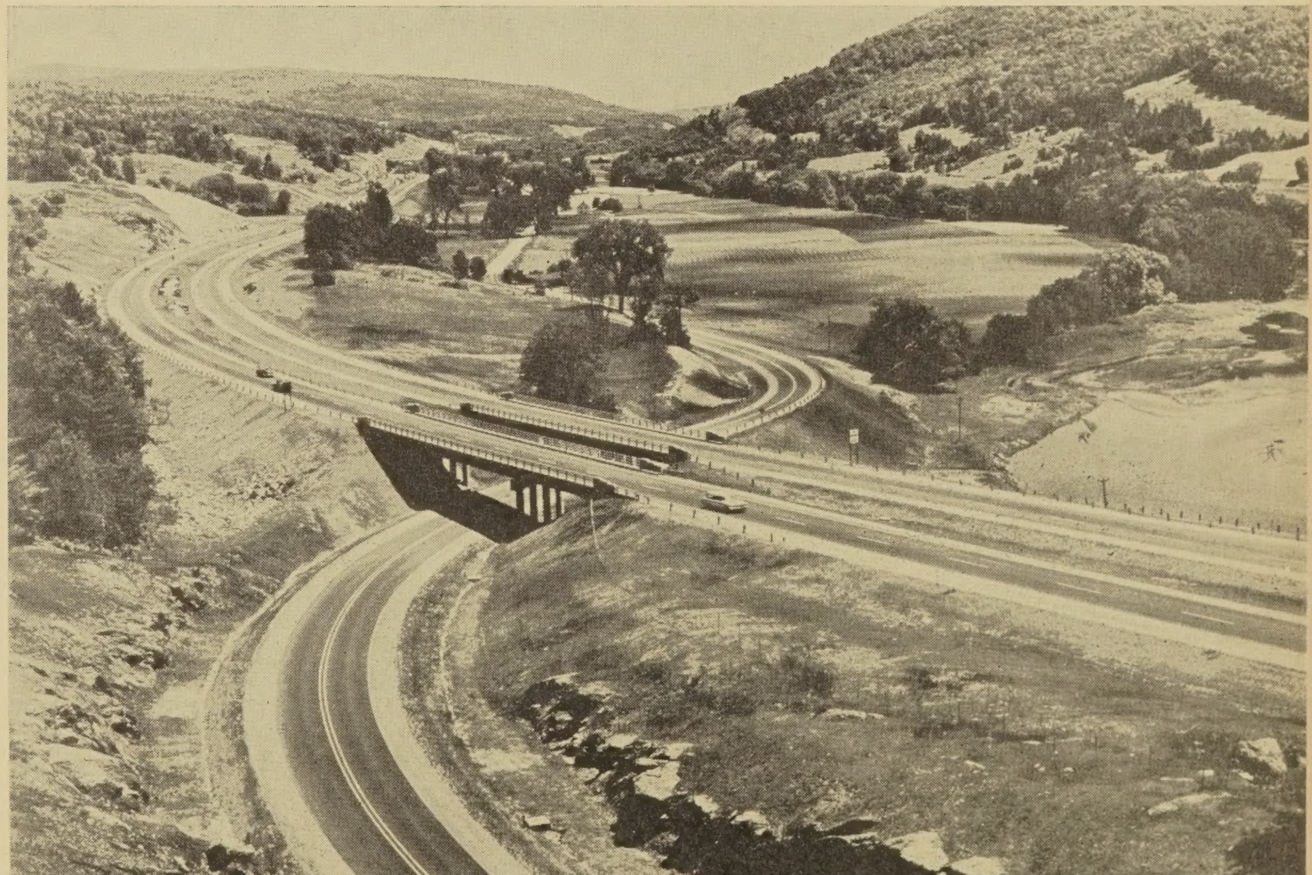

Interstate Highway 89 west of Waterbury, Vermont.
This view faces east up the Winooski River Valley; in the center of the photograph I–89 overpasses relocated US–2 on twin bridges.

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Contents of this publication may be reprinted. Mention of source is requested.

IN THIS ISSUE

Errata

In vol. 32, No. 7, April 1963, PUBLIC ROADS change IN THIS ISSUE the initials of Mr. Shufflebarger to read: C. L. and in the title, *Estimated Travel by Motor Vehicles in 1962,* change the date to *1961.*

U.S. DEPARTMENT OF COMMERCE
LUTHER H. HODGES, Secretary

BUREAU OF PUBLIC ROADS
REX M. WHITTON, Administrator

Analyses of Direct Costs and Frequencies of Illinois Motor-Vehicle Accidents, 1958

By[1] **CHARLES M. BILLINGSLEY, Transportation Economist,**
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The Illinois Accident Cost Study was designed to provide comprehensive data on the cost of motor-vehicle accidents and incidents of all degrees of severity, ranging from incidents involving only a few dollars damage to the most severe and costly accidents.

During the study year nearly 10 million persons resided in the State and more than 4 million of these individuals were licensed to drive. Also, nearly 3⅓ million privately owned Illinois passenger cars and trucks were in use during 1958, and one-tenth of the owners of these vehicles were involved in an accident of such severity as to require an owner's report to be filed with the Bureau of Traffic, Division of Highways.

Data developed in the Illinois study, as well as in earlier studies conducted in other States, indicated that a substantial part of the accident problem is overlooked by basing studies only upon the official accident records of a State. Findings of the Illinois study showed that approximately three-fourths of the total number of accident involvements and slightly more than two-fifths of the total direct costs were attributed to unreported events. Although most of the unreported involvements were minor happenings, in the aggregate they represented a significant part of the total direct cost of motor-vehicle accidents in Illinois.

Motor-vehicle accidents generate a wide array of tangible and intangible effects. A satisfactory appraisal of all the economic and social consequences of an accident is a practical impossibility in statistical terms. Thus, to interpret the data presented in this article, it is necessary to emphasize that only the costs directly associated with accidents were included.

Although the study was restricted to the determination of direct costs, the task of accounting for and verifying all cost items accruing from a vehicle being involved in an accident was considerable. Interviewers traveling over the 102 counties of the State made nearly 23,000 personal and 4,000 telephone calls. To ferret out and verify costs, they completed 16,600 interviews with owners and drivers of vehicles, with injured persons and their relatives, with doctors, insurance brokers, attorneys, police officials, and others.

Introduction

SOME OF the principal findings of the Illinois motor-vehicle accident cost study, a cooperative project of the Illinois Division of Highways and the U.S. Bureau of Public Roads, are discussed in this article. The study, which was undertaken in 1959, was designed to measure the direct costs of accidents and incidents involving owners of Illinois registered passenger cars and trucks during calendar year 1958 and to relate such costs to the highway, the vehicle, and the persons involved.

The only distinction between a motor-vehicle accident and a motor-vehicle incident is the element of motion. In an incident, there is no motion on the part of the motor vehicle. In general, losses through motor-vehicle incidents include such events as storm damage, acts of vandalism, fires, mishaps occurring during the servicing and repair of a motor vehicle, collisions of conveyances other than motor vehicles with parked or standing motor vehicles, and similar happenings.

Many cost items can be associated with traffic accidents and other mishaps, but cooperative studies of the Bureau of Public Roads and State highway organizations undertaken to date have been concerned only with the direct costs of accidents and incidents.[2] A broad but not quite accurate definition is that the Illinois study and previous studies have reflected only the "out-of-pocket" costs. Stated more precisely, the costs were those directly attributable to accidents, and the costs thus determined represented the use of resources that would have been available for other purposes had the accidents not occurred. Cost elements included in the study are discussed in subsequent sections of this article.

Legal requirements in all States specify that owners must file a report of motor-vehicle accidents involving death or injury. The laws relating to property damage only accidents vary from State to State. In Illinois the statutory requirement specifies that an accident report must be filed with the State for any motor-vehicle accident involving death or injury, and any accident in which damage to property of any one person exceeds $100.

With few exceptions, accident statistics published by different private and public organizations are based solely upon official reports of accidents filed with State agencies. Data developed in cooperative studies undertaken by the Bureau of Public Roads have indicated that a substantial part of the accident problem is overlooked by relying only upon official accident records. Many accidents occur for which no reports are filed, and although the events are usually minor happenings they add significantly to the number and cost of accidents.

The Illinois study, as well as previous studies, was designed to determine the direct costs of accidents and incidents ranging from minor fender-denting collisions to the most serious accidents involving death or injury.

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[1] Presented at the 42d annual meeting of the Highway Research Board, Washington, D.C., January 1963.

[2] Other cooperative studies and the year of survey were: Passenger car phase—Massachusetts, 1953; New Mexico, 1955; and Utah, 1955. Truck phase—Massachusetts, 1955; New Mexico, 1956; and Utah, 1957.

Summary

The major findings of the Illinois accident cost study discussed in this article are presented in the following paragraphs.

Direct costs of motor-vehicle accidents and incidents involving Illinois registered passenger cars during 1958 totaled $309.5 million. For Illinois trucks, such costs amounted to $29.3 million. For events, occurring both on and off the highways and in and out of the State of Illinois, the resultant costs to persons and property totaled one-third of a billion dollars or an amount equivalent to three-fifths of the total outlay of funds by State, Federal, and local governments for the construction and maintenance of Illinois roads and streets during 1958.

The one-third of a billion dollars represented an average cost of $928,000 per day, $104 per vehicle in use, $84 for each person having a permit to drive, and $35 per capita.

Approximately 1.3 million Illinois passenger cars were involved in traffic accidents on Illinois highways costing $258.8 million, or an average of $196 per event; similarly, 128,000 trucks were involved in traffic accidents costing $18.1 million, or an average of $141 per event. A further comparison on the basis of exposure indicated costs of 0.97 of a cent per passenger-car mile and 0.36 of a cent per truck-mile.

Three-fourths of the 1.3 million passenger car involvements and four-fifths of the 128,000 truck involvements were not recorded in the official accident files of the State. Although most of these events were minor happenings in which property damage costs were below the legal reporting minimum, they accounted for 42 percent of the total direct costs of passenger car accidents and 55 percent of the total direct costs of truck accidents.

The distribution of the accident cost dollar for all severity classes of accidents was, as follows: Property damage, 60 cents; treatment of injuries, 8 cents; loss of use of vehicle, 1 cent; value of work time lost, 8 cents; legal and court fees, 10 cents; and damage awards and settlements in excess of known costs, 13 cents.

The problems inherent in sampling the universe of traffic accidents for the purpose of determining costs were made evident by the wide range in costs found for the different severity classes of accidents. Extreme cost values for individual sample cases were, as follows: Fatal injury involvements, $136,000; nonfatal injury, $73,000; and property damage only, $30,000. In contrast, median cost values were $2,280 for fatal injury involvements, $310 for nonfatal injury involvements, and $50 for property damage only involvements.

Passenger car owners were involved in accidents within municipalities 3½ times as often as in rural areas. For truck owners, the ratio was 1 involvement in rural areas for every 5 involvements in municipalities. Costs per passenger-car mile ranged from 0.61 of a cent in rural areas to 1.18 cents in municipalities; similarly, costs per truck-mile ranged from 0.32 of a cent to 0.42 of a cent, respectively.

Comparisons made of accident frequencies and costs by major highway systems indicated that roads and streets of a local character had the least desirable rates. Many of the accidents that took place on residential streets were relatively minor events but, when considered in the aggregate, they represented a sizable part of the total direct costs of traffic accidents.

Sampling Procedure

To attempt a study of Statewide vehicle owners' accident experience for a 1-year period dictated the use of the sampling method. Two sources were used: Owners' accident reports filed with the Illinois Division of Highways, Bureau of Traffic; and registration lists of vehicle owners published by the office of the Illinois Secretary of State. Official accident reports filed with the State during 1958 represented the known population of motor-vehicle accidents. Vehicle owners selected from registration lists represented the unknown area in determining accident and incident occurrence.

The sampling unit used for reported accidents was the license plate number of a privately owned passenger car or truck involved in an accident. Reports on file yielded 320,700 license numbers of Illinois registered passenger cars (or the equivalent of that number) involved in accidents and 26,200 trucks. These data were available on tabulating cards, thus permitting the selection of samples by machine method. The cards were grouped according to severity classes—fatal injury, nonfatal injury, and property damage only—and each group was systematically sampled. Truck involvements were further stratified on the basis of two major vehicle types—single units and truck combinations.

To explore the unknown area of accident and incident occurrence for which no owners' reports were on file with the State, approximately 14,000 license plate numbers, equally divided between passenger cars and trucks, were selected from vehicle registration lists. Passenger car license plate numbers were selected at random and no consideration was given to size or weight of vehicle; truck license plate numbers were stratified on the basis of light, medium, and heavy registered weights and different sampling rates were applied thereto. In Illinois a license plate remains with the owner and may be transferred to another vehicle in the event a vehicle is replaced. The 14,000 vehicle owners thus selected were requested to enumerate their *total* accident and incident experience for 1958 involving the vehicle or vehicles bearing the designated license plate number.

Obviously, as owners selected from vehicle registration lists were requested to give total accident and incident experience, such events reported by owners had to be checked against the official accident records of the State to eliminate happenings that had a chance of being selected in samples of officially reported accidents. Accordingly, those events reported by owners in response to the mailed questionnaire for which a record could be found in the State's files were dropped from the study. The remaining unmatched groups of accidents and incidents were processed as unreported events. Details concerning sampling procedures, rates of return, data collection and processing methods have been described at considerable length in a previous report and need not be repeated here (*1*).[3] In the aggregate the study produced 7,184 sample cases of passenger cars and trucks involved in an accident or incident.

Frequent mention is made throughout this article of the cost of passenger car accidents as opposed to the cost of truck accidents. Although the passenger car and truck phases of the study were conducted concurrently, they were in effect two separate surveys. This approach was used because the two classes of vehicles represented different universes, not only from the standpoint of numbers of vehicles registered and frequencies of accidents but also from the consideration of vehicle and vehicle-use characteristics.

Definitions

In general, the terms used throughout the study conform with the definitions given in the manual, *Uniform Definitions of Motor Vehicle Accidents*, adopted by the National Conference on Uniform Traffic Accident Statistics. To aid the reader, some of the commonly used terms are defined here.

Motor-vehicle traffic accident.—Any accident occurring on a trafficway (street, road, highway), causing death, injury, or property damage that involves a motor vehicle *in motion* is a motor-vehicle traffic accident.

Motor-vehicle nontraffic accident.—Any accident involving a motor vehicle *in motion* that occurs entirely on private property or in any place other than a trafficway and causes death, injury, or property damage is a motor-vehicle nontraffic accident.

Motor-vehicle traffic incident.—Any incident involving a motor vehicle *not in motion* that occurs on a trafficway and causes death, injury, or property damage is a motor-vehicle incident.

Motor-vehicle nontraffic incident.—Any incident involving a motor vehicle *not in motion* that occurs entirely on private property or in any other place that is not a trafficway and causes death, injury, or property damage is a motor-vehicle nontraffic incident.

Involvement.—An involvement is defined as a vehicle involved in an accident. As the sampling unit for the study was a license plate number of a vehicle involved in an accident, the cost data developed were the accumulation of costs surrounding selected vehicles involved in accidents and/or incidents. The costs thus determined were factored on the basis of sample selection rates and appropriate adjustments were made for incompleted cases. The term involvement is a useful expression in describing the components of an accident, that is, size and weight of vehicle involved, age of vehicle, age and sex of driver, etc.

Accidents as such were not sampled in the study because of the procedural difficulties in-

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[3] References indicated by italic numbers in parentheses are listed on page 213.

Table 1.—Direct cost of accidents and incidents in Illinois, involving Illinois registered passenger cars and trucks

Accident or incident class	Direct cost of accidents and incidents involving—	
	Passenger cars	Trucks
	1,000 dollars	*1,000 dollars*
Traffic accidents	258, 770	18, 081
Nontraffic accidents	8, 514	1, 951
Traffic incidents	15, 321	610
Nontraffic incidents	8, 064	2, 174
TOTAL	290, 669	22, 816

herent in sampling single vehicle accidents and multiple vehicle accidents and in tracing the ownership of vehicles involved in multivehicular accidents.

Scope of Study

As the primary purpose for undertaking studies of this type is to develop accident cost data, a discussion of cost concepts is necessary. The theory upon which such studies are based, as developed by a committee of the Highway Research Board in 1949, may be stated briefly as those costs represented by the money value of damages and losses to persons and property. Money spent by persons involved in accidents may or may not be the same as the money value of damages or losses. Damage to property may not be repaired and losses may not be compensated for, but such costs are included in the money value concept as they will be realized in the form of depreciated value or decreased earnings. Payment for damages and losses is not always made by the vehicle owner or person injured; the driver or owner of another vehicle may pay the costs; insurance companies may reimburse in full or in part for damages; hospitals, doctors, and others may furnish services and not be compensated fully; and courts may award damages in excess of or less than actual costs. No attempt has been made here to trace the transfer of money or to determine actual amounts of money spent, except to the extent that such expenditures measure the money value of damages or losses to persons and property.

Direct costs are composed of the money value of: Damage to property, ambulance use, hospital and treatment services, doctor and dentist services, loss of use of vehicle, value of work time lost, legal and court fees, damage awards and settlements, and other miscellaneous items. The valuation of these direct costs was made on the basis of information supplied by persons whose vehicles were involved in accidents, by persons who were injured in accidents, relatives of injured persons, doctors and dentists, insurance agents and brokers, attorneys, police, and others. A detailed explanation of the different cost elements considered in the study is given in reference *1*.

Table 2.—Number of vehicles involved in reported and unreported traffic accidents in Illinois during 1958, and the total direct cost of such accidents

Vehicle type	Number of vehicles involved in accidents	Percent of total	Total direct cost	Percent of total	Cost per involvement	Involvements per 10 million vehicle-miles [1]	Cost per vehicle-mile [2]
PASSENGER CARS							
Reported involvements	317, 100	24. 1	$149, 198, 000	57. 7	$471	119	0. 56
Unreported involvements	1, 000, 600	75. 9	109, 572, 000	42. 3	110	374	. 41
TOTAL	1, 317, 700	100. 0	258, 770, 000	100. 0	196	493	. 97
TRUCKS							
Single-unit trucks:							
Reported involvements	20, 600	18. 8	$5, 818, 000	43. 3	$282	50	0. 14
Unreported involvements	89, 100	81. 2	7, 607, 000	56. 7	85	216	. 19
Subtotal	109, 700	100. 0	13, 425, 000	100. 0	122	266	. 33
Truck combinations:							
Reported involvements	4, 500	24. 5	2, 367, 000	50. 8	526	54	0. 28
Unreported involvements	13, 900	75. 5	2, 289, 000	49. 2	165	167	. 28
Subtotal	18, 400	100. 0	4, 656, 000	100. 0	253	221	. 56
All types of trucks:							
Reported involvements	25, 100	19. 6	8, 185, 000	45. 3	326	51	0. 16
Unreported involvements	103, 000	80. 4	9, 896, 000	54. 7	96	207	. 20
TOTAL	128, 100	100. 0	18, 081, 000	100. 0	141	258	. 36

[1] Travel of Illinois registered vehicles: Passenger cars, 26,748,000,000 vehicle-miles; single-unit trucks, 4,124,000,000 vehicle-miles; and truck combinations, 832,000,000 vehicle-miles.

[2] Fraction of one cent.

Such items as loss of future earnings of persons killed or permanently injured in accidents were excluded from the direct cost phase of the study, except to the extent that damage awards or settlements made either in or out of court might have compensated for such losses. Expenditures also excluded from the direct cost phase of the study were those made by public and private agencies in the interest of accident prevention or to mitigate the economic burden of accidents and the overhead cost of automobile and certain other types of insurance.

The summary in table 1 provides an overall perspective of total direct costs of accidents and incidents that occurred in Illinois during 1958, as determined in this study. Upon adding the cost out-of-State accidents and incidents of Illinois vehicles to the above data, total direct costs would be as follows: Passenger cars, $309.5 million; and trucks, $29.3 million. The costs thus determined in the study amounted to one-third of a billion dollars, or an average of $928,000 per day.

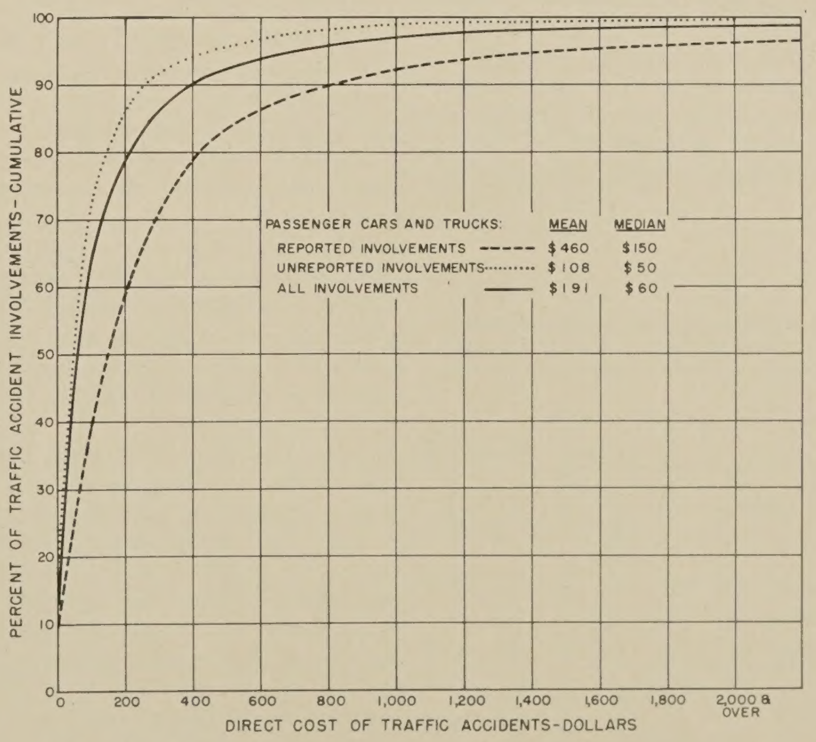

Figure 1.—Cumulative percentage distribution of reported and unreported traffic accident involvements, plotted in $100 direct-cost intervals.

Table 3.—Number of Illinois registered vehicles in use during 1958, and average annual in-State travel per vehicle

Vehicle type	Vehicles in use	Average annual travel
Passenger cars	2, 876, 000	9, 300
Single-unit trucks:		
Panels and pickups	194, 400	11, 950
Other 2-axle trucks	153, 800	10, 900
3-axle trucks	6, 600	19, 140
All single-unit trucks	354, 800	11, 620
Truck combinations:		
3-axle tractor semitrailers	12, 000	24, 850
Other truck combinations	11, 300	47, 340
All combinations	23, 300	35, 740

In order to avoid possible misconceptions, the fact is emphasized that the data do not include the cost of all accidents occurring on Illinois highways. Only direct costs to persons and property associated with accidents or incidents involving privately owned Illinois registered passenger cars and trucks have been included. Specifically, the data are representative of the costs incurred by owners and occupants of Illinois passenger cars and trucks, pedestrians, and other nonmotorists involved in such accidents. Direct costs excluded from the study were those to persons and property associated with accidents that involved: (1) Out-of-State registered motor vehicles of all types, (2) publicly owned motor vehicles of all types, and (3) Illinois registered buses, motorcycles, motorized bicycles and scooters, and any special purpose vehicles. Costs incurred by owners and occupants of these three categories of vehicles have been excluded even though such vehicles may have been involved in an accident with a privately owned Illinois passenger car or truck.

Although the study encompassed total accident and incident experience of Illinois passenger car and truck owners, regardless of whether the events occurred on or off the highway or in or out of State, subsequent discussion in this article is restricted to traffic accidents occurring on Illinois highways and streets.

Table 4.—Distribution of Illinois registered vehicles involved in traffic accidents and the corresponding direct costs, by severity of accident

Severity of accident	Distribution of accident involvements and costs	
	Percent of vehicles involved	Percent of cost
Passenger cars:		
Fatal injury	0. 1	3. 1
Nonfatal injury	12. 5	52. 2
Property damage only	87. 4	44. 7
TOTAL	100. 0	100. 0
Trucks:		
Fatal injury	0. 2	6. 7
Nonfatal injury	7. 6	37. 2
Property damage only	92. 2	56. 1
TOTAL	100. 0	100. 0

Table 5.—Number of traffic accident involvements in Illinois involving vehicles of Illinois registry, 1958, classified by severity of accident and cost elements incurred

Cost element	Passenger car accidents				Truck accidents			
	Fatal injury	Nonfatal injury	Property damage only	Total	Fatal injury	Nonfatal injury	Property damage only	Total
Number of involvements having:								
Damage to vehicle	1, 391	142, 824	990, 672	1, 134, 887	189	6, 001	66, 639	72, 829
Damage to property in vehicle	75	2, 708	12, 929	15, 712	44	384	2, 158	2, 586
Damage to objects struck by vehicle	85	2, 067	17, 252	19, 404	18	195	3, 295	3, 508
Miscellaneous property damage	28	3, 450	5, 263	8, 741	27	137	1, 488	1, 652
Involvements having one or more property damage cost elements	1, 391	143, 259	1, 000, 539	1, 145, 189	193	6, 087	68, 539	74, 819
Ambulance costs	625	7, 224	--------	7, 849	55	761	------	816
Doctor and dentist fees	903	84, 104	--------	85, 007	105	2, 827	------	2, 932
Hospital and treatment costs	940	64, 188	--------	65, 128	93	2, 089	------	2, 182
Miscellaneous injury costs	334	6, 885	--------	7, 219	27	261	------	288
Involvements having one or more injury cost elements	1, 067	94, 703	--------	95, 770	119	2, 967	------	3, 086
Loss of use of vehicle costs	43	6, 473	23, 037	29, 553	55	780	5, 796	6, 631
Value of time lost from work	653	77, 368	22, 817	100, 838	94	2, 428	3, 612	6, 134
Legal and court costs	734	37, 296	10, 108	48, 138	90	1, 342	644	2, 076
Damage awards in excess of known costs	705	48, 810	9, 227	58, 742	109	1, 130	96	1, 335
SUMMARY:								
Involvements having one or more direct cost elements	1, 532	155, 057	1, 003, 041	1, 159, 630	232	6, 718	69, 882	76, 832
Involvements incurring no costs	28	9, 534	148, 466	158, 028	5	2, 955	48, 293	51, 253
Total involvements	1, 560	164, 591	1, 151, 507	1, 317, 658	237	9, 673	118, 175	128, 085

Reported and Unreported Accident Involvements

Data included in table 2 show the relationship of reported and unreported accident involvements and the corresponding costs. An unreported involvement refers to an event for which no record of an owner's report could be found in the accident report files maintained by the Illinois Division of Highways. Several factors could account for this, but the principal one would be that property damage costs were less than the legal reporting minimum. If the accident were of the reportable category and no record could be found, one of the following conditions might apply: The owner may have reported the accident to local authorities but not to the State; the owner may have failed to report the happening to any governmental authority; or through error the accident report may have been overlooked in the search of the State's accident files. Every effort was made to prevent the latter possibility through a careful review of all reportable accidents.

Approximately 1.3 million Illinois passenger cars of private ownership were involved in traffic accidents on Illinois roads and streets during 1958. Direct costs of these accidents amounted to $258.8 million or an average of $196 per passenger car involved. Totals include all degrees of severity—fatal, nonfatal, and property-damage-only accidents. Three-fourths of these events were not officially reported to the Illinois Division of Highways, and in the aggregate they accounted for more than two-fifths of the total cost. The mean value for unreported passenger car involvements was $110 and the median value was $50.

Approximately 128,000 trucks were involved in accidents costing $18.1 million, or an average of $141 for each event. Unreported involvements accounted for four-fifths of the number and more than one-half of the total cost. The mean and median values for unreported truck involvements were $96 and $20, respectively.

It should not be construed that all unreported involvements in which costs exceeded $100 were in violation of the reporting law. The cost values include elements that do not enter into the legal reporting requirement of damage to property. For example, such elements as time lost from work or loss of use of vehicle are included when applicable in the cost values shown in table 2.

The cost distribution of reported and unreported involvements is illustrated in figure 1. It is clearly evident that a very high proportion of unreported involvements were relatively minor events. Ninety-two percent of these unreported events cost less than $300 each. The same percentage for officially reported involvements indicated costs of less than $1,000.

Accident Exposure

Accident involvement rates for passenger cars calculated on the basis of 10 million vehicle-miles of travel, as shown in table 2, were nearly twice those for trucks, and the cost of accidents per vehicle-mile of travel approached 1 cent for passenger cars, 2.7 times the rate for trucks. When trucks were considered on the basis of single units and combinations, the data showed a lower involvement rate for combinations but a higher cost per vehicle-mile. This relationship could logically be expected as most operators of truck combinations would be more experienced and skillful drivers. Vehicle and vehicle-use characteristics should also be considered in such a comparison. On the other hand, when the heavy units were involved in accidents, they tended to be more severe and costly, particularly when cargo damage was involved. Among the single-unit trucks, panels and pickups accounted for 55 percent of the vehicles in use, 56 percent of the travel, and 53 percent of the single-unit vehicles involved in accidents. These two truck types are often used for personal transportation, and in many respects their operation is similar to that of passenger cars.

Privately owned Illinois vehicles registered and in use during 1958 and their average annual in-State travel per vehicle (*2*) are shown in table 3. In relating vehicles in use to the number of vehicles involved in accidents, it was found that the probability of a passenger car being involved in a traffic accident was once in 26 months; for single-unit trucks, once in 39 months; and for truck combinations, once in 15 months. Exposure to accidents, based on average annual travel, was three times greater for truck combinations than for single-unit trucks, and nearly four times greater than for passenger cars.

Table 6.—Direct cost of traffic accidents in Illinois involving vehicles of Illinois registry, 1958, classified by severity of accident and cost elements incurred

Cost element	Direct cost of passenger car accidents				Direct cost of truck accidents			
	Fatal injury	Nonfatal injury	Property damage only	Total	Fatal injury	Nonfatal injury	Property damage only	Total
Property damage:								
Damage to vehicle	$1, 196, 385	$41, 368, 456	$109, 795, 996	$152, 360, 837	$270, 836	$2, 191, 845	$7, 642, 290	$10, 104, 971
Damage to property in vehicle	8, 225	160, 670	645, 458	814, 353	38, 222	80, 001	171, 903	290, 126
Damage to objects struck by vehicle	23, 218	406, 368	1, 688, 634	2, 118, 220	2, 368	164, 805	704, 232	871, 405
Miscellaneous property damage	846	69, 548	142, 302	212, 696	1, 761	6, 095	17, 267	25, 123
Subtotal	1, 228, 674	42, 005, 042	112, 272, 390	155, 506, 106	313, 187	2, 442, 746	8, 535, 692	11, 291, 625
Treatment of injuries:								
Ambulance costs	19, 317	173, 300	--------	192, 617	1, 495	17, 234	------	18, 729
Doctor and dentist fees	354, 709	10, 304, 366	--------	10, 659, 075	25, 325	615, 569	------	640, 894
Hospital and treatment costs	686, 858	9, 415, 140	--------	10, 101, 998	32, 178	339, 578	------	371, 756
Miscellaneous injury costs	29, 845	318, 974	--------	348, 819	1, 246	11, 395	------	12, 641
Subtotal	1, 090, 729	20, 211, 780	--------	21, 302, 509	60, 244	983, 776	------	1, 044, 020
Loss of use of vehicle costs	10, 152	666, 718	1, 013, 342	1, 690, 212	61, 697	236, 266	1, 446, 990	1, 744, 953
Value of time lost from work	636, 239	17, 274, 842	846, 022	18, 757, 103	63, 436	1, 688, 287	129, 008	1, 880, 731
Legal and court costs	1, 557, 909	23, 301, 020	1, 091, 790	25, 950, 719	146, 509	542, 818	28, 056	717, 383
Damage awards in excess of known costs	3, 372, 203	31, 655, 984	534, 784	35, 562, 971	570, 297	830, 934	1, 301	1, 402, 532
TOTAL COST	7, 895, 906	135, 115, 386	115, 758, 328	258, 769, 620	1, 215, 370	6, 724, 827	10, 141, 047	18, 081, 244

Direct Cost Elements

The cost elements that make up the total cost figures shown in table 2 are shown in considerable detail in tables 5–7. The relative number and cost of each of the three severity classes of accidents are shown in table 4. It is evident that fatal injury involvements accounted for a small proportion of the number and cost of accidents. Also, nonfatal injury accidents involving passenger cars represented a considerably higher proportion of the total costs than similar events involving trucks. Injuries to passengers would largely account for this difference. Trucks normally have only one occupant, the driver.

As mentioned earlier, the cost data do not include values for the loss of future earnings of persons killed or permanently injured, except to the extent that awards or settlements may measure this loss. Awards or settlements are based primarily on the fault concept, and thus the victim or survivors may not have recourse to recover losses caused by death or injury. This situation would apply particularly to single vehicle accidents.

Passenger car and truck involvements that occasioned no costs (or less than $5.00) were very numerous as indicated in table 5. A comparison of such events is shown in table 8. The finding that approximately 2 percent of the fatal injury involvements were of the no cost category might appear unreasonably high at the outset. A typical case would be a passenger car or truck colliding with a pedestrian. Assume that the pedestrian was at fault, that the victim died instantly, that the vehicle was not damaged, that no time was lost from work by the vehicle owner or driver, and that a police vehicle was used to remove the victim from the scene. Under the conditions just outlined, no costs would be assessed for this accident within the scope of the direct cost phase of the study. Funeral costs are not considered as an element of cost in connection with a motor-vehicle accident. Such costs are inevitable; an accident merely fixes the time when they are incurred.

Another example of a no cost involvement applies to a multiple vehicle accident. In a two-car collision, one vehicle might be damaged and the bumper of the other vehicle absorbs the shock. Under the sampling procedure used in the study, either vehicle or both might be selected. A large proportion

Table 7.—Mean values for cost elements incurred in Illinois traffic accidents involving vehicles of Illinois registry, classified by severity of accident

Cost element	Mean cost values for each element of cost incurred in—							
	Passenger car traffic accidents				Truck traffic accidents			
	Fatal injury	Nonfatal injury	Property damage only	All severity classes	Fatal injury	Nonfatal injury	Property damage only	All severity classes
Property damage:								
Damage to vehicle	$860	$290	$111	$134	$1, 433	$365	$115	$139
Damage to property in vehicle	110	59	50	52	869	208	80	112
Damage to objects struck by vehicle	273	197	98	109	132	845	214	248
Miscellaneous property damage	30	20	27	24	65	44	12	15
Mean cost value for involvements in which one or more property damage cost elements were incurred	883	293	112	136	1, 623	401	125	151
Treatment of injuries:								
Ambulance costs	31	24	------	25	27	23	------	23
Doctor and dentist fees	393	123	------	125	241	218	------	219
Hospital and treatment costs	731	147	------	155	346	163	------	170
Miscellaneous injury costs	89	46	------	48	46	44	------	44
Mean cost value for involvements in which one or more injury cost elements were incurred	1, 022	213	------	222	506	332	------	338
Loss of use of vehicle costs	236	103	44	57	1, 122	303	250	263
Value of time lost from work	974	223	37	186	675	695	36	307
Legal and court costs	2, 122	625	108	539	1, 628	404	44	346
Damages awards in excess of known costs	4, 783	649	58	605	5, 232	735	14	1, 051
Mean cost value for involvement in which one or more cost elements were incurred	5, 154	871	115	223	5, 239	1, 001	145	235

Table 8.—Traffic accident involvements, in which no costs were incurred, related to severity of involvements

Severity of accident	No cost involvements as a percent of severity classes	
	Passenger cars	Trucks
	Percent	*Percent*
Fatal injury	1.8	2.1
Nonfatal injury	5.7	30.5
Property damage only	12.9	40.9
All severity classes	12.0	40.0

Table 9.—Samples sizes compared with expanded number of traffic accident involvements

Severity of accident	Number of involvements	Number of sample cases
Passenger cars:		
Fatal injury	1,560	332
Nonfatal injury	164,591	1,761
Property damage only	1,151,507	1,290
TOTAL	1,317,658	3,383
Trucks:		
Fatal injury	237	200
Nonfatal injury	9,673	1,270
Property damage only	118,175	1,556
TOTAL	128,085	3,026

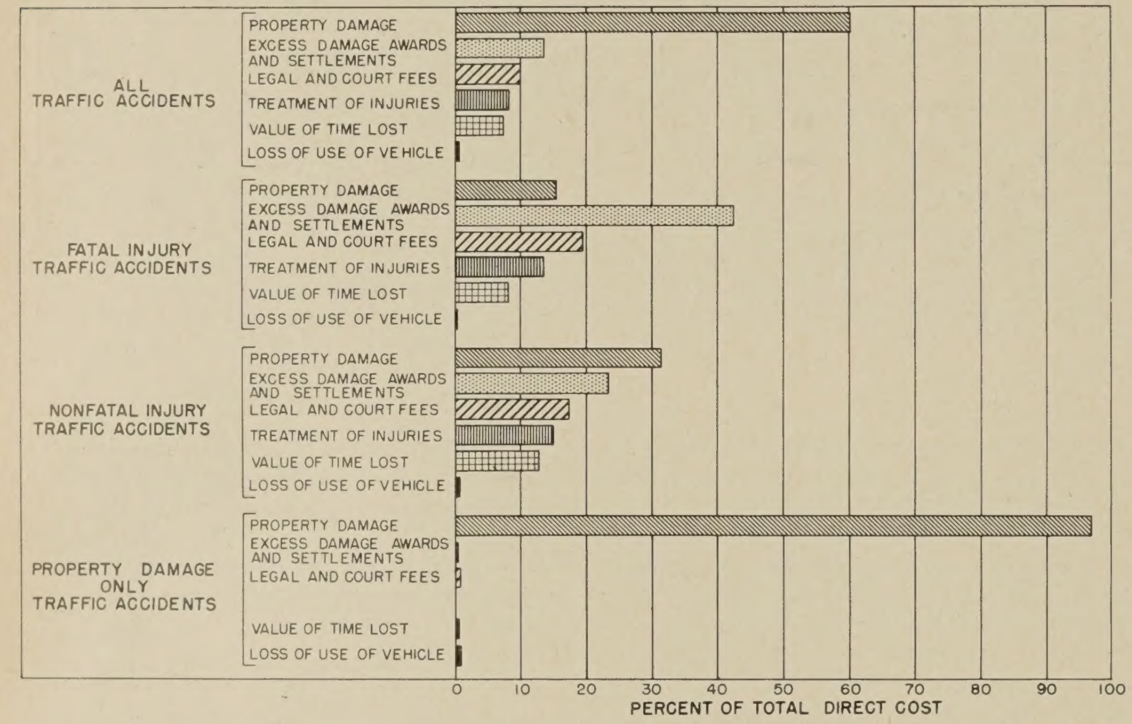

Figure 2.—Percentage distribution of the direct costs of passenger car traffic accidents, by cost element.

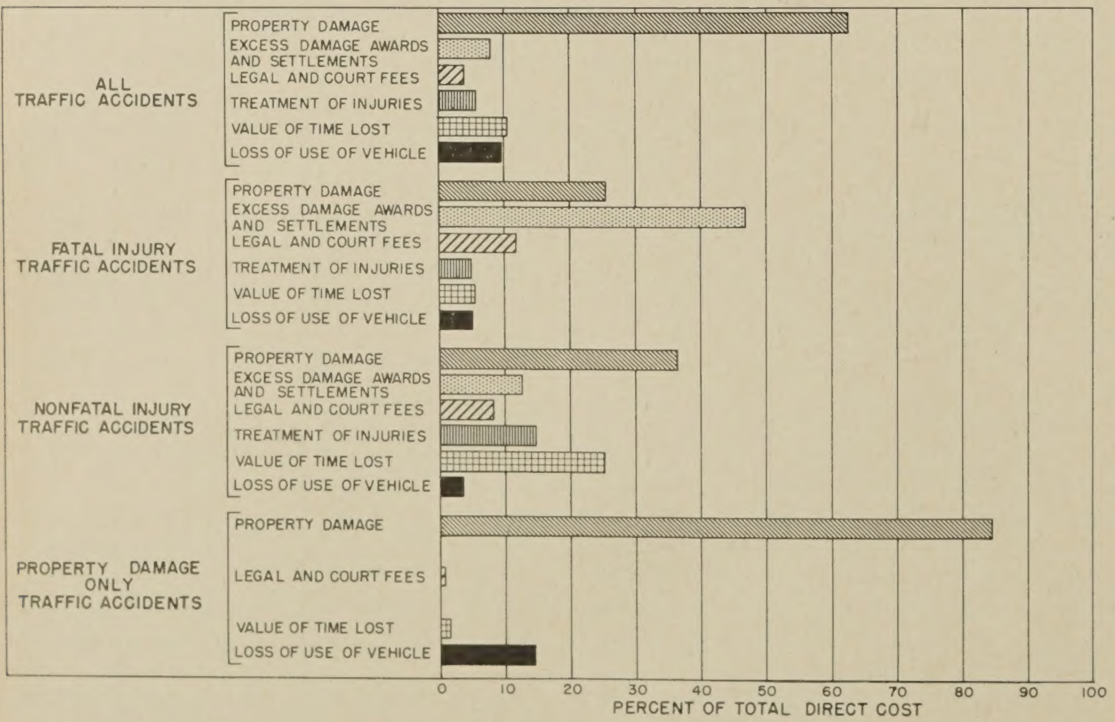

Figure 3.—Percentage distribution of the direct costs of truck traffic accidents, by cost element.

of the no cost involvements were of the unreported accident category, as illustrated in figure 1. Trucks, in particular, were involved in a number of nonfatal injury and property damage only accidents in which no costs were incurred by the owner or occupants of the vehicle selected. This situation is explained partially by the fact that most truck accidents involved collisions with passenger cars. Conditions acting in favor of trucks from the cost standpoint were the lower occupancy rate (persons per vehicle) and vehicle capability to withstand impact. The severity classification is determined by the accident and not by what takes place in one of the vehicles involved.

In a study based upon sampling techniques, it is obvious that the greater the detail provided in tabular form the greater the chance of exceeding the built-in limitations of sample size. As an indication of the strength of the data reported in tables 5–7, a comparison of sample sizes and expanded totals is provided in table 9.

The total cost figure of $258.8 million for passenger car accidents, reported in table 6, is based upon 3,383 completed sample cases, and the amount of $18.1 million for trucks is based upon 3,026 cases. The ratios of sample cases to the expanded number of involvements do not reflect the sampling rates as originally selected. As mentioned earlier, two sampling sources were used—official accident reports and registration lists—and different sampling rates applied. A full description of sampling procedures is given in reference *1*.

Cost data shown in table 6 are further illustrated in figures 2 and 3. The top set of bars in figure 2, arranged in order of magnitude, shows the distribution of the accident dollar. Property damage accounted for 60 percent (60 cents of the accident dollar) of the total cost of all passenger car traffic accidents, and 62 percent of all truck traffic accidents (fig. 3). Treatment of injuries, legal and court fees, and excess damage awards and settlements accounted for a larger proportion of the total cost of passenger car accidents than for trucks. On the other hand, costs related to time loss and loss of use of vehicle represented a larger proportion of the total cost for trucks than for passenger cars. The cost element "loss of use of vehicle" is not too significant in the case of passenger car owners because in most cases the use of the vehicle is not essential in earning a livelihood. The latter criterion is used in determining such costs.

For truck owners, and particularly fleet operators, no loss of use of vehicle costs have been included when standby equipment was available to replace the damaged vehicle. Only a part of the cost of maintaining standby equipment could properly be charged to motor-vehicle accidents as standby vehicles are brought into service for purposes other than accidents; such as, peak operations, maintenance of equipment, etc. The pro-rata share of the overhead cost of maintaining standby equipment to be charged to accidents would be included in the indirect cost phase of accident cost studies.

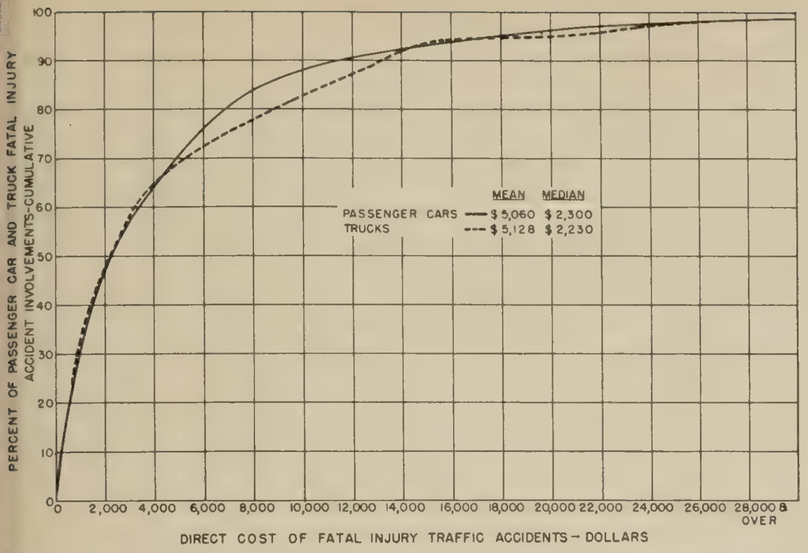

Figure 4.—Cumulative percentage distribution of passenger car and truck fatal injury traffic accident involvements, plotted in $1,000 direct-cost intervals.

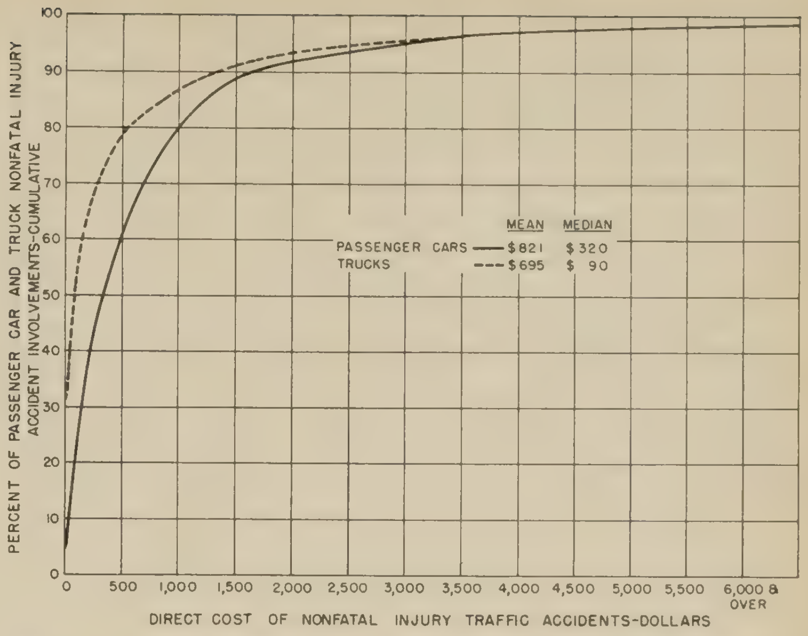

Figure 5.—Cumulative percentage distribution of passenger car and truck nonfatal injury traffic accident involvements, plotted in $100 direct-cost intervals.

Damage awards and settlements in excess of known costs represented the greatest part of the accident dollar for both passenger car and truck fatal injury accidents. In determining excess awards and settlements, compensation received by each injured person or survivor and by each vehicle owner was considered on an individual basis. Payments received by the injured person or vehicle owner from his own insurance company were not considered as awards or settlements, as such payments would simply represent a return of capital. Damage awards and settlements include payments made by the other party, presumably the one found liable. Lump-sum payments under workmen's compensation were included also.

In the case of an injured person, known costs of ambulance use, hospitalization, doctor and dentist fees, time loss, legal fees, etc., were deducted from the award or settlement, and any surplus represented reimbursement for costs that could not be classified. A vehicle owner may also receive a settlement for damage to his vehicle, other property, time loss, loss of use of vehicle, etc., and the settlement may exceed the known costs. The surplus again was treated as an unclassified cost.

In the study procedure, awards and out-of-court settlements were recorded in total, regardless of whether the amounts were less than, equal to, or greater than the actual money value of damages and losses. Obviously, the total amount of an award or settlement could not be added to the previously determined money value of damages and losses as this procedure would duplicate all or part of the costs. For this reason, the amount of damage awards and settlements was ascertained, but only the part that was in excess of the value of damages and losses was included in the cost of accidents. Such excess awards or settlements could represent compensation for pain and suffering, loss of future earnings of persons killed or permanently injured, future medical expenses, and other indeterminable costs.

Mean values for each element of cost incurred in passenger car and truck accidents, as reported in table 7, were heavily influenced by high cost accidents. Median values for each cost element would be substantially lower than the values reported. The positive skewness of the cost curves for each of the severity classes of accidents is illustrated later.

The final entry in table 7 indicates the average costs of accident involvements in which one or more cost elements were incurred. Truck involvements for each severity class averaged higher costs than was the case for passenger cars. Costs sustained in traffic accidents of all severity classes averaged $223 for passenger car involvements and $235 for truck involvements. After including involvements in which no costs were incurred, as reported in table 5, the averages dropped to $196 and $141, respectively.

Skewness of Cost Distribution

The difficulties of sampling the universe of traffic accident involvements for the purpose of determining cost data are apparent after viewing the cumulative percentage curves in figures 4–7. Findings of the study show a range of costs per vehicle involvement from zero (or less than $5) to $136,800. Figure 4

Table 10.—Number of vehicles involved in traffic accidents and the direct costs of such accidents, classified by vehicle type and accident location

Vehicle type	Rural areas	Municipality populations				
		Under 5,000	5,000—24,999	25,000—125,000	1,000,000 and over	All municipalities
NUMBER OF VEHICLES INVOLVED IN TRAFFIC ACCIDENTS						
Passenger cars	190, 975	77, 463	234, 189	302, 828	512, 203	1, 126, 683
Trucks:						
Single-unit:						
Panels and pickups	9, 376	7, 539	6, 663	11, 412	22, 095	47, 709
Other single-unit trucks	13, 172	2, 345	5, 806	9, 985	19, 789	37, 925
All single-unit trucks	22, 548	9, 884	12, 469	21, 397	41, 884	85, 634
Truck combinations	3, 781	1, 049	1, 797	3, 220	8, 506	14, 572
Unknown truck type	487	--------	102	493	468	1, 063
All single-unit trucks and truck combinations	26, 816	10, 933	14, 368	25, 110	50, 858	101, 269
DIRECT COST OF TRAFFIC ACCIDENTS						
Passenger cars	$60, 981, 882	$11, 324, 294	$29, 745, 538	$45, 289, 744	$111, 428, 162	$197, 787, 738
Trucks:						
Single-unit:						
Panels and pickups	4, 046, 099	552, 199	507, 201	1, 025, 711	1, 494, 471	3, 579, 582
Other single-unit trucks	2, 991, 158	291, 468	305, 192	832, 470	1, 309, 983	2, 739, 113
All single-unit trucks	7, 037, 257	843, 667	812, 393	1, 858, 181	2, 804, 454	6, 318, 695
Truck combinations	2, 059, 289	522, 112	516, 291	347, 532	1, 211, 188	2, 597, 123
Unknown truck type	9, 963	--------	3, 057	40, 528	15, 332	58, 917
All single-unit trucks and truck combinations	9, 106, 509	1, 365, 779	1, 331, 741	2, 246, 241	4, 030, 974	8, 974, 735

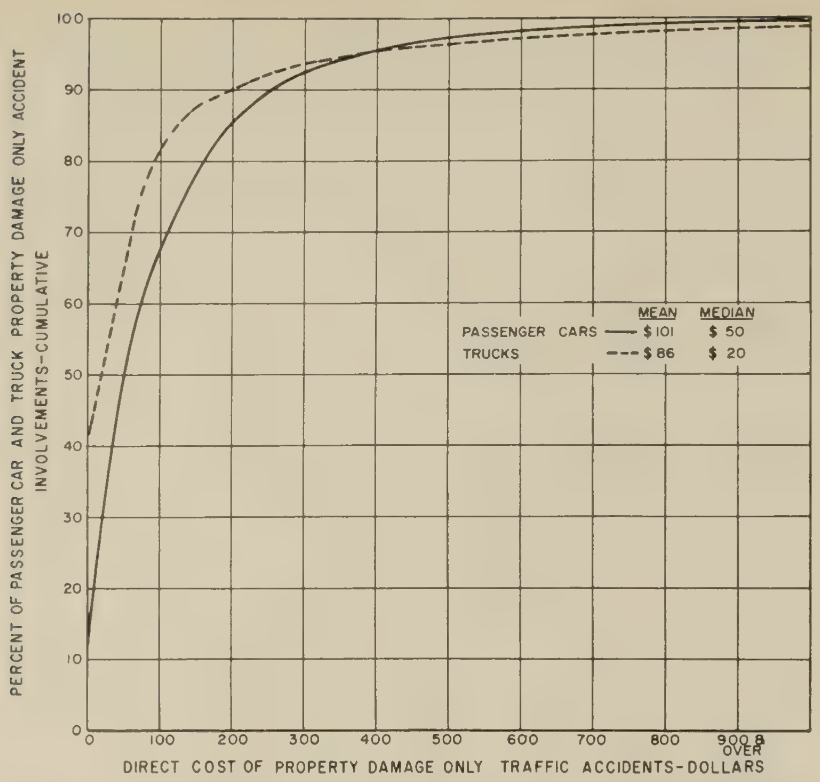

Figure 6.—Cumulative percentage distribution of passenger car and truck property damage only traffic accident involvements, plotted in $50 direct-cost intervals.

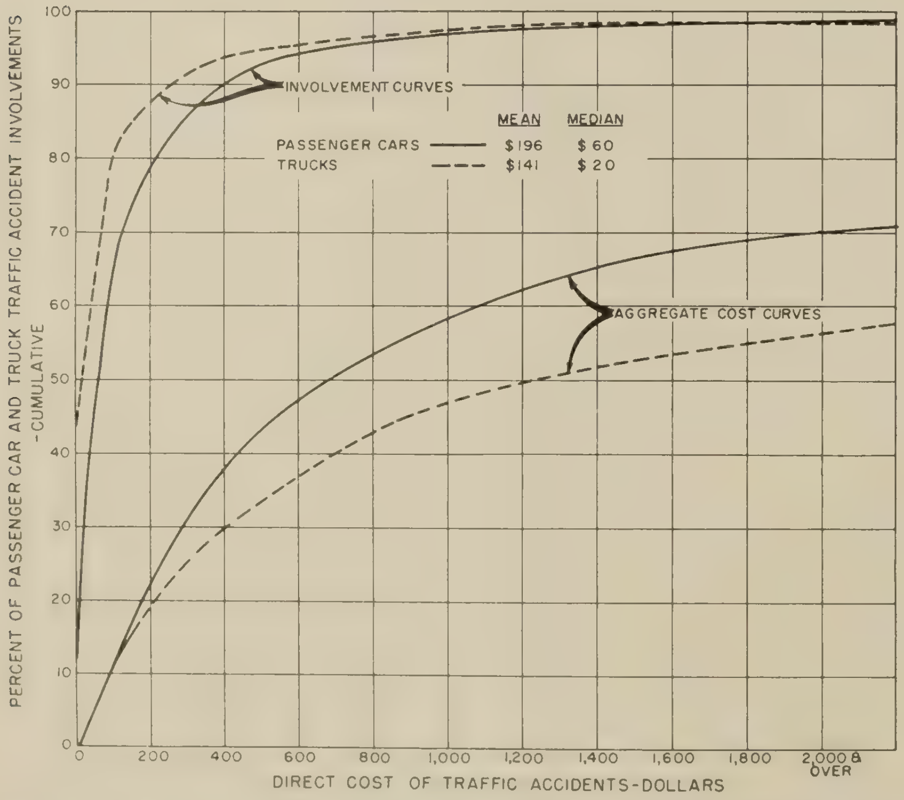

Figure 7.—Cumulative percentage distribution of passenger car and truck traffic accident involvements and aggregate costs, plotted in $100 direct-cost intervals.

illustrates the case in point. Ninety percent of the fatal injury passenger car involvements fell within the cost range of $11,600 or less; a similar percentage for trucks indicated a range of $13,200 or less. The remaining 10 percent of the fatal injury passenger car involvements accounted for 48 percent of the total direct costs of fatal injury accidents. For trucks, the same proportionate group accounted for 45 percent of the total direct costs of fatal injury accidents. The extreme plotting interval in figure 4 of $28,000 and over was representative of only 1½ percent of the total fatal injury involvements for both passenger cars and trucks, and yet this remote class accounted for nearly 19 percent of the costs of fatal injury passenger car accidents and nearly 12 percent of the total in the case of trucks.

The cumulative percentage curves for nonfatal injury accident involvements are illustrated in figure 5. Again the extreme plotting interval of $6,000 and over was representative of 1½ percent of both passenger car and truck nonfatal injury involvements. This group, however, accounted for 26 percent of the total cost of nonfatal injury passenger car involvements and 22 percent of the total in the case of trucks.

As would be expected, the range in costs of property damage only involvements was less extreme than was found for fatal and nonfatal injury involvements. There are exceptional cases though. A heavily damaged passenger car usually causes injury to the driver or a passenger. Trucks, on the other hand, may run off the highway, overturn, and cause excessive damage to vehicle and load, but the driver may escape unscathed. The plotting interval of $900 and over, shown in figure 6, accounted for 0.5 percent of the passenger car involvements and slightly over 1 percent for trucks. Costs represented by these small groups accounted for 5 percent of the total for passenger cars and 25 percent of the total for trucks.

As a further indication of the extreme cost values found in the study, fatal injury involvements ranged from zero to $136,800 for passenger cars and from zero to $46,200 for trucks. Nonfatal injury involvements ranged from zero to $73,300 for passenger cars and to $53,700 for trucks. Property damage only involvements reached a maximum of $1,400 for passenger cars and $30,100 for trucks.

High cost accident cases found in the Illinois study pointed to the need for further refinement in sample design. The extent of such refinement in sample design depends largely upon the data available on tabulating cards in a given State's files of officially reported accidents. Of necessity, the sampling procedures in the past have been adapted to existing records.

Composite involvement and aggregate cost curves for all severity classes of involvements are shown in figure 7. The average or mean value for passenger car involvements was $196 and for trucks was $141. The midvalues or medians were considerably less—$60 and $20. The cost interval of $2,000 and over, plotted at the extreme right of figure 7, represents only 1 percent of the total of 1.3 million passenger car involvements and 30 percent of the total direct costs of $258.8 million. An identical comparison for trucks indicates that 1½ percent of the 128,100 involvements fell within the cost interval of $2,000 and over, and this group accounted for 44 percent of the $18.1 million total.

By selecting the cost interval of $10,000 and over, generally the lower limit for bodily injury and liability insurance, 0.1 percent or 1,339 passenger car involvements out of the total of 1,317,700 and 0.07 percent or 90 of the truck involvements out of a total of 128,100 fell into this cost interval. These relatively few involvements, however, accounted for 10 and 11 percent, respectively, of the total direct cost of passenger car and truck accidents.

On the basis of the above Statewide comparison, and assuming that 1958 experience of Illinois owners was typical, the chance of a passenger car owner being involved in an accident in which the costs associated with his vehicle would amount to $10,000 or more would be about 1 in 1,000; for truck owners, the probability of such an event would be about 1 in 1,400. As indicated previously, 2,876,000 Illinois passenger cars were driven the equivalent of 26.7 billion vehicle-miles in 1958. By referring again to the 1,339 passenger car involvements in which costs equalled or exceeded $10,000, it is evident that the frequency of such an occurrence would be 5.0 involvements per 100 million vehicle-miles, or 1.0 involvement per 20 million vehicle-miles. On this basis, one of approximately forty passenger car owners in a lifetime of vehicle ownership would be expected to experience an accident in which the costs associated with his vehicle would equal or exceed $10,000.

Data included in figures 8–10 show the cost distribution of fatal, nonfatal, and property damage only involvements on the basis of the number of involvements rather than percent of involvements as illustrated in figures 4–7. The bars in figures 8–10 are representative of the combined number of passenger car and truck involvements. Figure 11 represents a composite distribution for all severity classes of involvements. Many of the characteristics of the cost distribution for each of the severity classes have already been mentioned and need no further emphasis. The bar charts, however, illustrate more forcefully the positive skewness of accident cost curves and emphasize the inherent problems in sampling the universe of accident involvements for the purpose of determining costs. Obviously, the high cost involvements are subject to considerable sampling variability.

Frequencies and Costs of Accident Involvements Related to Accident Location

The usual approach in determining accident exposure is to relate the number of accidents to vehicle-miles of travel. Fortunately the motor-vehicle-use study, conducted by the Illinois Division of Highways during 1958, complements the motor-vehicle accident cost study. The availability of this information is an invaluable aid in relating accidents to highway- and vehicle-use characteristics.

Data included in tables 10 and 11 provide the basis for determining the frequencies and costs of accident involvements occurring in rural areas and municipalities. The term municipality is used to denote incorporated places regardless of population size. Unincorporated places are included in the rural classification.

Numbers of vehicles involved in traffic accidents and the corresponding costs are not too meaningful unless such events can be related to exposure. Involvement and cost rates per 10 million vehicle-miles of travel are reported in table 12 for passenger cars and major classes of trucks. Passenger car involvement rates ranged from 191 per 10 million vehicle-miles of travel in rural areas to 672 in municipalities of all population sizes, or a ratio of 1 accident involvement in ruaal areas for every 3.5 involvements in municipalities. For single-unit trucks, the ratio was 1 to 4.8; and for truck combinations, 1 to 6.4.

Table 11.—Vehicle-miles of travel in Illinois by vehicles of different types, classified by the location of travel [1]

Vehicle type	Vehicle-miles of travel (1,000)					
	Rural areas	Municipality populations				
		Under 5,000	5,000–24,999	25,000–125,000	1,000,000 and over	Total
Passenger cars	9, 986, 084	1, 984, 221	3, 012, 843	4, 064, 738	7, 700, 420	16, 762, 222
Trucks:						
Single-unit:						
Panels and pickups	1, 239, 747	176, 595	236, 846	246, 216	422, 536	1, 082, 193
Other single-unit trucks	1, 072, 841	125, 410	144, 528	149, 807	309, 226	728, 971
All single-unit trucks	2, 312, 588	302, 005	381, 374	396, 023	731, 762	1, 811, 164
Truck combinations	521, 188	63, 672	60, 389	42, 480	144, 929	311, 470
All single-unit trucks and truck combinations	2, 833, 776	365, 677	441, 763	438, 503	876, 691	2, 122, 634

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[1] Data represent travel of Illinois registered vehicles in use. Source: *Motor Vehicle Use Study*, State of Illinois, Department of Public Works and Buildings, Division of Highways, October 1961.

Table 12.—Number of vehicles involved in traffic accidents and the direct costs of such accidents, per 10 million vehicle-miles of travel, classified by vehicle type and accident location

Vehicle type	Rural areas	Municipality populations				
		Under 5, 000	5, 000–24, 999	25, 000–125, 000	1, 000, 000 and over	All municipalities
NUMBER OF VEHICLES INVOLVED IN TRAFFIC ACCIDENTS PER 10 MILLION VEHICLE-MILES						
Passenger cars	191	390	777	745	665	672
Trucks:						
Single-unit:						
Panels and pickups	76	427	281	463	523	441
Other single-unit trucks	123	187	402	667	640	520
All single-unit trucks	98	327	327	540	572	473
Truck combinations	73	165	298	758	587	468
All single-unit trucks and truck combinations	95	299	325	573	580	477
DIRECT COST OF TRAFFIC ACCIDENTS PER 10 MILLION VEHICLE-MILES						
Passenger cars	$61, 067	$57, 072	$98, 729	$111, 421	$144, 704	$117, 996
Trucks:						
Single-unit:						
Panels and pickups	32, 636	31, 269	21, 415	41, 659	35, 369	33, 077
Other single-unit trucks	27, 881	23, 241	21, 116	55, 569	42, 363	37, 575
All single-unit trucks	30, 430	27, 936	21, 302	46, 921	38, 325	34, 887
Truck combinations	39, 511	82, 000	85, 494	81, 811	83, 571	83, 383
All single-unit trucks and truck combinations	32, 136	37, 349	30, 146	51, 225	45, 979	42, 281

Table 13.—Number of municipalities and population, by city size groups in Illinois

Population group	Number of cities	Population, 1958
Under 5,000	1, 026	1, 135, 700
5,000–24,999	138	1, 399, 500
25,000–125, 000	33	1, 750, 100
1,000,000 and over	1	3, 614, 100
Subtotal	1, 198	7, 899, 400
Rural areas		1, 762, 700
TOTAL	1, 198	9, 662, 100

Table 14.—Number and cost of traffic accidents in Cook and Du Page Counties, Ill., during 1958

Street system	Rates per 10 million vehicle-miles	
	Number of accidents	Direct costs
Expressways	51	$30, 800
Arterials	243	107, 200
Local streets	1, 021	309, 400
All systems	347	132, 400

Direct costs of accident involvements per 10 million vehicle-miles of travel are shown in the lower half of table 12. On the basis of relative exposure, the cost of passenger car involvements ranged from $61,100 per 10 million vehicle-miles in rural areas to $118,000 in municipalities. Similar comparisons for single-unit trucks indicated a range of $30,400

Table 15.—Number of vehicles involved in traffic accidents and the direct costs of such accidents, classified by major vehicle type and highway system

Highway systems	Illinois registered passenger cars			Illinois registered single-unit trucks [1]			Illinois registered truck combinations			Illinois registered trucks, all types		
	Rural	Municipal	Total	Rural	Municipal	Total	Rural	Municipal	Total	Rural	Municipal	Total
NUMBER OF VEHICLES INVOLVED IN TRAFFIC ACCIDENTS												
Federal-aid primary and State highways	88, 809	221, 656	310, 465	10, 855	17, 485	28, 340	3, 082	5, 257	8, 339	13, 937	22, 742	36, 679
Federal-aid secondary:												
State highways	19, 876	5, 928	25, 804	788	667	1, 455	36	33	69	824	700	1, 524
Local roads	14, 166	4, 135	18, 301	1, 714	24	1, 738	38	----------	38	1, 752	24	1, 776
Subtotal	34, 042	10, 063	44, 105	2, 502	691	3, 193	74	33	107	2, 576	724	3, 300
Non-Federal-aid:												
State highways	9, 330	111, 402	120, 732	1, 534	12, 165	13, 699	252	2, 025	2, 277	1, 786	14, 190	15, 976
Local roads	58, 794	783, 562	842, 356	8, 144	56, 356	64, 500	373	7, 257	7. 630	8, 517	63, 613	72, 130
Subtotal	68, 124	894, 964	963, 088	9, 678	68, 521	78, 199	625	9, 282	9, 907	10, 303	77, 803	88, 106
All roads and streets:												
State highways	118, 015	338, 986	457, 001	13, 177	30, 317	43, 494	3, 370	7, 315	10, 685	16, 547	37, 632	54, 179
Local roads	72, 960	787, 697	860, 657	9, 858	56, 380	66, 238	411	7, 257	7, 668	10, 269	63, 637	73, 906
TOTAL	190, 975	1, 126, 683	1, 317, 658	23, 035	86, 697	109, 732	3, 781	14, 572	18, 353	26, 816	101, 269	128, 085
DIRECT COST OF TRAFFIC ACCIDENTS												
Federal-aid primary and State highways	$34, 089, 866	$45, 582, 939	$79, 672, 805	$4, 543, 900	$1, 305, 646	$5, 849, 546	$1, 510, 563	$1, 743, 175	$3, 253, 738	$6, 054, 463	$3, 048, 821	$9, 103, 284
Federal-aid secondary:												
State highways	3, 292, 274	1, 270, 202	4, 562, 476	144, 672	95, 649	240, 321	4, 641	788	5, 429	149, 313	96, 437	245, 750
Local roads	4, 611, 364	327, 622	4, 938, 986	429, 755	231	429, 986	315, 935	----------	315, 935	745, 690	231	745, 921
Subtotal	7, 903, 638	1, 597, 824	9, 501, 462	574, 427	95, 880	670, 307	320, 576	788	321, 364	895, 003	96, 668	991, 671
Non-Federal-aid:												
State highways	2, 963, 087	28, 358, 274	31, 321, 361	337, 210	1, 146, 764	1, 483, 974	98, 502	298, 835	397, 337	435, 712	1, 445, 599	1, 881, 311
Local roads	16, 025, 291	122, 248, 701	138, 273, 992	1, 591, 683	3. 829, 322	5, 421, 005	129, 648	554, 325	683, 973	1, 721, 331	4, 383, 647	6, 104, 978
Subtotal	18, 988, 378	150, 606, 975	169, 595, 353	1, 928, 893	4, 976, 086	6, 904, 979	228, 150	853, 160	1, 081, 310	2, 157, 043	5, 829, 246	7, 986. 289
All roads and streets:												
State highways	40, 345, 227	75, 211. 415	115, 556, 642	5, 025, 782	2, 548, 059	7, 573, 841	1, 613, 706	2, 042, 798	3, 656, 504	6, 639, 488	4, 590, 857	11, 230, 345
Local roads	20, 636, 655	122, 576, 323	143, 212, 978	2, 021, 438	3, 829, 553	5, 850, 991	445, 583	554, 325	999, 908	2, 467, 021	4, 383, 878	6, 850, 899
TOTAL	60, 981, 882	197, 787, 738	258, 769, 620	7, 047, 220	6, 377, 612	13, 424, 832	2, 059, 289	2, 597, 123	4, 656, 412	9, 106, 509	8, 974, 735	18, 081, 244

[1] Includes 1,550 trucks of unknown type involved in traffic accidents of which 487 were involved in rural accidents and 1,063 were involved in municipal accidents.

to $34,900; and truck combinations, $39,500 to $83,400.

The comparison of involvement and cost rates in rural areas versus municipalities points to the fact that many of the accidents in cities were relatively minor events. For all classes of vehicles considered in the study, involvement rates ranged from 170 per 10 million vehicle-miles of travel in rural areas to 650 in municipalities, or a ratio of 1 to 3.8. Cost rates, on the other hand, ranged from $54,700 per 10 million vehicle-miles in rural areas to $109,500 in municipalities, a ratio of 1 to 2.

An analysis of the types of accidents shows that nearly one-half of all accidents in municipalities were collisions with parked vehicles and rear-end collisions. These two types of accidents accounted for only 15 percent of the total direct costs of accidents in municipalities. But regardless of the severity or costs of specific types of accidents, the fact still remains that a large part of the accident problem is concentrated in cities, and prevailing vehicle insurance rates for urban residents reflect that condition. Eighty-five percent of the accident involvements occurring in the State during the study year took place in municipalities, and those events accounted for 75 percent of the total direct costs of accidents.

A rather unusual finding of the study was the doubling of the accident cost rate for truck combinations in cities versus rural areas. A similar relationship did not hold for single-unit trucks. As shown in table 12, the cost of approximately 0.8 of a cent per vehicle-mile for combinations was uniform for all city size groups. A further analysis of these data indicated that the rates for combinations were

Table 16.—In-State travel of Illinois registered passenger cars and trucks, distributed by highway systems [1]

[thousands of vehicle-miles]

Highway systems	Travel of Illinois registered passenger cars			Travel of Illinois registered single-unit trucks			Travel of Illinois registered truck combinations			Travel of Illinois registered trucks of all types		
	Rural	Municipal	Total	Rural	Municipal	Total	Rural	Municipal	Total	Rural	Municipal	Total
Federal-aid primary and State highways	5, 844, 957	4, 985, 517	10, 830, 474	1, 292, 470	560, 818	1, 853, 288	473. 874	162, 882	636, 756	1, 766, 344	723. 700	2, 490, 044
Federal-aid secondary highways:												
State highways	409, 629	137, 276	546, 905	78, 716	18, 874	97, 590	6, 051	2, 422	8, 473	84, 767	21, 296	106, 063
Local roads	1, 066, 522	133, 976	1, 200, 498	223, 545	14, 263	237, 808	5, 413	647	6, 060	228, 958	14, 910	243, 868
Subtotal	1, 476, 151	271, 252	1, 747, 403	302, 261	33, 137	335, 398	11, 464	3, 069	14, 533	313, 725	36, 206	349, 931
Non-Federal-aid highways:												
State highways	586, 552	1, 403, 184	1, 989, 736	126, 168	155, 565	281. 733	24. 595	33, 061	157, 656	150, 763	188, 626	339, 389
Local roads	2, 078, 424	10, 102, 269	12. 180, 693	591, 689	1, 061, 644	1, 653, 333	11, 255	112, 458	23, 713	602, 944	1, 174. 102	1, 777, 046
Subtotal	2, 664, 976	11, 505, 453	14, 170, 429	717, 857	1, 217, 209	1, 935, 066	35, 850	145, 519	181, 369	753, 707	1, 362, 728	2, 116, 435
All roads and streets:												
State highways	6, 841, 138	6, 525, 977	13, 367. 115	1, 497, 354	735, 257	2, 232, 611	504, 520	198, 365	702, 885	2, 001, 874	933, 622	2, 935, 496
Local roads	3, 144, 946	10, 236. 245	13. 381, 191	815, 234	1, 075. 907	1, 891, 141	16, 668	113, 105	129, 773	831, 902	1, 189, 012	2, 020, 914
TOTAL	9, 986, 084	16, 762, 222	26, 748, 306	2, 312, 588	1, 811, 164	4, 123, 752	521, 188	311, 470	832, 658	2, 833, 776	2, 122, 634	4, 956, 410

[1] Data source: *Motor Vehicle Use Study*, State of Illinois, Department of Public Works and Buildings, Division of Highways, October 1961.

Table 17.—Number of vehicles involved in traffic accidents and the direct costs of such accidents per 10 million vehicle-miles of travel, classified by major vehicle type and highway system

Highway systems	Illinois registered passenger cars			Illinois registered single-unit trucks			Illinois registered truck combinations			Illinois registered trucks, all types		
	Rural	Municipal	Total	Rural	Municipal	Total	Rural	Municipal	Total	Rural	Municipal	Total
NUMBER OF VEHICLES INVOLVED IN TRAFFIC ACCIDENTS PER 10 MILLION VEHICLE-MILES OF TRAVEL												
Federal-aid primary and State highways	152	445	287	84	312	153	65	323	131	79	314	147
Federal-aid secondary:												
State highways	485	432	472	100	(1)	149	(1)	(1)	(1)	97	(1)	144
Local roads	133	(1)	152	77	(1)	73	(1)	--------	(1)	77	(1)	73
Subtotal	231	371	252	83	(1)	95	(1)	(1)	(1)	82	(1)	94
Non-Federal-aid:												
State highways	159	794	607	122	782	486	(1)	613	395	118	752	471
Local roads	283	776	692	138	531	390	(1)	645	617	141	542	406
Subtotal	256	778	680	135	563	404	(1)	638	546	137	571	416
All roads and streets:												
State highways	173	519	342	88	412	195	67	369	152	83	403	185
Local roads	232	770	643	121	524	350	(1)	642	591	123	535	366
TOTAL	191	672	493	100	479	266	73	468	220	95	477	258
DIRECT COST OF TRAFFIC ACCIDENTS PER 10 MILLION VEHICLE-MILES OF TRAVEL												
Federal-aid primary and State highways	$58, 324	$91, 431	$73, 564	$35. 157	$23. 281	$31, 563	$31, 877	$107. 021	$51, 099	$34, 277	$42, 128	$36, 559
Federal-aid secondary:												
State highways	80, 372	92. 529	83, 424	18, 379	(1)	24, 626	(1)	(1)	(1)	17, 615	(1)	23, 170
Local roads	43, 237	(1)	41, 141	19, 225	(1)	18, 081	(1)	--------	(1)	32, 569	(1)	30, 587
Subtotal	53, 542	58, 906	54, 375	19. 004	(1)	19, 985	(1)	(1)	(1)	28, 528	(1)	28, 339
Non-Federal-aid:												
State highways	50, 517	202, 099	157, 415	26, 727	73, 716	52, 673	(1)	90. 389	68, 915	28, 900	76, 638	55, 432
Local roads	77. 103	121. 011	113, 519	26, 901	36, 070	32, 788	(1)	49, 292	55, 287	28, 549	37, 336	34, 355
Subtotal	71, 252	130, 901	119, 683	26, 870	40, 881	35, 683	(1)	58, 629	59, 619	28, 619	42, 776	37, 735
All roads and streets:												
State highways	58, 974	115, 249	86, 448	33, 564	34, 655	33, 924	31, 985	102, 982	52, 021	33, 166	49, 173	38, 257
Local roads	65, 618	119, 747	107, 026	24, 796	35, 594	30, 939	(1)	49, 010	77, 051	29, 655	36, 870	33, 900
TOTAL	61, 067	117, 996	96, 742	30, 473	35, 213	32, 555	39, 511	83, 383	55, 922	32, 136	42, 281	36, 481

[1] Sample was too small to provide significant data (20 or less sample cases).

Table 18.—In-State travel of Illinois registered passenger cars and trucks, distributed by highway systems and average daily travel per mile of road or street

Item of comparison	Federal-aid primary and State highways	Federal-aid secondary highways			Non-Federal-aid highways			All roads and streets		
		State highways	Local roads	Total	State highways	Local roads	Total	State highways	Local roads	Total
TRAVEL IN RURAL AREAS										
Miles of rural roads	8, 625	1, 618	10, 050	11, 668	2, 391	79, 503	81, 894	12, 634	89, 553	102, 187
Annual passenger car travel (1,000 vehicle-miles)	5, 844, 957	409, 629	1, 066, 522	1, 476, 151	586, 552	2, 078, 424	2, 664, 976	6, 841, 138	3, 144, 946	9, 986, 084
Average daily passenger car travel (1,000 v.-m.)	16, 014	1, 122	2, 922	4, 044	1, 607	5, 694	7, 301	18, 743	8, 616	27, 359
Average daily passenger car travel per mile of road	1, 857	693	291	347	672	72	89	1, 484	96	268
Annual truck travel (1,000 vehicle-miles)	1, 766, 344	84, 767	228, 958	313, 725	150, 763	602, 944	753, 707	2, 001, 874	831, 902	2, 833. 776
Average daily truck travel (1,000 vehicle-miles)	4, 839	233	627	860	413	1, 652	2, 065	5, 485	2, 279	7, 764
Average daily truck travel per mile of road	561	144	62	74	173	21	25	434	25	76
TRAVEL IN MUNICIPALITIES										
Miles of streets	1, 498	203	209	412	988	18, 192	19, 180	2, 689	18, 401	21, 090
Annual passenger car travel (1,000 vehicle-miles)	4, 985, 517	137, 276	133, 976	271, 252	1, 403, 184	10, 102, 269	11, 505, 453	6, 525, 977	10, 236, 245	16, 762, 222
Average daily passenger car travel (1,000 v.-m.)	13, 659	376	367	743	3, 844	27, 678	31, 522	17, 879	28, 045	45, 924
Average daily passenger car travel per mile of street	9, 118	1, 852	1, 756	1, 803	3, 891	1, 521	1, 643	6, 649	1, 524	2, 178
Annual truck travel (1,000 vehicle-miles)	723, 700	21, 296	14, 910	36, 206	188, 626	1, 174, 102	1, 362, 728	933, 622	1, 189, 012	2, 122, 634
Average daily truck travel (1,000 vehicle-miles)	1, 983	58	41	99	516	3, 217	3, 733	2, 557	3, 258	5, 815
Average daily truck travel per mile of street	1, 324	287	195	241	523	177	195	951	177	276
TOTAL TRAVEL										
Miles of roads and streets	10, 123	1, 821	10, 259	12, 080	3, 379	97, 695	101, 074	15, 323	107, 954	123, 277
Annual passenger car travel (1,000 vehicle-miles)	10, 830, 474	546, 905	1, 200, 498	1, 747, 403	1, 989, 736	12, 180, 693	14, 170, 429	13, 367, 115	13, 381, 191	26, 748, 306
Average daily passenger car travel (1,000 v.-m.)	29, 673	1, 498	3, 289	4, 787	5, 451	33, 372	38, 823	36, 622	36, 661	73, 283
Average daily passenger car travel per mile of road and street	2, 931	823	321	396	1, 613	342	384	2, 390	340	594
Annual truck travel (1,000 vehicle-miles)	2, 490, 044	106, 063	243, 868	349, 931	339, 389	1, 777, 046	2, 116, 435	2, 935, 496	2, 020. 914	4, 956, 410
Average daily truck travel (1,000 vehicle-miles)	6, 822	291	668	959	929	4, 869	5, 798	8, 042	5, 537	13, 579
Average daily truck travel per mile of road and street	674	160	65	79	275	50	57	525	51	110

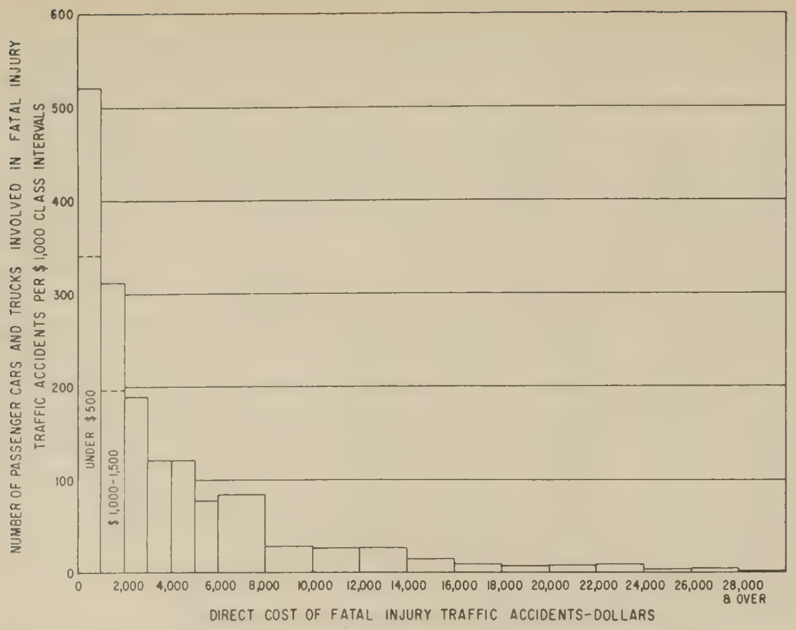

Figure 8.—Number of passenger cars and trucks (combined) involved in fatal injury traffic accidents, distributed according to direct costs.

influenced to a considerable extent by the occurrence of a limited number of fatal and nonfatal injury accidents in which the costs exceeded $10,000 per involvement. A summary of the number of municipalities and the population for each of the city size groups (given in tables 10—12) and total populations are shown in table 13.

The population group of 1,000,000 and over obviously applies to Chicago. Incorporated places surrounding the corporate area of Chicago such as Evanston, Oak Park, Berwyn, Cicero, and others were included in the lesser population groups. Forty-six percent of the accident involvements and 56 percent of the total costs of accidents occurring in municipalities of the State were traceable to the corporate area of Chicago. This finding was not unusual as 46 percent of the urban population of the State resided in the one city, and 45 percent of the Statewide municipal travel was performed there. In relating the costs of passenger car and truck accidents to travel of these vehicles in Chicago, the rate per vehicle-mile was found to be 1.35 cents.

A recent publication of the Chicago Area Transportation Study (C.A.T.S.) provides useful comparisons of accident costs and rates for streets and highways of the Greater Chicago area (*3*). The area covered in the analysis included Cook and Du Page Counties, the confines of which were nearly equivalent to the perimeters of the C.A.T.S. study.

The locations of traffic accidents occurring in Cook and Du Page Counties during 1958 were classified on the basis of three systems: expressways, arterials, and local streets. Accident rates and costs developed in the analysis are listed in table 14.

The cost of accidents per vehicle-mile of travel on all street systems of the two counties was calculated to be 1.32 cents, which was slightly less than the rate of 1.35 cents for the corporate area of Chicago. Of primary interest is the range in costs per vehicle-mile by street systems: Expressways, 0.31 of a cent; arterials, 1.07 cents; and local streets, 3.09 cents. Frequency rates were based on the number of accidents per 10 million vehicle-miles rather than involvements, and thus direct comparisons cannot be made with the data shown in table 12. (In the C.A.T.S. analysis, a conversion factor of 1.89 involvements per traffic accident was used.) Results show that the chance of being involved in a traffic accident on a local street was 20 times greater than on an expressway, and on arterial streets the accident rate was nearly 5 times that on expressways.

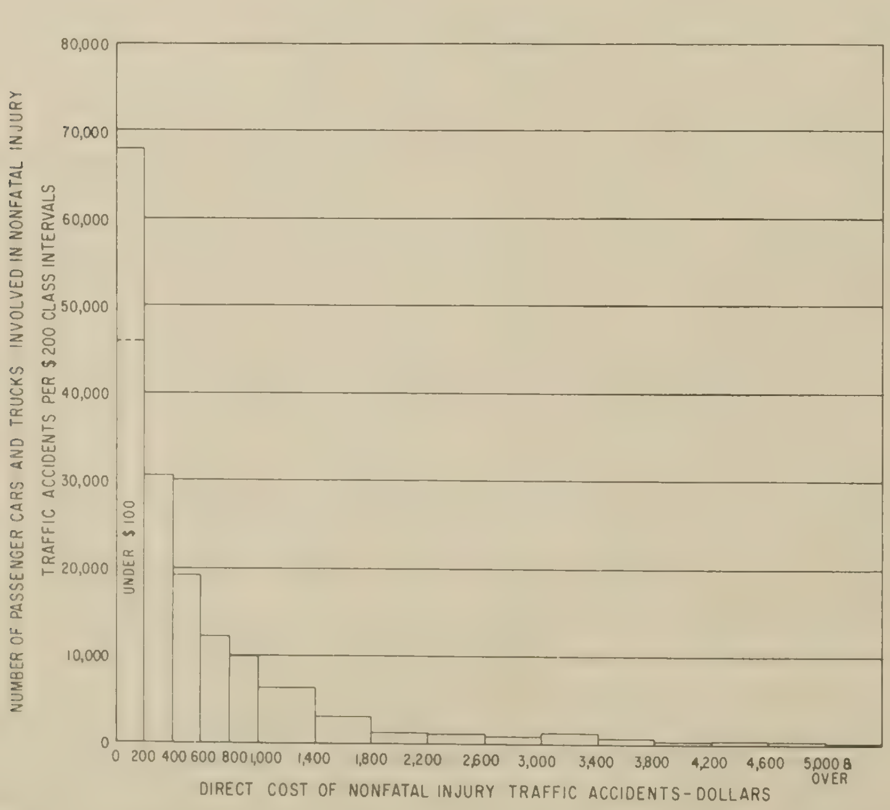

Figure 9.—Number of passenger cars and trucks (combined) involved in nonfatal injury traffic accidents, distributed according to direct costs.

Frequencies and Costs of Accident Involvements Related to Highway Systems

Data included in tables 15 and 16 provide the necessary information to appraise the major highway systems of the State on the basis of accident frequencies and costs. The same limitations apply to this series of tables as to tables 5–7. Sampling variability should be kept in mind when viewing the detailed information. Values shown for subtotals and totals obviously are supported by a greater number of sample cases than the component values that make up the totals. Table cells believed to have too few sample cases to provide significant comparisons are indicated by footnote in table 17. No estimates of sampling error have been computed, however.

Table 19.—Average daily travel of Illinois passenger cars and trucks on Illinois roads and streets, 1958

Highway system	Average daily traffic per mile of road or street	
	Rural	Municipal
Federal-aid primary	2,418	10,442
Federal-aid secondary	421	2,044
Non-Federal-aid	114	1,838
All systems	344	2,454

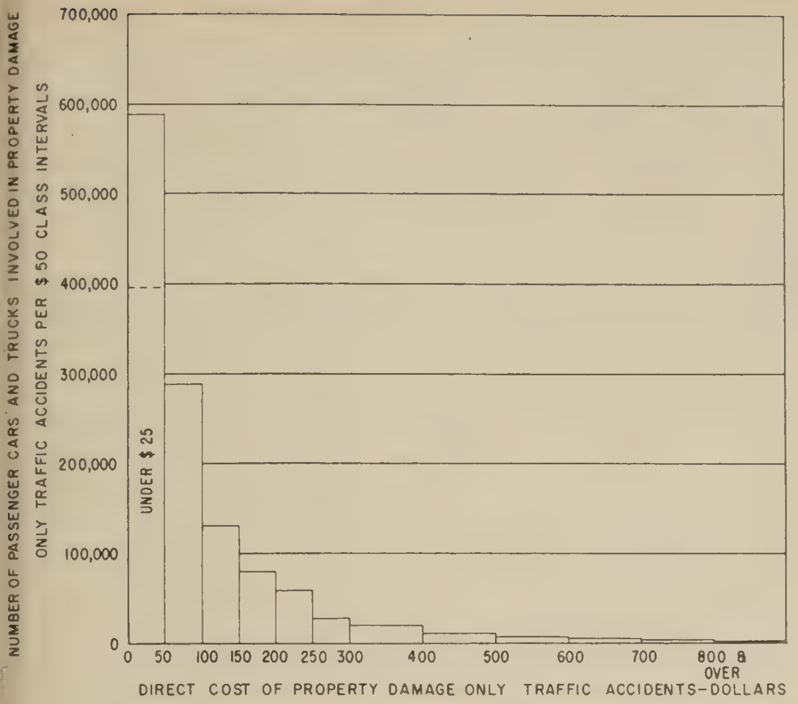

Figure 10.—Number of passenger cars and trucks (combined) involved in property damage only traffic accidents, distributed according to direct costs.

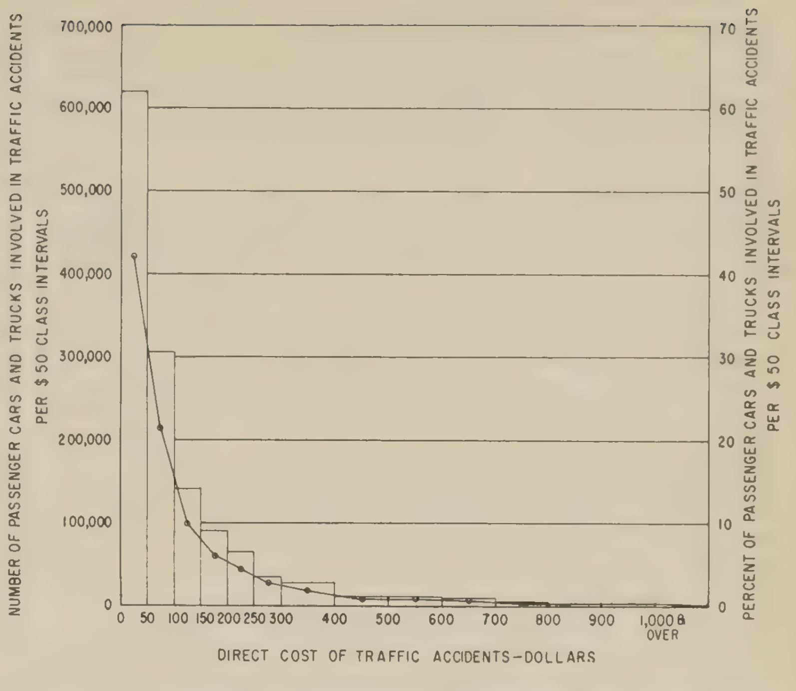

Figure 11.—Number and percent of passenger cars and trucks (combined) involved in traffic accidents, distributed according to direct costs.

Accident involvement and cost rates, as reported in table 17, point to the fact that passenger car drivers traveling on local rural roads and on city streets (principally of the residential class) experienced more accidents on a vehicle-mile basis than when driving on State highways. Rates on rural State highways were 173 involvements per 10 million vehicle-miles as compared to 232 involvements on local roads, or a ratio of 1 accident involvement on State highways for every 1.3 involvements on local roads. In municipalities, the rates per 10 million vehicle-miles were 519 and 770, respectively, or a ratio of 1 to 1.5. Costs per vehicle-mile for passenger car involvements ranged from 0.59 of a cent on rural State highways to 0.66 of a cent on local rural roads. A similar comparison for municipalities indicated costs of 1.15 cents and 1.20 cents. Involvement ratios were somewhat greater in the State–local comparisons than were the cost ratios, which indicates that accidents on the local systems tended to be less severe or costly. Involvement rates for trucks of all types were higher on local roads and streets than on State highways, but costs per vehicle-mile indicated an inverse relation.

A comparison of involvement and cost rates on the basis of the three classes of highways—Federal-aid primary, Federal-aid secondary, and non-Federal-aid—is not too conclusive. However, the emphasis placed on improving the design of major highways shows some benefits from the standpoint of accident frequencies and costs. One principal observation is that the roads and streets not a part of the Federal-aid systems should not be overlooked in accident reduction programs. This class of roads and streets, composed largely of county and township roads in rural areas and residential streets in municipalities, is representative of 82 percent of the road and street mileage of the State. During the year of the study, these facilities accounted for 51 percent of the travel, 73 percent of the accident involvements, and 64 percent of the total direct costs of accidents.

The percentage distribution of travel, accident involvements, and accident costs is illustrated in figure 12 for the three classes of highways. The system classifications used in the study are fairly realistic from the standpoint of vehicle usage, particularly in rural areas. A preferred classification for major cities would be expressways, arterials, and residential streets. Streets of the Federal-aid secondary classification represent a very small part of the total municipal mileage, as shown in table 18.

Average daily travel of Illinois passenger cars and trucks on the three systems during 1958 was distributed as shown in table 19.

REFERENCES

(*1*) *Cost of Motor Vehicle Accidents to Illinois Motorists, 1958,* State of Illinois Department of Public Works and Buildings, Division of Highways, December 1962.

(*2*) *Motor Vehicle Use Study,* State of Illinois Department of Public Works and Buildings, Division of Highways, October 1961. (Study period covered 12-month interval beginning in October 1957.)

(*3*) *Accident Costs and Rates on Chicago Area Streets and Highways,* by D. P. Jorgenson, Chicago Area Transportation Study Research News, vol. 4, No. 4, March 30, 1962, pp. 2–11.

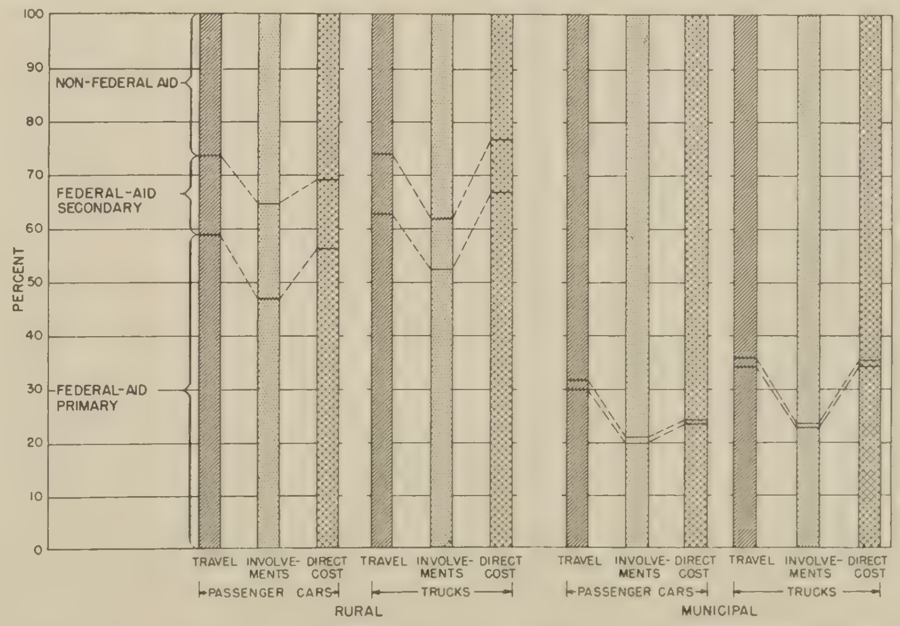

Figure 12.—Percentage distribution of travel, accident involvements, and accident costs on the basis of major vehicle type, rural and municipal location, and highway system.

Silicones as Admixtures for Concrete

BY THE
MATERIALS RESEARCH DIVISION
BUREAU OF PUBLIC ROADS

Reported by [1] WILLIAM E. GRIEB,
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This article presents a report on the results obtained from tests in which eight different silicones were used as admixtures for portland cement concrete. These tests were made because previous tests had shown the addition of silicone to be beneficial in preventing scaling caused by de-icing agents.

The results of tests from the lastest study showed that some of the silicones improved the strength and durability of the concrete. An optimum amount of silicone admixture was required to obtain maximum strength and durability. However, in most of the tests, the addition of silicones retarded the setting time of the concretes more than can usually be tolerated for normal construction purposes.

Introduction

A RECENT REPORT of the Bureau of Public Roads[2] showed that given amounts of a certain silicone used as an admixture for concrete were effective in preventing scaling caused by de-icing agents. This silicone also increased the compressive strength of the concrete but caused a marked retardation in the setting of the concrete. Because of these effects on concrete, additional tests were made to determine whether other silicones used as admixtures would have similar effects on concrete.

Eight different silicones, manufactured by the three major producers, were used in this project. Tests were made to determine the effect of silicone admixtures on the properties of fresh concrete and on the strength and durability of hardened concrete. Some of the tests were limited because sufficient quantities of the silicone samples were not available.

Conclusions

Based on results of tests in which only one brand of cement was used, the following conclusions are warranted. These conclusions apply specifically to concrete prepared with the materials, mixes, and mixing procedures described in this article.

- When used as admixtures in certain amounts, solutions of sodium methyl siliconates increased the compressive strength and durability of concrete.
- The alkyl silane esters and the silicone resin emulsion types of silicones in most cases either had no effect or were detrimental to the compressive strength and durability of concrete.
- There appears to be a critical amount of silicone admixture needed to obtain maximum compressive strength or durability of the concrete. This amount varies according to the properties of the silicones.
- In most cases, silicones retarded the setting time of the concrete. When the silicones were used in amounts needed to obtain maximum strength or durability of concrete, most of them caused retardation of the set greater than can be tolerated for normal construction purposes.
- The use of silicones as admixtures had no appreciable effect on the water required for a given slump or on the air content of the concrete.

Materials

The tests were made on air-entrained concrete prepared with varying amounts of eight different silicone solutions. The physical and chemical properties of these silicone solutions are given in table 1. The silicones are grouped into three general classes. Four of them (silicones *A*, *B*, *C*, and *D*) are classified as sodium methyl siliconates, two (silicones *E* and *F*) are classified as alkyl silane esters, and two (silicones *G* and *H*) are classified as silicone resin emulsions. Typical infrared spectra of the silicones are given in figure 1. The silicones in each group have the same general characteristic spectra.

With the exception of the two milky white emulsions of silicones *G* and *H*, all silicones were colorless liquids. The solvent or thinner for the six silicones *A*, *B*, *C*, *D*, *G*, and *H* was water and for the other two (*E* and *F*) was an alcohol. Except for the silicone admixtures, the same concrete materials were used for all of the tests. The cement was a type I portland cement having an equivalent alkali content of 0.6 of a percent. The chemical analysis of the cement is given in table 2. The aggregates were similar to those used in the previous investigation of a silicone as an admixture. These were a siliceous sand having a fineness modulus of 2.75 and a uniformly graded crushed limestone having a 1-inch maximum size. A commercially available aqueous solution of neutralized Vinsol resin was used to entrain air.

Mix Data

The mix data for the concretes are given in table 3. The concrete contained 6 bags of cement per cubic yard. The air content was approximately 5 percent and the slump was about 3 inches. A control or reference mix was made each day without silicone, and the mixes containing silicone were compared to the corresponding control mix made on the same day. The average properties for all of the control mixes are given in footnote 1 of table 3.

The total solids in the silicone solutions added to the mixes ranged from 0.01 percent to 1.33 percent by weight of the cement. The concentration of the total solids in the eight silicone solutions differed. For convenience in designing the mixes, data from literature furnished by the producers, which gives the approximate percentage of total solids in each solution, were used. These data are given in footnote 2 of table 3.

The actual percentage of total solids in six of the eight solutions was determined chemically; these percentages are shown in table 1. These results were within 5 percentage points of the amounts used for designing the mixes. For silicones *E* and *F*, the alkyl silane esters, it was impossible to determine

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[1] Presented at the 42d annual meeting of the Highway Research Board, Washington, D.C., January 1963.

[2] *Resistance of Concrete Surfaces to Scaling by De-Icing Agents*, by W. E. Grieb, George Werner, and D. O. Woolf, PUBLIC ROADS, vol. 32, No. 3, Aug. 1962, pp. 64–73.

Table 1.—Physical and chemical properties of silicone solutions

	Sodium methyl siliconate				Alkyl silane ester		Silicone resin emulsion	
	Sodium methyl siliconate (Sodium salt of methyl polysiloxane) [1]				Methyl chlorosilane M ester [1]	Ethyltriethoxysilane [1]	Silicone resin emulsion of silicone resin [1]	
							Nonionic	Anionic
	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*
Physical properties:								
pH (electrometric method)	12.1	12.0	12.2	12+	2.6	7.2	7.2	8.4
Specific gravity $\frac{25°}{4°}$C	1.244	1.252	1.102	1.227	0.952	0.901	1.027	1.008
Chemical analysis:								
Total solids (nonvolatile at 150° C., 90 min.) Percent	33.5	33.3	32.1	30.1	(3)	(3)	41.4	16.9
Total sodium as Na_2O do	10.4	10.3	11.2	12.4	--------	--------	--------	--------
Silicon (Si) do	8.2	8.1	8.5	5.6	21.7	3.8	8.9	3.4
Chlorine (Cl) do	--------	--------	--------	--------	[2] 0	--------	--------	--------
Silicone solids as $CH_3SiO_{1.5}$ do	19.6	19.4	20.3	13.4	--------	--------	--------	--------
Molecular ratio ($CH_3SiO_{1.5}$ to Na_2O) do	1.7	1.7	1.7	1.0	--------	--------	--------	--------
Infrared analysis of active constituent	All four materials were similar and showed a methyl siliconate structure. Silicone *D* had a greater amount of sodium carbonate impurity than the others.				Spectra of both materials were fairly similar; they had an alkyl silane ester structure. *F* had ethyl groups, and *E* had mostly methyl substitution.		Both materials had similar spectra of presumably condensed silicones having ethyl substitution.	
Infrared analysis of volatile solvent or thinner					Both solvents appeared to be an alcohol type, but exact identification was difficult because of some volatility of the active constituent.			
Probable formulas	$[CH_3Si(OH)_2O^-]$ Na^+(in dilute aqueous solution) $[CH_3SiO_2Na]_n$ (in dry form)				$(CH_3)_nSi(OCH_3)_{4n}$	$C_2H_5Si(OC_2H_5)_3$	$\left[R''O(R'_x)SiO_{\frac{4-x}{2}}\right]_n R'$	

[1] Producer's description.
[2] Qualitative test.
[3] Not determined because of volatility of silicone material.

the amount of total solids because of the volatility of the silicone materials.

For the six silicones *A*, *B*, *C*, *D*, *E*, and *F*, the assumed concentration of the solutions was 30 percent total solids. For this concentration, 10 ounces of the solution per bag of cement is equivalent to 0.2 of a percent of total solids by weight of cement. In table 3, the amount of the silicone solution used in each mix is given as the weight of total solids in the quantity of solution used, expressed as a percentage of the weight of cement. It is also given as the number of ounces of the solutions per bag of cement.

Mixing and Curing

The mixing and curing was completed in accordance with standard laboratory procedures. The aqueous solution of each silicone was added, with part of the mixing water, to the cement and aggregates in the mixer, prior to the addition of the aqueous solution of the air-entraining admixture.

ASTM standard methods were followed in making tests on the plastic concrete and in molding, curing, and testing the specimens of hardened concrete. The tests for outdoor scaling were made as described in reference *2*.

Water and Air Content

Data showing the effect of silicones as admixtures on the water and air content of concrete are presented in table 3 and figure 2. As shown in figure 2, concretes made with silicone admixtures generally needed less water than the control concrete to provide the same slump. This reduction in water requirement however was 3 percent or less for most of the mixtures. In 9 of the 11 mixes that did show a reduction of more than 3 percent, more than 10 ounces of the silicone solution per bag of cement (0.2 of a percent of total solids by weight of cement) had been used. The erratic data in amount of mixing water obtained from use of some of the silicones may be attributed to time and mold limitations. Because of these limitations not all of the mixtures prepared with the different amounts of any specific silicone were made on the same day. Mixtures containing varying amounts of the same silicone were therefore compared with different control mixes.

Table 2.—Chemical analysis and physical properties of portland cement

Chemical composition:	
Silicon dioxide percent	20.9
Aluminum oxide do	6.0
Ferric oxide do	2.5
Calcium oxide do	65.3
Magnesium oxide do	1.4
Sulfur trioxide do	2.2
Loss on ignition do	0.7
Insoluble residue do	0.19
Sodium oxide do	0.14
Potassium oxide do	0.75
Chloroform soluble do	0.007
Free lime do	0.76
Equivalent alkali as Na_2O do	0.63
Computed compound composition:	
Tricalcium silicate percent	57
Dicalcium silicate do	17
Tricalcium aluminate do	12
Physical properties:	
Apparent specific gravity	3.14
Specific surface (Blaine) sq. cm./g.	3,250
Autoclave expansion percent	0.05
Normal consistency do	24.2
Time of setting (Gillmore test)	
Initial hours	4.25
Final do	6.83
Compressive strength (1:2.75 mortar):	
3 days p.s.i.	2,850
7 days do	3,830
28 days do	5,170
Mortar air content percent	9.4

For mixtures containing silicones *B* and *E*, except for one mixture for each, a progressive reduction occurred in the amount of mixing water required as the amount of silicone was increased. Silicone *H* also caused a reduction in the amount of mixing water required when 0.5 of a percent or more of silicone solids was used. Addition of silicone *C* or *F* in an amount up to 0.5 of a percent of silicone solids reduced the mixing water requirements; when more *C* or *F* was used the mixing water requirement increased.

Although the general trend was for greater reductions in the water requirements as the amount of silicone used was increased, these data fail to show that the silicones used are effective water-reducing agents.

The use of silicones as admixtures had some effect on the air content of the concrete. Table 3 gives the amount of air-entraining agent needed in the mixes prepared with the silicone admixtures as a percentage of the amount of agent needed in the control concrete made on the same day. The same data are also shown in the upper portion of figure 3. In general, when mixes were prepared with less than 0.2 of a percent of total silicone solids, less air-entraining agent was needed than had been used in the control mix. However, for mixes prepared with larger amounts of the silicones, more air-entraining agent was required than for the control mix. With one exception, more air-entraining agent was required for all mixes prepared with silicone *D*.

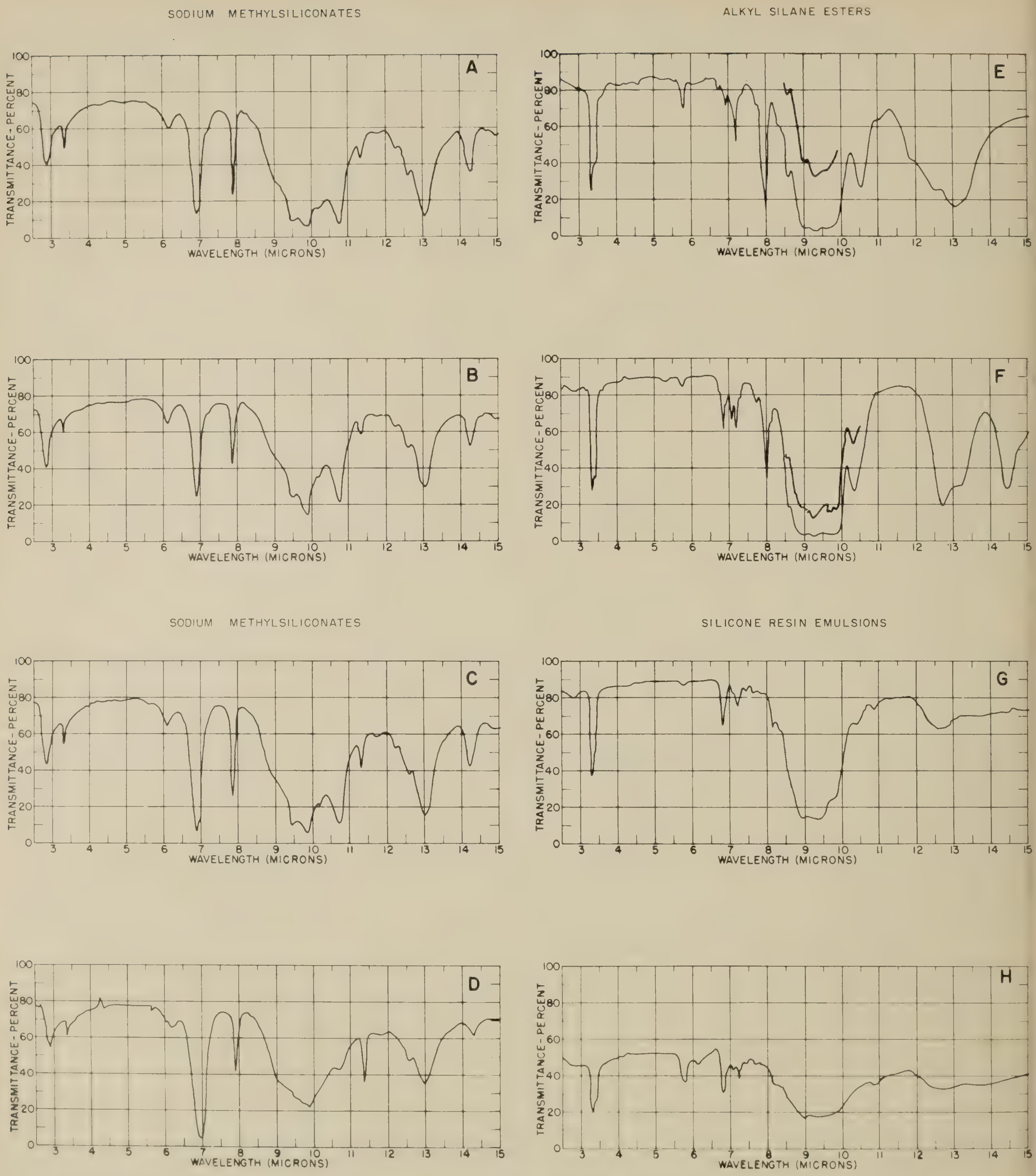

Figure 1.—Infrared spectra of silicone admixtures.

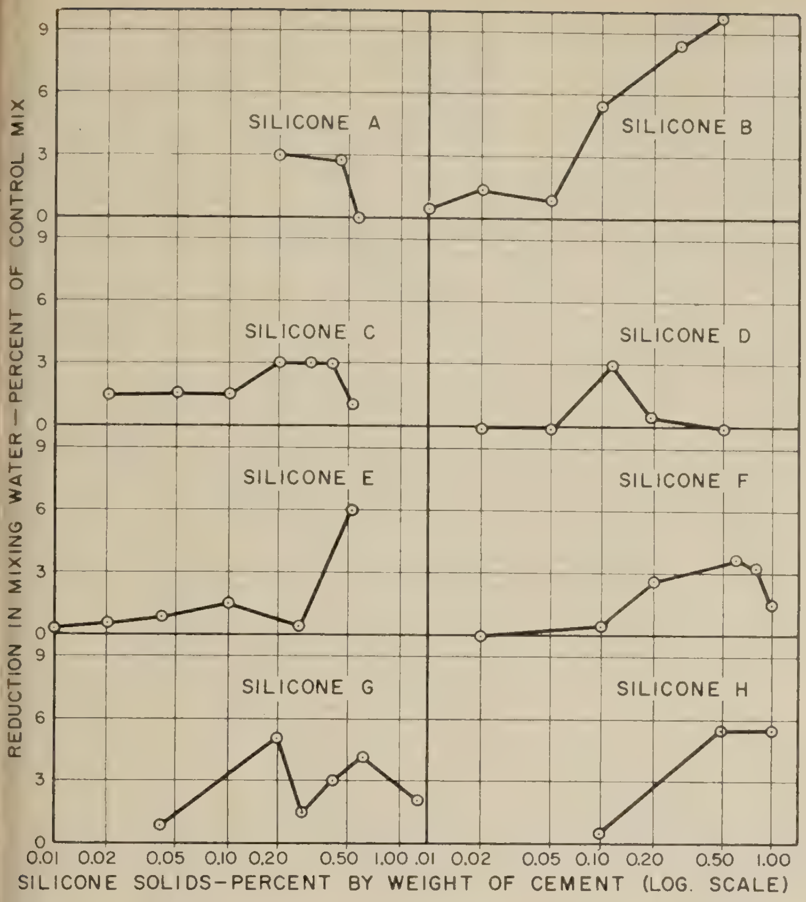

Figure 2.—Effect of silicone on reduction in amount of mixing water—based on control mix.

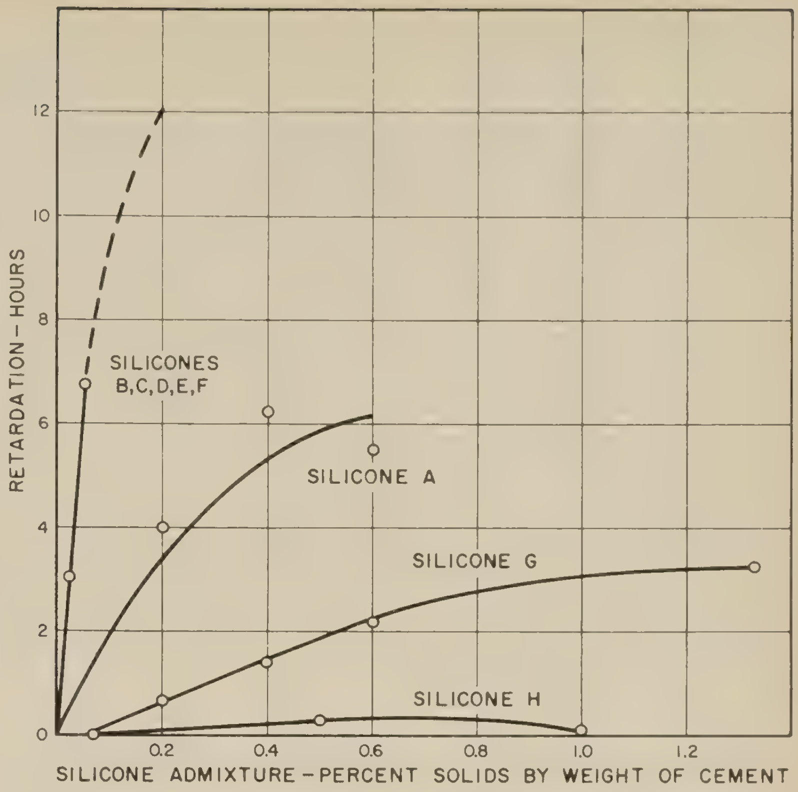

Figure 4.—Relation between amount of silicone added and retardation.

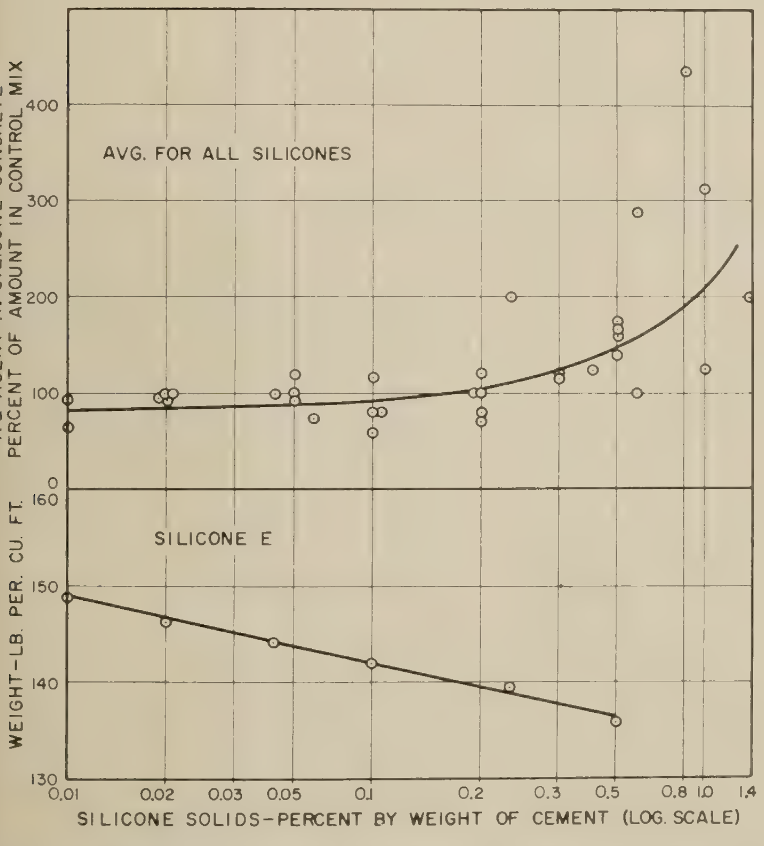

Figure 3.—Effect of silicones on amount of AE agent needed and of one silicone on unit weight of concrete.

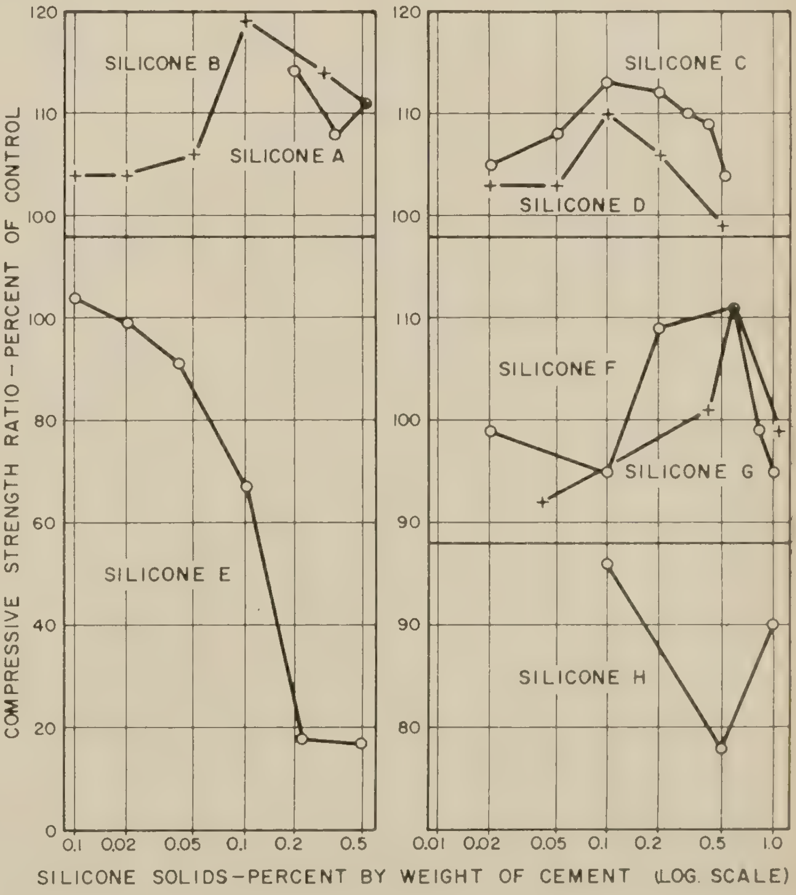

Figure 5.—Effect of silicones on compressive strength at 28 days.

Table 3.—Mix data [1]

Silicone: Total solids [2]	Silicone: Liquid	Slump	Reduction in water [3]	Air	A.E.A. [4]	Weight hardened concrete [5]
Percent by wt. of cement	*Oz./bag of cement*	*In.*	*Pct.*	*Pct.*	*Pct.*	*Lb./cu. ft.*
A:						
0.20	10.0	3.1	2.9	5.3	100	-----
.40	20.0	3.3	2.9	5.7	100	-----
.60	30.0	2.5	0	4.9	75	-----
B:						
0.01	0.5	2.9	0.5	5.3	94	-----
.02	1.0	3.1	1.4	5.5	94	-----
.05	2.5	3.2	0.9	4.7	100	-----
.10	5.0	3.0	5.4	4.9	80	-----
.30	15.0	3.1	8.4	5.0	120	-----
.50	25.0	3.3	9.9	5.5	160	-----
C:						
0.02	1.0	3.2	1.6	5.0	93	-----
.05	2.5	3.2	1.6	5.2	93	-----
.10	5.0	3.2	1.5	5.0	80	-----
.20	10.0	2.6	3.0	5.0	100	-----
.30	15.0	2.9	3.0	5.0	117	-----
.40	20.0	2.5	3.0	5.5	125	-----
.50	25.0	3.0	1.1	5.1	174	-----
D:						
0.02	1.0	2.5	0	5.0	100	-----
.05	2.5	3.0	0	5.4	120	-----
.10	5.0	2.7	3.0	5.5	117	-----
.20	10.0	2.8	0.5	5.1	120	-----
.50	25.0	2.8	0	5.4	140	-----
E:						
0.01	0.5	2.9	0.4	5.9	65	148.7
.02	1.0	3.0	0.6	6.0	70	146.4
.04	2.0	3.0	0.9	6.8	80	144.2
.10	5.0	3.7	1.5	8.0	188	142.0
.25	12.5	4.2	0.4	4.7	200	139.5
.50	25.0	2.7	6.0	4.5	167	135.9
F:						
0.02	1.0	3.3	0	7.2	70	-----
.10	5.0	3.2	0.5	6.8	70	-----
.20	10.0	3.0	2.5	6.0	80	-----
.60	30.0	3.5	3.8	4.2	287	-----
.80	40.0	3.0	3.3	4.5	437	-----
1.00	50.0	3.5	1.5	4.5	313	-----
G:						
0.04	1.5	3.2	0.9	6.3	50	-----
.20	7.5	3.4	5.1	9±	0	-----
.27	10.0	4.7	1.5	9±	80	-----
.40	15.0	4.2	3.1	8.0	200	-----
.60	20.0	2.9	4.2	5.1	100	-----
1.33	50.0	2.5	2.1	5.1	200	-----
H:						
0.10	10.0	2.5	0.6	5.0	60	-----
.50	50.0	3.0	5.4	8.5	187	-----
1.00	100.0	3.0	5.4	5.0	125	-----

[1] Control mix (average properties):
Proportions, 94–200–300.
Cement, 6.0 bags per cubic yard.
Slump, 3.0 inches.
Water, 5.58 gal. per bag.
Air-entraining agent, 20.7 ml. per bag.
Weight of hardened concrete, 149.1 lb. per cu. ft.
Air content, 5.2 percent.

[2] Based on total solids for each silicone, from information furnished by the producers, 30 percent solids for silicones *A, B, C, D, E,* and *F*, 40 percent for silicone *G* and 15 percent for silicone *H*.

[3] Reduction in water as compared with that required for the control mix made on the same day.

[4] Relative amount of air-entraining agent used, amount used in control mix considered 100 percent.

[5] Weight determined on cylinders prior to testing for compressive strength.

When silicone *E* was used, the concrete expanded during the hardening process; when the largest amount of silicone *E* (0.5 of a percent of solids by weight of cement) was used the concrete expanded 1 inch above the tops of the 6- by 12-inch cylinder molds. The air content of this plastic concrete, determined immediately after its mixing, was 4.5 percent. The unit weight of the hardened concrete for each of the mixes prepared with silicone *E* was determined on the cylinders prior to their being tested for compressive strength. These weights are shown in table 3 and the lower portion of figure 3. The weight of the control concrete was 149.1 pounds per cubic foot, whereas the weight of the concrete prepared with 0.5 percent silicone solids was only 135.9 pounds per cubic foot. As the weights of the two plastic concretes immediately after mixing were nearly the same, the concrete containing 0.5 of a percent percent of silicone solids expanded about 10 percent.

Tests were made to determine the cause of the expansion of the concrete prepared with silicone *E*. It was found that when a silicone *E* solution is treated with saturated limewater, it hydrolyzes and produces a mixture of alcohol containing perhaps both the methyl and ethyl types. As the parent silicone is an ester, such hydrolysis would be expected. The same result could be expected when silicone *E* is added to concrete where lime is immediately produced by the reaction of cement with mixing water. If the alcohols are produced in a gaseous form, this would account for the foaming (swelling) observed.

Retardation of Setting Time

The effect of different amounts of the silicone solutions on the retardation of the setting time of the concrete was determined by use of the Proctor penetration test (ASTM C 403). This test was made as described in reference *3*.[3] Retardation is the difference in time required for concrete prepared with the silicone admixtures and the control concrete made on the same day to support penetration loads of 500 p.s.i. The results of these tests are shown in table 4. Readings were taken at regular intervals for about 15 hours or until about 11 p.m. If the test specimens had not reached a penetration load of 500 p.s.i. by that time, the readings were resumed the next morning, but the concrete usually hardened before then.

The results of these tests for a penetration load of 500 p.s.i. are shown in figure 4. When silicones *B, C, D, E,* or *F* were used in amounts of only 0.05 of a percent of silicone solids, the retardation was approximately 6 hours. When 0.2 of a percent of silicone solids was used, the retardation was probably about 12 hours. It is estimated that a further increase in the amount of silicone used would cause only a small increase in the retardation. It was estimated that if 0.5 of a percent of solids were to be used the retardation would be between 15–20 hours. These five silicones are considered to retard the setting of the concrete more than would be desirable for normal construction purposes.

The use of 0.2 of a percent of solids of silicones *A* and *G* retarded the setting of the concrete 4 hours and three-fourths of an hour respectively, based on a 500 p.s.i. load in the Proctor test. Silicone *H* had no appreciable effect on the retardation of the concrete.

Table 4.—Results of retardation and strength tests

Silicone, total solids	Air	Proctor penetration test, retardation at 500 p.s.i.[1]	Crushing [2] strength at—: 7 days	Crushing [2] strength at—: 28 days
Percent by wt. of cement	*Percent*	*Hr., Min.*	*Percent*	*Percent*
A:				
0.20	5.3	4:15	107	114
.40	5.7	6:15	104	108
.60	4.9	6:30	100	111
B:				
0.01	5.3	1:30	104	104
.02	5.5	2:30	105	104
.05	4.7	6:45	112	106
.10	4.9	[4] 12	116	119
.30	5.0	----------	110	114
.50	5.5	----------	107	111
C:				
0.02	5.0	2:35	107	105
.05	5.2	6:35	108	108
.10	5.0	[4] 11:30	108	113
.20	5.0	----------	113	112
.30	5.0	----------	109	110
.40	5.5	----------	109	109
.50	5.1	[4] 15	106	104
D:				
0.02	5.0	1:10	100	103
.05	5.4	5:00	102	103
.10	5.5	9:45	112	110
.20	5.1	----------	105	106
.50	5.4	----------	100	99
E:				
0.01	5.9	2:20	106	104
.02	6.0	5:15	102	99
.04	6.8	8:40	100	91
.10	8.0	----------	65	67
.25	4.7	----------	21	18
.50	4.5	----------	18	17
F:				
0.02	7.2	3:45	95	99
.10	6.8	[4] 10	97	95
.20	6.0	[4] 11	114	109
.60	4.2	[4] 12	113	111
.80	4.5	----------	102	99
1.00	4.5	----------	93	95
G:				
0.04	6.3	0:35	95	92
.20	[3] 9±	0:40	77	79
.27	[3] 9±	1:35	72	69
.40	8.0	1:40	102	101
.60	5.1	2:10	107	111
1.33	5.1	3:15	98	99
H:				
0.10	5.0	0	100	96
.50	8.5	0:20	79	78
1.00	5.0	0:05	90	90

[1] Retardation is delay in time of hardening of concrete containing silicones as compared with control concrete made on the same days. Average time for control concrete to reach Proctor penetration load of 500 p.s.i. was 4 hrs. 15 min., and for 4,000 p.s.i. was 7 hrs., 20 min.

[2] Strength expressed as ratio (in percent) of the strength of the concrete containing silicones to the strength of the control concrete made on the same day. Average strength of control concrete was 4,140 p.s.i. at 7 days and 5,220 p.s.i. at 28 days.

[3] Air content high, strength values disregarded.

[4] Time estimated.

Strength Tests

Compressive strength tests were made at ages of 7 and 28 days on concrete prepared with different amounts of the silicone admixtures. These strengths were compared with the strengths of the control concrete made and tested on the same days. In table 4, the strength of the concrete prepared with silicone admixtures is given as the percentage of that of the corresponding control concrete. The relative compressive strengths at 28 days are shown in figure 5.

Concretes prepared with silicones *A, B, C,* and *D* (the sodium methyl siliconates) regardless of the amount used had higher strengths than the control concrete, except for one mixture.

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[3] *Water-Reducing Retarders for Concrete*, by W. E. Grieb, G. Werner, and D. O. Woolf, PUBLIC ROADS, vol. 31, No. 6, Feb. 1961, pp. 136–152.

When silicone *E* was used in amounts of less than 0.02 of a percent of solids, the strengths of these concretes were slightly higher than those of the control mix. When amounts of silicone solid greater than 0.02 of a percent were used, the strengths decreased considerably as the amount of silicone used was increased. When 0.50 of a percent of solids was used, the strength of concrete containing silicone *E* was only 18 percent of that of the corresponding control mix. This loss in strength was related to the foaming of the concrete previously mentioned.

For several of the mixes containing silicones *F* and *G*, the strengths were lower than that of the control concrete. However an examination of the data shows that these mixes contained 6.0 percent or more air.

Only three different amounts of silicone *H* were used. When 0.50 of a percent of solids of this material was used, a reduction in strength of 21 percent was obtained, but this mix had an air content of 8.5 percent. The other two mixes containing silicone *H* both showed slight reductions in strength. With the exception of silicones *E* and *H*, an optimum amount appears to exist at which the other silicones provide the maximum strength.

Laboratory Freezing and Thawing

Laboratory freezing and thawing tests were made on some of the mixes included in the strength tests. These tests were made on 3- by 4- by 16-inch beams, which were frozen in air and thawed in water in accordance with ASTM Method C 291. These tests were continued through 1,000 cycles of freezing and thawing; at 300 cycles only one of the mixes showed a loss in N^2 of more than 10 percent. Table 5 gives the durability factors of the concretes prepared with the different silicones at 1,000 cycles and the durability factor of the control mix. In addition, the relative durability factor is also given for each mix. This is the ratio of the durability factor of the silicone concrete to the durability factor of the control mix. A relative durability of 80 percent or more for concrete prepared with admixtures is acceptable. This durability is specified in AASHO Specification M 154 for air-entraining admixtures and is contained in the proposed specification for retarders made by the Subcommittee III–h of ASTM Committee C–9 (ASTM Designation C 494–62 T). On the basis of durability, all of the silicones used are acceptable. Although there appears to be an optimum amount of silicone admixture for obtaining maximum durability, these tests were too limited to determine this quantity.

Outdoor Scaling Tests

Outdoor exposure tests were made on 16- by 24- by 4-inch slabs to determine the effect silicone admixtures have on the resistance of concrete to scaling caused by de-icing agents. A description of the test is given in reference *2*, results also are given for tests in which a silicone similar to silicone *A* was used. Those tests showed that the use of silicone in proper amounts was effective in preventing scaling.

Similar exposure tests were made on concretes in which silicones *B* and *C* had been used. At the time this article was prepared these specimens had been exposed for only one winter. At the last inspection neither the control slabs nor the slabs containing silicone showed any appreciable scaling. All slabs were given a rating of less than 2. These tests are being continued.

Summary

Use of the four silicones classified as sodium methyl siliconates—silicones *A*, *B*, *C*, and *D*—gave the best results. These were all furnished in about the same concentration, about 30 percent solids. Three of these silicones, *B*, *C*, and *D*, retarded the setting time of the concrete much more than would be desirable for ordinary usage.

From the available data, if these three silicones had been used in amounts of 0.2 of a percent of silicone solids by weight of the cement, the retardation of set would have been more than 10 hours. Use of this same amount of silicone *A* caused retardation of only 4 hours. Concretes having 10 to 20 percent higher strength than the control mixes were obtained from mixtures prepared with each of these four silicones. The most favorable results were obtained by use of 0.1 to 0.2 of a percent of silicone solids. Freezing and thawing tests in the laboratory showed concretes prepared with silicones *A*, *B*, and *C* to have practically the same or greater durability than the control concrete. Tests for durability were not made on concretes prepared with silicone *D* because of the lack of material.

The two silicones classified as alkyl silane esters, silicones *E* and *F* were unstable. It was not possible to determine the amount of total solids in these solutions because of the volatility of the silicone materials. These two silicones used as an admixture caused excessive retardation of the setting time of the concrete. Silicone *E* caused a reduction in the strength of concrete by foaming during hardening. There was a corresponding reduction in the weight of the hardened concrete. Concrete prepared with silicone *F* had strengths 10 to 15 percent greater than that of the control concrete when 0.2 to 0.6 of a percent of solids were used. There is no apparent reason for the differences in the behavior of these two similar materials. Concrete prepared with either of these materials had good durability but only a few mixes were tested and these all contained more air than the control concrete.

Table 5.—Laboratory freezing and thawing[1]

Silicone, total solids	Air	Durability factor [2]	Relative durability factor [3]
Percent by weight of cement	*Percent*	*Percent*	*Percent*
Control:			
None	5.1	83	----------
A:			
0.05	5.8	92	111
B:			
0.01	5.3	91	110
.02	5.5	90	108
.05	5.7	93	112
.10	4.9	83	100
.30	5.0	82	99
.50	5.5	81	98
C:			
0.02	5.0	82	99
.05	5.2	80	96
.20	6.5	87	105
.50	6.1	74	107
E:			
0.01	5.9	91	110
.04	6.4	89	107
F:			
0.02	7.2	94	113
.10	6.8	92	111
.20	6.0	75	90
G:			
0.20	9±	81	98

[1] Each value is an average of tests on three 3- by 4- by 6-inch beams. Beams were frozen and thawed in accordance with ASTM Method C 291.

[2] Durability factor based on loss in N^2 after 1,000 cycles of freezing and thawing.

[3] Relative durability factor is the ratio in percent of the durability factor of the concrete containing silicone to the durability factor of the control concrete made on the same day.

The use of silicones *G* and *H*, which were classified as silicone resin emulsions, had beneficial effects on the properties of the concrete only in isolated cases. Their use provided unpredictable results on reduction in mixing water and air content. It appears that if either were to be used in construction, very careful control of the amount of silicone would be required. Silicone *G* caused only a modest amount of retardation of setting time of concrete, however silicone *H* had practically no effect. When used in amounts that did not cause excessive amounts of entrained air, concretes containing each of these silicones had 90 to 109 percent of the strength of the control concrete. Only one concrete prepared with silicone *G* was tested for resistance to freezing and thawing. Although this concrete had low strength, its air content was high and the relative durability was almost equal to that for the control concrete.

The retardation of the setting time offers a problem that must be resolved before this material can be used commercially. However, the tests reported here show that when some of these silicones are used as admixtures in concrete, both the strength and durability of the concrete will be improved.

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